Final report

R & D plan 200 97 106

Investigations to avoid and reduce possible impacts of wind energy parks on the marine environment in the offshore areas of North and Baltic Sea

- OffshoreWEP -

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16. Zusammenfassung

Anhand von Literaturstudien, der Analyse vorhandener Daten, Expertenbefragungen und einigen wenigen ergänzenden Feldstudien wurden mögliche Belastungen der Meeresumwelt durch Offshore-Windenergieparks im küstenfernen Bereich der Nord - und Ostsee untersucht und potentielle Wege zur Vermeidung und Verminderung solcher Belastungen aufgezeigt. Ein weiterer wichtiger Aspekt des Vorhabens war es möglichen Forschungsbedarf zu benennen. In den Untersuchungen wurden die biotischen Systemkompartimente "Benthos- und Fischgemeinschaften", "Rast- und Zugvögel" und "Marine Säugetiere" berücksichtigt.

Mögliche Auswirkungen des Baus der Anlagen, des Betriebs, inklusive Schallemission ins Wasser und in den Meeresboden, elektromagnetischer Felder von Kabel- und Energieableitungssystemen, der Wartung und Instandhaltung der Anlagen, des Gefährdungspotentials durch Kollision mit Schiffen und des Rückbaus der Anlagen nach der Betriebsdauer wurden ebenso berücksichtigt.

In der ausschließlichen Wirtschaftszone (AWZ) der Deutschen Bucht und der Ostsee sind von unterschiedlichen Betreibern mehrere Suchräume für den Bau von Windenergieanlagen beantragt worden. Die Größe der Parks variiert zwischen 80 und weit über 200 Einzelanlagen pro Park. Offshore-Windparks von solchen Größenordnungen und in den angedachten Wassertiefen sind weltweit nicht vorhanden und somit fehlen Erkenntnisse über ihre Auswirkungen auf marine Säuger, Vögel, Endo-/Epibenthos und die Fische. Zum momentanen Zeitpunkt ist eine Genehmigung für den Bau eines aus zwölf Einzelanlagen bestehenden Pilotparks nördlich von Borkum durch das BSH erteilt worden. Bisherige Erkenntnisse beruhten demnach vorrangig auf Expertengesprächen, Literaturstudien Workshops und Vortragsveranstaltungen wie z.B. dem Workshop zu ökologischen Auswirkungen von technischen Eingriffen in die marine Umwelt im Herbst 1999 auf der Insel Vilm (zusammengefasst in Kube, 2000).

17. Schlagwörter

Offshore Windenergie, Belastungen der Umwelt, Lebensgemeinschaften des Meeresbodens, Benthos, Fische, Avifauna, Vogelzug, Rastvögel, marine Säuger, Schiffskollisionen, Hydroakustik, Veränderung der Sedimentstrukturen, Barrierewirkung

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16. Abstract

The potential impact of offshore wind energy parks on the marine environment in the North and Baltic seas was investigated by combining literature surveys, analysis of available data, consultation of experts and a few complementary field studies. Potential mechanisms of prevention and reduction of detrimental effects were documented. An additional aspect of the project was to identify possible research requirements the following biological system compartments were identified: Benthos and fish communities, resting and migratory birds and marine mammals.

The potential impact of the construction and running of such a plant, the electro magnetic fields caused by cables and energy shunting systems, the servicing and maintenance of the plants, the danger of ship collisions as well as the subsequent dismantling of the plant were also considered.

Various operating agencies determined potential sites for the construction of wind energy plants within the exclusive economic zone (EEZ) in the German Bight and the Baltic Sea. The sizes of the parks range between 80 and over 200 single towers per park. Large offshore parks such as those envisaged and located in deep water do not exist anywhere else in the world. No information is therefore available on their impact on marine mammals, birds, the endo and epi benthos or fish.
Permission to build a park consisting of 12 single plants north of Borkum has currently been granted by the BSH. The present state of knowledge is based primarily on discussions with experts, literature surveys, workshops and talks such as the one on Ecological Impacts due to Technical Interference in the Marine Environment held on the island Vilm in Autumn 1999 (summarized by Kube, 2000).

17. Keywords

Offshore wind energy, environmental impact, communities of the seafloor, benthos, fish, birds, bird migration, resting birds, marine mammals, risks of collision, hydro acoustics, changes of sediment characteristics, barrier for bird migration

18. Price	19.	20.

A Project description

A-1 Summary of the R & D plan

The potential impact of offshore wind energy parks on the marine environment in the North and Baltic seas was investigated by combining literature studies, analysis of available data, consultation of experts and a few complementary field studies. Potential mechanisms of prevention and reduction of detrimental effects were documented. An additional aspect of the project was to identify possible research requirements. In this report the following biological system compartments were taken into consideration: Benthos and fish communities, resting and migratory birds and marine mammals.

The potential impact of the construction and running of such plants, sound emission, electro magnetic fields caused by cables and energy shunting systems, the servicing and maintenance of the plants, the danger of ship collisions as well as the subsequent dismantling of the plant were also considered.

Various operating agencies determined potential sites for the construction of wind energy plants within the exclusive economic zone (EEZ) in the German Bight and the Baltic Sea. (Figs. A-1 and A-2). The sizes of the parks range between 80 and over 200 single towers per park. Large offshore parks such as those envisaged and located in deep water do not exist anywhere else in the world. No information is therefore available on their impact on marine mammals, birds, the endo and epi benthos or fish. Permission to build a park consisting of 12 single plants north of Borkum has currently been granted by the BSH. The present state of knowledge is based primarily on discussions with experts, literature studies, workshops and talks such as the one on Ecological Impacts due to Technical Interference in the Marine Environment held on the island Vilm in Autumn 1999 (summarized by KUBE, 2000)

Different effects can be expected, depending on the methods and manner of construction of such plants (flushing, ramming, building of foundations etc.). The type of substrate (sand or rock) and the water depth are also likely to have different effects. The effects will range from direct ones such as mortality by removal of settling area during the laying of foundations, covering of organisms by sediment displacement, and finally changes in community structure brought about by the availability of new artificial substrata such as foundations or pylons or the change in sediment composition due to small or meso scale alterations in the hydro dynamics. Also to be considered are the bird mortality and the effects of the noise produced by the WEP (during both the construction and running) on marine mammals. The duration of the recovery or the degree of permanent damage due to the construction and running of the WEP, can only be estimated on the grounds of results obtained from other investigations and is most likely dependant on the local circumstances.

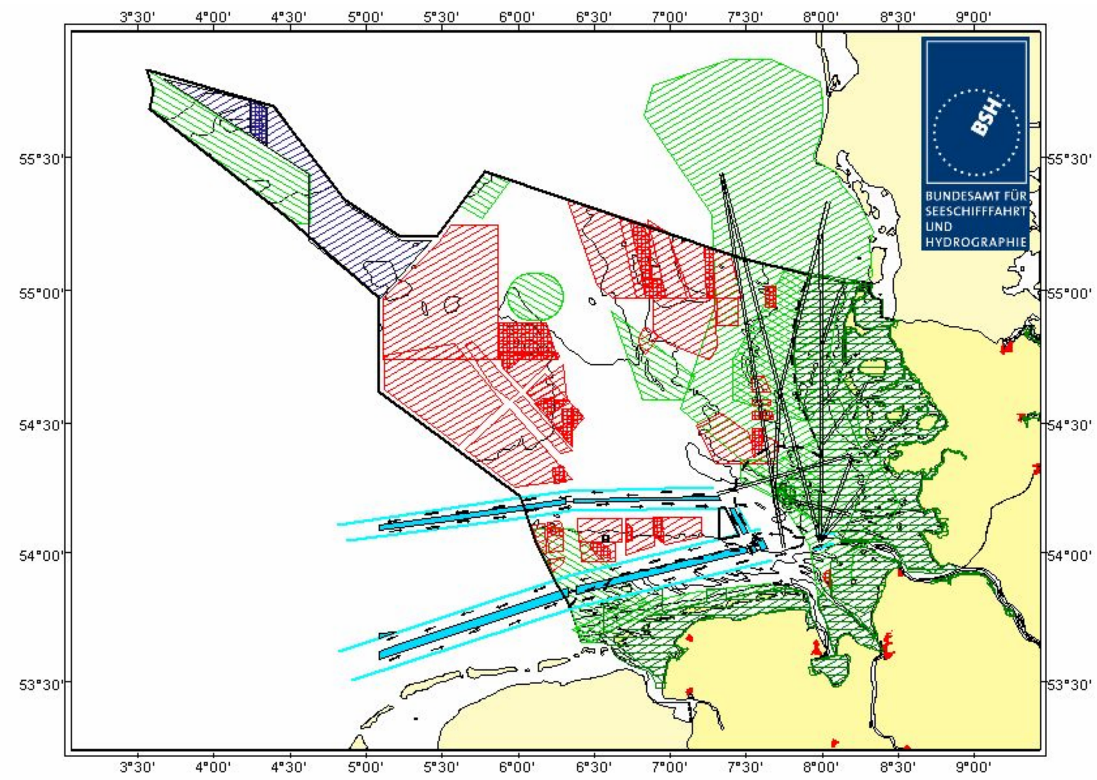


Fig. A-1: Proposed sites for the offshore wind energy parks in the North Sea (red areas), status September 2002 (Source: BSH)

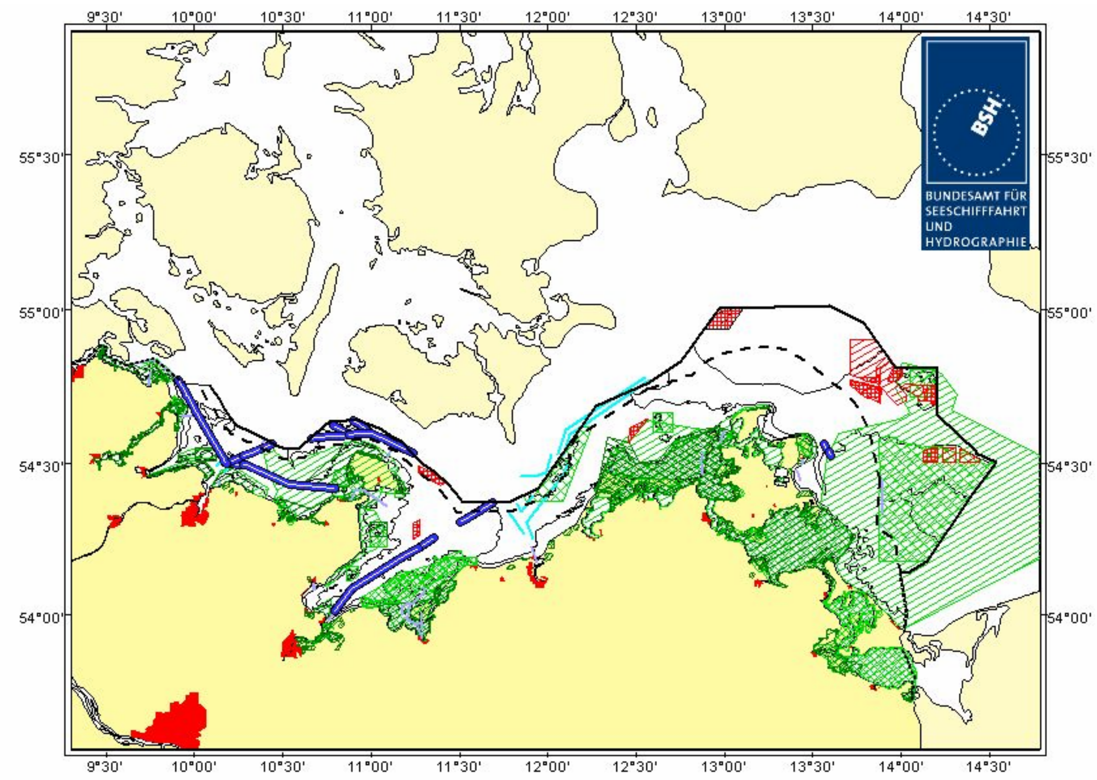


Fig. A-2: Proposed sites for the offshore wind energy parks in the Baltic Sea (red areas), status July 2002 (Source: BSH)

A-2 Aim of the R & D project

a. Depiction of the current state of knowledge on potential impacts of offshore wind parks (construction, running, dismantling) on the marine environment, taking into consideration benthos communities, demersale fish communities, birds and marine mammals.

b. Development of fundamental methodology to investigate and assess potential impacts on the marine environment by offshore wind energy plants

c. Assess potential risk of ship collisions and consequences

d. Formulation of measures to prevent and reduce impacts of offshore wind energy plant on the marine environment.

e. Determine research requirements and to close gaps in knowledge necessary to assess possible effects of offshore wind energy plant on the marine environment.

A-3 Task formulations and solutions

The task formulation was to establish a detailed presentation of possible impacts by offshore wind energy plants on the marine environment. Whereby the following points were taken into consideration:

- Type of possible damage to structure and function of the ecosystem including the causal mechanisms

- Areal extent of the damage (local, regional, supra-regional).

- Temporal extent of the damage (potential of reversibility).

- Uncertainties in the prediction of possible impacts (uncertainties regarding cause, effectivity and delay of potential ingress of damage).

Experts from different disciplines have collaborated to answer these questions. (Fig. A-3). Close co-operation between technicians and ecologists has facilitated an optimal evaluation of recommendations to prevent and minimise damage.

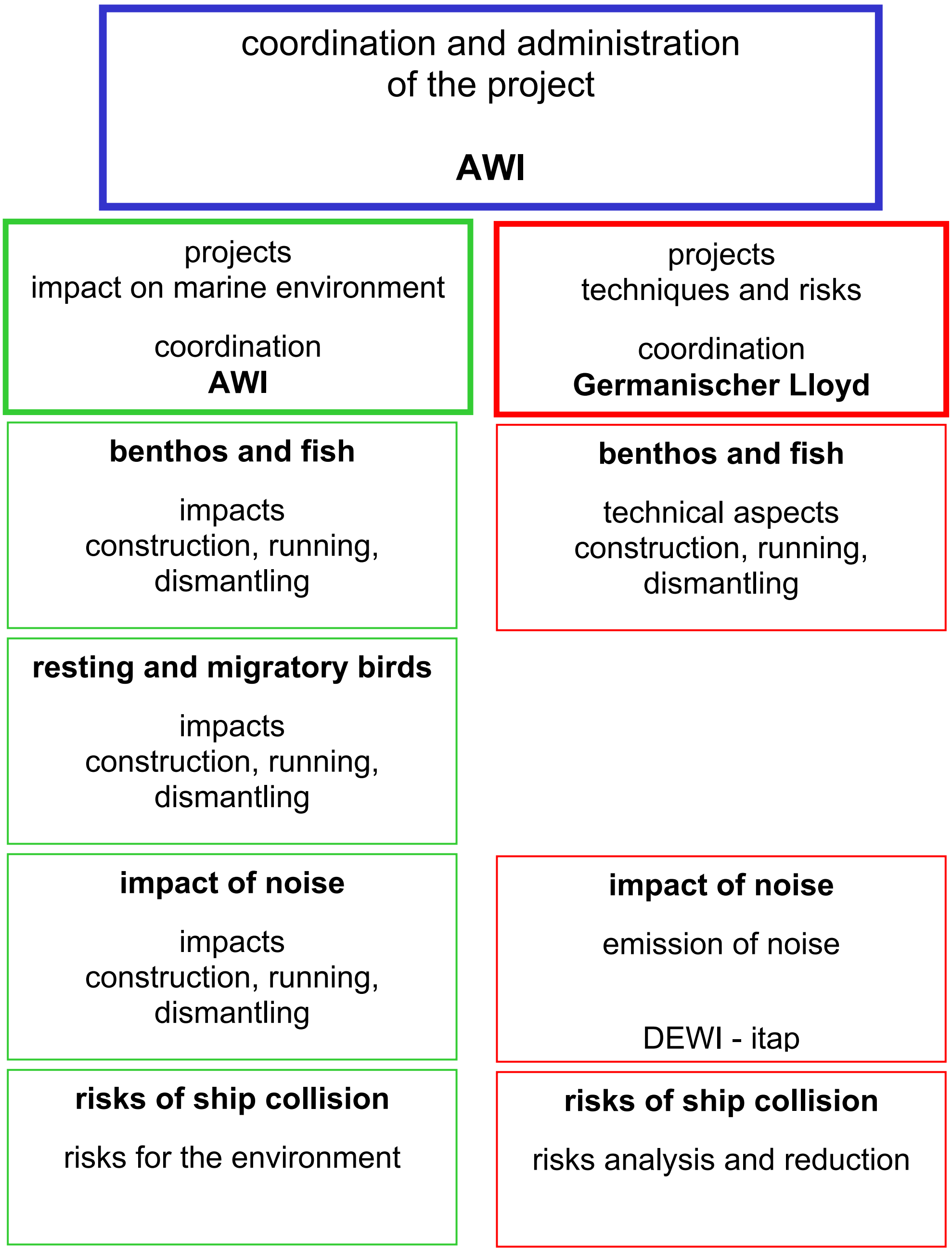


Fig. A-3: Project outline

A-4 Project outline and participating institutes

Sub project 1: Impacts on benthos and fish

This project deals with the potential effects of the construction, the running and the dismantling of offshore wind energy plants including the transmission of the electrical power. With regard to the transmission of electrical power, it was decided at the onset of the project, in conjunction with the Department of the environment (Umweltbundesamt), that this topic would not be dealt with in detail due to a separate application (apart from the actual construction of the plant) and a different legal status. The envisaged objectives on “servicing and maintenance” declared in the application have also been omitted from this sub project because of uncertainties pertaining to the speculation concerning the type and size of the envisaged plants. Measures of avoidance and minimisation of impacts on the marine environment are presented. Methods of investigation and assessment of potential effects of WEP on the benthos and fish in different areas were drafted. This included the specification and application of criteria for areal assessment as well as determining research requirements.

On the technical side, the Germanischer Lloyd WindEnergie GmbH carried out the sub-project whilst the Alfred-Wegener Institute for Polar and Marine Research (AWI) managed the ecological component**.** The AWI was also overall administrator.

Sub-project 2: Impact on resting and migratory birds

The aim of this project was to summarise the current state of knowledge, the research requirements, charting of the seasonal distribution of selected key species in the German parts of the North and Baltic Seas, the description of daytime bird migration, the charting of the area covered during migration as well as the development of a method to assess perspective areas for wind energy plants in relation to problems associated with resting and migratory birds.

This part was carried out by the Institute of Avian Research "Vogelwarte Helgoland"

Sub-project 3: Impact of noise by wind energy plants.

The aim was to estimate under-water sound emission by wind energy plants, measurements of efficiency of sound reduction measures concerning the emanation by towers (impact sound emanation). To estimate the natural noise at sea (background ocean noise resulting from natural factors such as wind, waves motion and anthropogenic factors such as ships). Finally to determine the significance of oscillations and sound emission on the marine ecosystem as well as the research requirements and the definition of feasible continuing research plans.

This sub-project was carried out by the German Wind-energy Institute (DEWI) in collaboration with the Research and Technology centre West coast (FTZ-Büsum) and the Institute for Technical and applied Physics (itap).

Sub-project 4: Risk of ship collisions with wind energy plants and danger of coastal contamination.

The aim was to determine the risk of ship collisions with wind energy plants, to assess the danger of a potential collision as well as to identify technical as well as organisational measures to minimise risks and to reduce and avoid pollution arising there from.

In charge of this sub-project was the Germanischer Lloyd WindEnergie GmbH. The likelihood of any consequences for the environment is presented by the AWI.

Sub-project 5: Overall concept

The aims of this subproject comprise the overall goal of the project as outlined in chapter A-2.

This is carried out by the AWI in cooperation with the GL Wind.

A-5 Responsibilities for the scientific and technical content.

The following Institutions and persons are responsible for the contents, as outlined in the project:

Institute	Subcontractor	Project leaders and implementation	co - workers	Chapter
AWI		Knust, Heuers	Brodte, Mintenbeck, Suck, Schroeder	A, B-I, B-IV-6, B-IV-7, B-IV-8, B-IV-9, B-IV-10, C
IFV		Hüppop, Wendeln	J.Dierschke, V.Dierschke, Exo, Garthe	B-II B-II-4 B-II-5 B-II-3 B-II-3, B-II-11
DEWI	itap Oldenburg FTZ-Büsum,	Gabriel	Neumann Schulz, von Glahn, Betke Lucke	B-III, E-1
GL		Dalhoff	Otto, Nusser, Braasch	B-I-4.6, B-IV-1, B-IV-2, B-IV-3, B-IV-4, B-IV-5, B-IV-8, B-IV-9, B-IV-10

B Results: subproject

I Impact on benthos and fish communities

I-1 Introduction

This chapter deals with the findings on the potential impact of the construction and operation of marine offshore wind energy parks on fish and macro zoo-benthic communities in the North Sea and Baltic Sea as well as with the measures to avoid or reduce possible effects.

The experience gathered in connection with other offshore industrial plants such as oil and gas platforms are useful to estimate the effects of offshore wind energy parks. In addition, the information gathered on the environmental effects of artificial reefs also served as a valuable source. Available data on existing or planned wind energy parks in Denmark or the Netherlands also served as a base for assessment although these projects are considerably smaller and localised in shallow waters compared to the wind parks which are planned in the German exclusive economic zone (EEZ).

I-2 Task formulations and solutions

- Concept

This sub-project deals with the potential consequences of the construction, the operation, and pass of electrical energy on land as well as the dismantling of the wind energy plants. Due to the current uncertainty regarding the degree of servicing and maintenance of the plants, it not possible at this stage to provide information on these issues. Measures to avoid and minimise impacts on the marine environment are presented, as are methods of investigation and assessment of potential consequences of wind energy plants on sea bottom communities in different areas. Criteria to assess the effects in different areas are identified and applied in specific examples. Requirements of research are also proposed.

- Solutions

The basis for the assessment of potential damage is the information obtained from the literature and the available existing un-published data on the colonisation of the sea floor by benthic organisms and fish. In addition, experience gathered on the impacts of large construction sites and for example ship wrecks on benthic communities in offshore areas has also been used. Possible technical modifications in the field of impact avoidance and or minimisation will be examined to establish measures based on the latest technology which are appropriate to prevent or minimise effects on benthic communities.

I-3 Benthic communities in the North and Baltic Seas

I-3.1 The macro-zoobenthos in the North Sea

The German Bight is situated in the southeastern region of the North Sea and is bordered in the East by the North-Frisian Islands and in the South by the East-Frisian coastline. The maximum water depth is 50 m, with the exception of the "Helgoländer Tiefe Rinne" south of the island Helgoland, which has a depth of up to 56 m. With the exception of the estuaries in the Weser and Elbe, the water column in the German Bight is usually not stratified. On occasion in summer, however, stratification of longer duration may occur in the offshore zones. Under extreme conditions, these may even lead to oxygen depletion near the sea floor in the German Bight. (Rachor & Albrecht 1983, Niermann & Bauerfeind 1990). The current regime in the German Bight is primarily governed by tidal currents while weather conditions, particularly winds, have an additional strong effect on the current regime. The long-term monthly mean water temperatures at Helgoland range between 3,3°C in February 17,2°C in August, whereas exceptional temperatures below 0°C and above 20°C have been recorded (Salzwedel et al. 1985). Salinity in the German Bight varies between 27 und 34 ‰.

With the exception of the rocky island Helgoland, the substratum in the German Bight is made up mainly of sand and mud and mixtures thereof. (Fig. I-1). Pebbles and larger rocks can be found in several areas with coarse sand. The composition of the sediment governed primarily by hydrodynamic conditions (Currents and water depth). The distribution of silt and clay correlates with the areas where stratification of the water column occurs. (Salzwedel et al. 1985).

The distribution of the macro zoobenthos is strongly dependant on the structure of the sediment and on the organic content as well as the water temperature of the various areas (Salzwedel et al. 1985; Eleftheriou & Basford 1989, Künitzer et al. 1992; Craeymeersch et al. 1997). Salzwedel et al. (1985) therefore differentiate between the benthic communities in the German Bight and divide them into 4 main groups (Fig. I-2). In areas of fine sand one finds *Fabulina fabula* communities, in areas with sandy mud *Amphiura filiformis* communities, in muddy areas *Nucula nitidosa* communities and in areas with coarse sand such as the "Borkum Riff" *Goniadella / Spisula* communities (see Kröncke & Bergfeld 2001). The typical species, after Salzwedel et al. (1985), of the different communities mentioned above (dominance > 1 %) are listed in Table I-1. The entire North Sea can be subdivided into three major zones of distribution according to the large scale distribution patterns of the benthic communities (in and epi fauna): A southern, central and northern zone which are structured mainly according to the increase in water depth (Kröncke & Bergfeld 2001). The North Sea Benthos Survey done in 1986 also confirms these zones (Duineveld et al. 1991).

The analysis of long-term data series has shown changes in the composition of the benthic macro fauna. A comparison of the zoobenthos in 1923/24 with that of 1984 revealed an increase in the sub littoral benthic biomass in the German Bight Rachor (1990). At the same time there was an increase in the short-lived opportunistic species compared to the long-lived species.
These changes could be due to anthropogenic or natural causes. While Rachor (1990) attributed the observed changes to eutrophication amongst other factors, Kröncke et al. (1998) found that the increase in biomass of sub littoral macro fauna was the result of persistent mild winters since 1989. . Further investigations revealed that fishing with heavy bottom gear has resulted in changes of the benthic communities whereby a decline in long-lived and fragile species in the communities was recorded. (Frid et al. 1999, Lindeboom & de Groot 1998).

It is difficult to interpret the causes of long-term changes in the benthos because the consequences of anthropogenic and natural influences overlap (Kröncke & Bergfeld 2001).

The main natural structuring factors of macro zoo benthos communities in the German Bight are water temperature, the hydrographic features (currents, wind, water depth) and the resulting sediment composition.

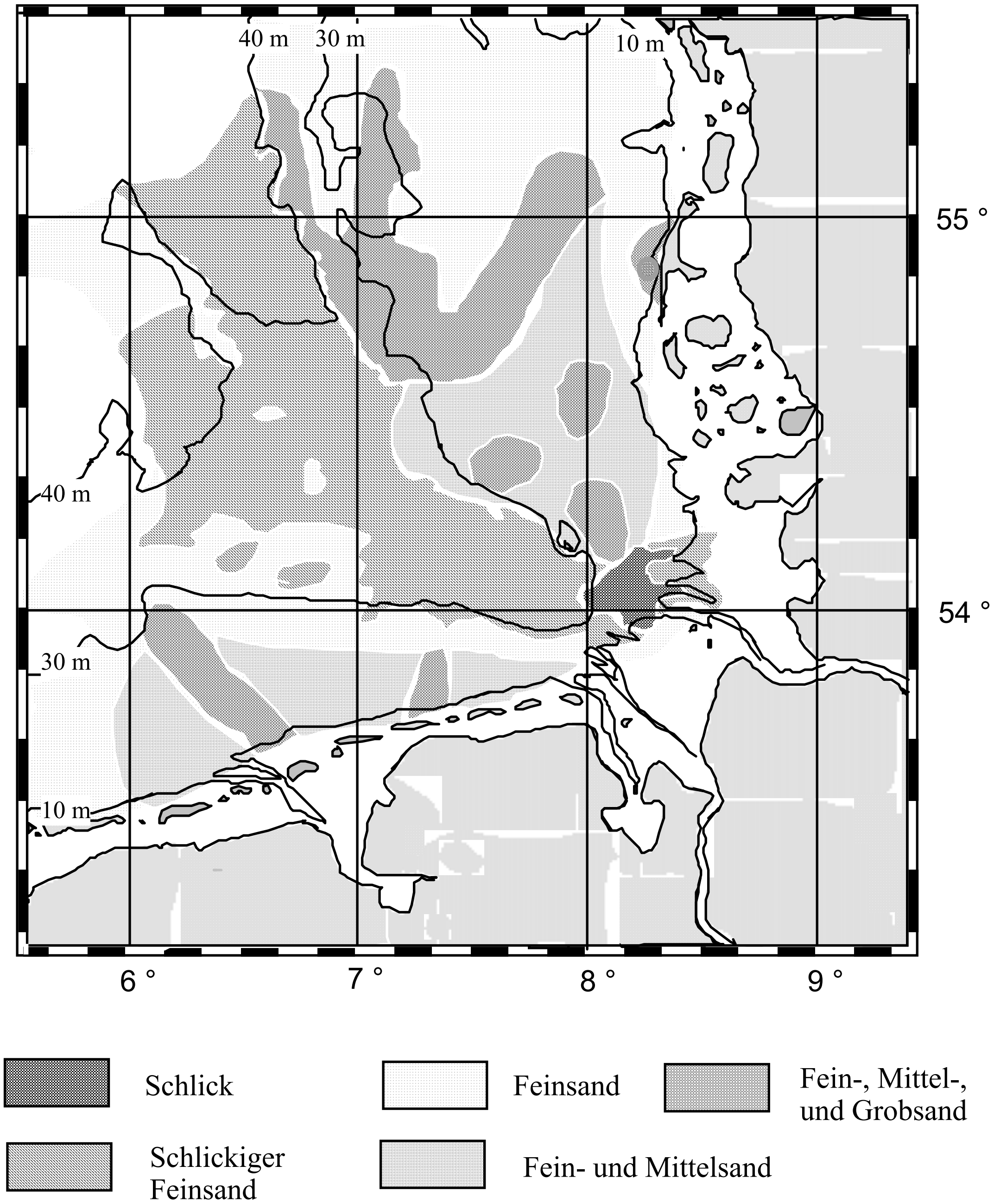


Fig. I-1: Sediment distribution in the German Bight (modified after Salzwedel et al. 1985)

Schlick	**= mud**
Schlickiger Feinsand	**= muddy fine sand**
Feinsand	**= fine sand**
Fein- und Mittelsand	**= medium grain sand**
Fein-, Mittel- Grobsand	**= fine, medium grain, coarse sand**

Table A-1: Dominant species (dominance >1%) of the benthic communities in the German Bight after Salzwedel et al. (1985)

Gem. = association

***Nucula nitidosa*-Gem.**	***Amphiura filiformis*-Gem.**	***Tellina fabula*-Gem.**	***Goniadella-Spisula*-Gem.**
Nucula nitidosa	*Amphiura filiformis*	*Magelona papillicornis*	*Spio filicornis*
Spiophanes bombyx	*Venus striatula*	*Tellina fabula*	*Goniadella bobretzkii*
Ophiura albida	*Pholoe minuta*	*Spiophanes bombyx*	*Nephtys cirrosa*
Mysella bidentata	*Mysella bidentata*	*Urothoe grimaldii*	*Branchiostoma lanceotatum*
Nephtys hombergii	*Echinocardium cordatum*	*Spio filicornis*	*Polygordius appendiculatus*
Phoronis sp.	*Pectinaria auricoma*	*Venus striatula*	*Spisula solida*
Ophiura texturata	*Edwardsia sp.*	*Bathyporeia guilliamsoniana*	*Aonides paucibranchiata*
Scoloplos armiger	*Spiophanes bombyx*	*Lanice conchilega*	*Spisula elliptica*
Abra alba	*Glycinde nordmanni*	*Nephtys hombergii*	*Synchelidium haplocheles*
Pectinaria koreni	*Cultellus pellucidus*	*Nephtys cirrosa*	*Pisione remota*
Lanice conchilega	*Nucula nitidosa*	*Scoloplos armiger*	*Spiophanes bombyx*
Pholoe minuta	*Nephtys hombergii*	*Synchelidium haplocheles*	*Ophelia limacina*
Thyasira flexuosa	*Cylichna cylindracea*	*Ophiura albida*	*Ensis ensis*
Diastylis rathkei	*Thyasira flexuosa*	*Bathyporeia elegans*	
Owenia fusiformis	*Abra alba*	*Edwardsia sp.*	
Abra nitida	*Lanice conchilega*	*Eumida punctifera*	
	Phoronis sp.	*Echinocardium cordatum*	
		Micropotopus maculatus	

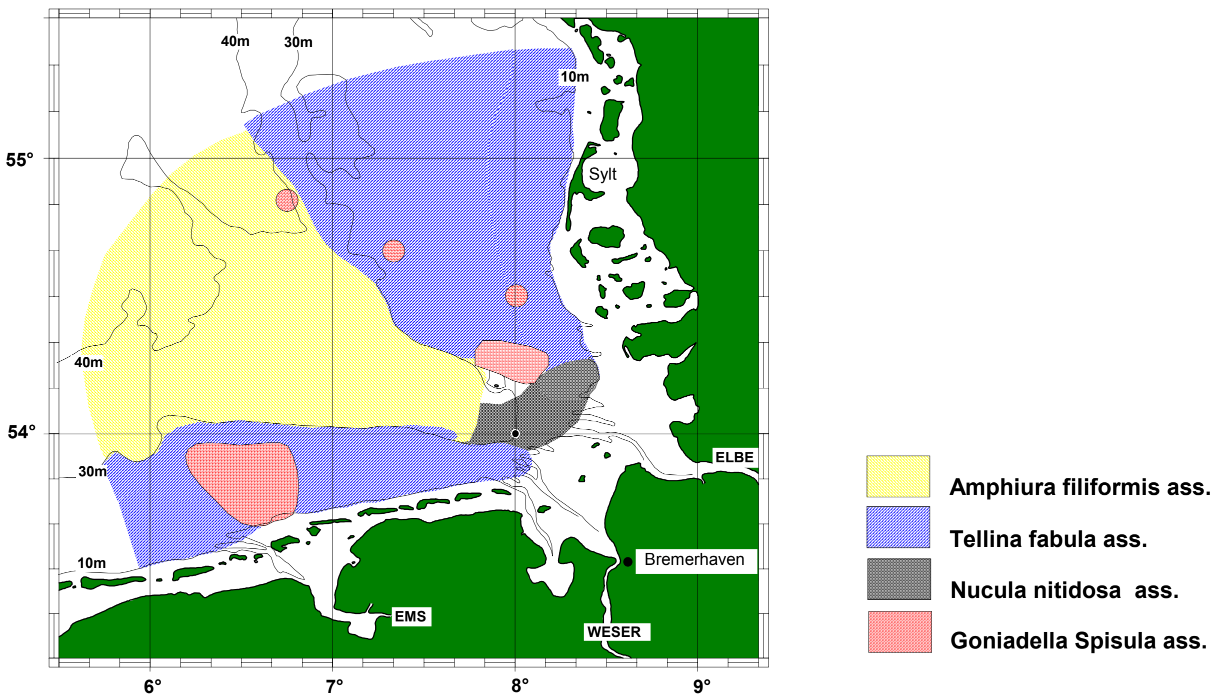


Fig. I-2: Benthic communities in the German Bight (Source: Salzwedel et al. 1985)

I-3.2 The macro zoo benthos communities of the Baltic Sea.

The Baltic Sea is one of the largest brackish bodies of water on earth and has very restricted access to the North Sea through the Danish Belt and the Kattegat. While the depth in some isolated basins, separated by sills, exceeds 200 m, the average depth is close to 52 m.

The distribution of temperature and salinity is governed by the river run off and salt-water inflow from the North Sea. . As a consequence the North West has a strong marine influence whereas the South East is brackish and the East and North East is almost fresh water. . Due to the higher density of the seawater there is a permanent halocline with the more saline water lying on the bottom, thus also hampering the vertical circulation. . Bottom water can only be renewed by, is horizontal inflow from the North Sea. This input, however, is impaired by the restricted exchange of water and the cascading basin structure of the Baltic. Thus the deep-water zones may be subjected to long-term stagnation, which results in the accumulation of organic material derived from production at the surface, sedimenting down and causing oxygen consumption. Extensive periods of stagnation may lead to complete exhaustion of oxygen and the production of hydrogen sulphide (Matthäus 1996, Arntz & Rumohr 1982, Arntz 1981a, Arntz 1977, Arntz & Brunswig 1975).

The Baltic does not have a strong tidal regime with the result that currents are mainly wind induced. The sediments range from fine muds, fine and coarse sands to fields with boulders originating from glacial deposits, reaching the surface.
The composition of macro zoo benthos in the Baltic is mainly structured by salinity, water depth and oxygen content. (Arntz & Brunswig 1975). Marine species are found in the north-western part and up to the southern part of the Baltic, where they occupy deeper more saline areas (submergence) and avoid the shallow zones that have brackish or almost fresh water. Furthermore the oxygen content also structures the benthic communities. As described above, oxygen deficiencies caused by the unique exchange of water may arise on the sea bottom. This may even occur in shallower areas after longer periods of stagnation. Eutrophication of the Baltic enhances these effects. Rumohr (1996) describes a sequence of typical events, which begins with a long-lived community dominated by mussels and echinoderms and changes to a high biomass mussel/worm community as eutrophication progresses. Further deterioration results in the establishment of a short-lived low biomass community of the small polychaetes (*Scoloplos*, *Capitella*, *Heteromastus*). The entire community perishes when oxygen becomes completely depleted resulting in a vagile epi fauna. In the Kiel Bight, Arntz & Brunswig (1975) distinguish between *Macoma baltica*-communities in depths up to 15 m and on sandy sediments and *Abra alba*-communities in depths from 15 m on sandy mud sediments.

Four benthic communities can be distinguished in the Baltic Sea (Arndt 1996) (Fig. I-3). The so-called *Macoma balthica* community occurs in shallow sandy coastal waters with the typical representatives being the Baltic Clam (*Macoma baltica*), the Lagoon Cockle (*Cerastoderma lamarcki*), the Soft-Shelled Clam (*Arenomya arenaria*), the mud snails (*Hydrobia ulvae* und *H. ventrosa*), the polychaetes *Nereis diversicolor*, *Arenicola marina*, *Pygospio elegans* as well as the tube dwelling amphipod *Corophium volutator*.

The *Abra alba* community can be found in depths below 15 to 20 m at higher salinities. Characteristic for this community are: the basket shell (*Corbula gibba*), the Icelandic cyprine (*Arctica islandica*), the bristle worm (*Lagis koreni*), the crab *Diastylis rathkei* and the brittle star *Ophiura albida*.

Deep areas with a soft bottom such as the Arkona and Bornholm Basins have a relict post glacial community which has developed under relatively low temperatures, even during summer and high salinities. This community, termed the *Macoma calcarea* community includes the following characteristic species: the Blunt Gaper (*Mya truncata*) and the highly low oxygen resistant bivalves of the genus *Astarte*.

Another postglacial relict community, poor in species numbers, exists in the eastern soft-bottom zones at depths below 20 m. This community termed the *Pontoporeia* community comprises the amphipods

Pontoporeia affinis and *P. femorata*. The species *Halicryptus spinulosus*, *Scoloplos armiger* and *Terebellides stroemi* often occur as accompanying low oxygen tolerant species.

The essential compositional structuring factors macro zoo benthos in the Baltic (salinity, water depth and oxygen can thus be identified, whereby the hydrodynamics, particularly the wind driven currents are of great importance for the exchange of water masses.

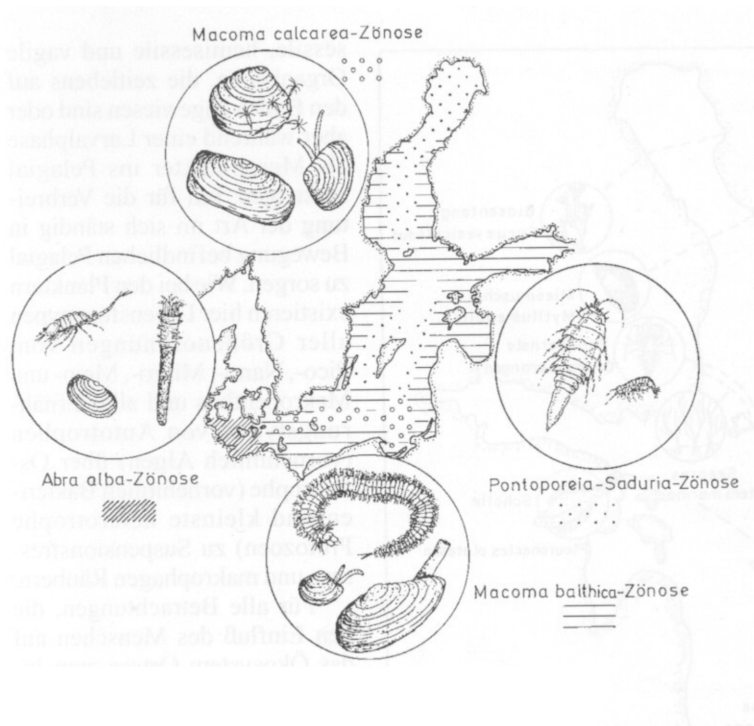


Fig. I-3: Benthic communities in the Baltic (Source: Arndt 1996)

I-3.3 Fish communities in the North Sea

Over 200 species of fish, including summer guests and stray species, occur in the North Sea. The bony fish form the largest component whereas the cartilaginous and cyclostomata play a minor role. Furthermore it is possible to distinguish between boreal, Lusitanian and Atlantic communities (Daan et al. 1990). The ten most dominant species in the shelf-edge region, central North Sea as well as the Southern and Eastern North Sea are listed in Table I-2 according to Daan et al. (1990) (Data for 1982 – 1985). These can be grouped into pelagic species (e.g. mackerel, herring) and demersal species (Cod, flatfish)

Table I-3 gives the dominant species in the German Bight compiled by Wätjen & Knust (in prep.) from data obtain in 2000. The data show that there has been no significant shift in the dominance of demersal fish in past 15 years. Table I-4 provides a complete list of species recorded by the same authors in the year 2000. Two of the recorded species (Twaite Shad and Piked Dogfish) have the Status 3 (endangered) on the Red List of endangered species whereas one species, the Salmon Wrasse has been given the status “P”, potentially endangered. Lozan (1990) has introduced a further division: 1- permanent residents; species which spend their entire lives in the North See, 2- Diadromous species which migrate either from the sea into freshwater to spawn (anadromous species) or vice versa, from fresh water to the sea (catadromous), 3- summer guests; which regularly migrate into the North Sea, particularly in summer without spawning, 4- Stray guests which have been observed in the North Sea at irregular intervals. Furthermore it is possible to differentiate between solely marine species and euryhaline species, which can occupy both marine and estuarine environments.

Water depth and the resulting temperature and salinity gradients, is the main structuring factor of fish communities in the North Sea (Daan et al. 1990). Also of importance is the sediment, in other word the composition of the sea bottom. The Salmon wrasse for instance only occurs in rocky areas. Species, which live on soft bottom macro zoo benthos on the other hand, have a corresponding pattern of distribution. .

Fishing has a strong influence on the fish fauna, which particularly in the North Sea is carried out with bottom gear such as bottom or beam trawl. Weber et al. (1990) have shown that a large proportion of the commercial fish stocks (e.g. Cod, Whiting, Haddock, Plaice and Sole) is being incorrectly managed. This means that they are over fished and that too many juveniles are being caught. In the past this has led to a strong decline of several species such as the collapse of the Herring stocks in the second half of the 1970’s, which could only be counteracted by a strict prohibition of their exploitation.

Overall the distribution of fish communities in the North Sea is very heterogeneous since there are large differences in the abundance of many species between summer and winter. The North Sea is not a closed system and thus the composition of fish communities may vary considerably with season and depending on climatic influences, due to the incursion of fish from outside areas. (Daan et al. 1990).

Table I-2: Dominant fish species caught with bottom trawl (%) in three zones of the North Sea between 1982 and 1985 (Daan et al. 1990)

Shelf edge	%	Central North Sea	%	Southern and Eastern North Sea	%
Pollachius virens (Saithe)	43,6	*Melanogrammus aeglefinus* (Haddock)	42,4	*Limanda limanda* (Dab)	21,8
Melanogrammus aeglefinus (Haddock)	11,6	*Merlangius merlangus* (Whiting)	13,9	*Merlangius merlangus* (Whiting)	21,6
Trisopterus esmarkii (Norway pout)	10,7	*Gadus morhua* (Cod)	9,2	*Eutrigla gurnadus* (Grey gurnard)	12,8
Merlangius merlangus (Whiting)	9,1	*Trisopterus esmarkii* (Norway pout)	4,7	*Trachurus trachurus* (Horse mackerel)	9,9
Trachurus trachurus (Horse mackerel)	7,6	*Pollachius virens* (Saithe)	4,5	*Pleuronectes platessa* (Plaice)	6,3
Micromesistius poutassou (Blue whiting)	4,1	*Limanda limanda* (Dab)	3,7	*Gadus morhua* (Cod)	5,5
Gadus morhua (Cod)	3,8	*Eutrigla gurnadus* (Grey gurnard)	2,0	*Melanogrammus aeglefinus* (Haddock)	4,7
Scomber scombrus (Mackerel)	1,6	*Clupea harengus* (Herring)	2,5	*Clupea harengus* (Herring)	4,5
Merluccius merluccius (European hake)	1,3	*Microstomus kitt* (Lemon sole)	1,8	*Scomber scombrus* (Mackerel)	3,0
Molva molva (Ling)	1,2	*Raja radiata* (Starry skate)	2,0	*Galeorhinus galeus* (Tope)	2,1

Table I-3: Dominant demersal fish species caught with bottom trawl (%) in the German Bight during 2000 (Wätjen & Knust, in prep.)

Doggerbank	%	Central German Bight	%	Tiefe Rinne (Deep Trough)	%
Limanda limanda (Dab)	62,9	*Limanda limanda* (Dab)	55,5	*Merlangius merlangus* (Whiting)	48,0
Melanogrammus aeglefinus (Haddock)	9,0	*Merlangius merlangus* (Whiting)	21,0	*Limanda limanda* (Dab)	41,0
Eutrigla gurnadus (Grey gurnard)	8,4	*Eutrigla gurnadus* (Grey gurnard)	12,0	*Trisopterus minutus* (Poor cod)	2,2
Hippoglossoides platessoides (American plaice)	7,1	*Pleuronectes platessa* (Plaice)	3,6	*Eutrigla gurnadus* (Grey gurnard)	2,1
Merlangius merlangus (Whiting)	7,0	*Hippoglossoides platessoides* (American plaice)	2,4	*Melanogrammus aeglefinus* (Haddock)	1,5
Gadus morhua (Cod)	3,2	*Callyonymus lyra* (Dragonet)	1,8	*Gadus morhua* (Cod)	1,3
Pleuronectes platessa (Plaice)	0,9	*Melanogrammus aeglefinus* (Haddock)	0,9	*Callyonymus lyra* (Dragonet)	0,6
Microstomus kitt (Lemon sole)	0,5	*Gadus morhua* (Cod)	0,6	*Pleuronectes platessa* (Plaice)	0,5
Callyonymus lyra (Dragonet)	0,3	*Trachinus vipera* (Weever fish)	0,3	*Plathyichtys flesus* (Flounder)	0,3
Hyperoplus lanceolatus (Greater sand eel)	0,2	*Microstomus kitt* (Lemon sole)	0,2	*Microstomus kitt* (Lemon sole)	0,2

Table I-4: List of fish species caught by bottom trawl in the German Bight in 2000 (Wätjen & Knust, in prep.)

Species name		Presence in %	Red List
Alosa fallax	Twaite shad	3,7	**[3]**
Anguilla anguilla	Eel	3,7	
Enchelyopus cimbrius	Fourbeard rockling	3,7	
Merluccius merluccius	European hake	3,7	
Syngnathus spp.	Pipe fish spp.	3,7	
Galeorhinus galeus	Tope shark	3,7	
Squalus acanthias	Piked dogfish	3,7	**[3]**
Trisopterus luscus	Pouting	7,4	
Zoarces viviparus	Eelpout (viviparous blenny	7,4	
Scophthalmus rhombus	Brill	7,4	
Raja radiata	Starry skate	11,1	
Sardina pilchardus	Sardine	11,1	
Engraulis encrasicolus	Anchovy	11,1	
Buglossidium luteum	Solenette	14,8	
Trachinus vipera	Weever fish	14,8	
Trisopterus minutus	Poor cod	14,8	
Psetta maximus	Turbot	18,5	
Arnoglossus laterna	Scaldfish	25,9	
Platichthys flesus	Flounder	29,6	
Ammodytes lancea	Sand eel	29,6	
Agonus cataphractus	Hooknose	33,3	
Solea solea	Common sole	33,3	
Myoxocephalus scorpius	Short-spined Bullhead	33,3	
Mullus surmuletus	Striped Red Mullet	40,7	
Trigla lucerna	Tub gurnard	51,9	
Hippoglossoides platessoides	American plaice	51,9	
Hyperoplus lanceolatus	Greater Sand eel	55,6	
Microstomus kitt	Lemon sole	59,3	
Trachurus trachurus	Horse mackerel	59,3	
Gadus morhua	Cod	63	
Sprattus sprattus	Sprat	63	
Clupea harengus	Herring	66,7	
Melanogrammus aeglefinus	Haddock	70,4	
Scomber scombrus	Mackerel	74,1	
Callionymus lyra	Common dragonet	92,6	
Eutrigla gurnardus	Grey gurnard	92,6	
Pleuronectes platessa	Plaice	100	
Merlangius merlangus	Whiting	100	
Limanda limanda	Dab	100	
*Ctenolabrus rupestris**	Salmon wrasse		**[P]**

Classification in the „Red List“
1 = Threatened with extinction
2 = highly endangered
3 = endangered
P = potentially endangered
* The Salmon Wrasse *Ctenolabrus rupestris* could be identified on photographs taken in the vicinity of Helgoland.

I-3.4 Fish communities in the Baltic

The distribution of fish in the Baltic is mainly governed by the strong salinity gradients. Marine species therefore occupy the western Baltic whereas fresh water fish tend to occur in the eastern Baltic. The deep basins are usually not frequented by fish due to the almost permanent oxygen paucity as a result of the strong layering of the water column. . For more details on the specific hydrographic features of the Baltic see chapter I-3.2.

Currently there are 144 fish species in the Baltic. Of these, 97 are marine species, 7 migratory fish and 40 fresh water fish. (Table I-5). The number of marine fish decreases from West to East and from South to North (Thiel et al. 1996).

Table I-5: Species numbers of marine, migratory and fresh water fish in the different zones of the Baltic: Thiel et al. 1996)

	Marine fish	Migratory fish	Fresh water fish	Total number
Entire Baltic (Excluding the Kattegat)	97	7	40	144
Arkona Sea und Belt Sea (Western. Baltic)	97	7	22	126
Bornholm Sea, Gotland Sea, Gulf of Riga (Central Baltic)	41	7	23	71
Aland Sea, Gulf of Finland, Bodden Sea, Archipelago (Eastern and Northern Baltic)	27	5	33	65
Bodden Bay	10	5	25	40

Western Baltic

Marine fish dominate in the Western Baltic where most live on the bottom in shallow waters. The only species of economic importance here are the herring, sprat and cod. Apart from the above mentioned species, the following are regularly found in the western Baltic: Whiting, plaice, dab, turbot, flounder, mackerel, horse mackerel, haddock, gurnard, anchovy, grey mullet, garfish, black goby and sand goby (Nellen & Thiel 1995)

Central Baltic

Only 36 of the 71 fish species in the Central Baltic are regularly seen in greater numbers. A large proportion of these are fresh water fish, which frequent the shallow coastal waters. Amongst the frequent marine species are the Cod, Whiting, Plaice and Dab. Many smaller fish species are found on the sandy grounds along the coasts of Mecklenburg and Pomerania. Very little, however, is known about their distribution. Winkler & Thiel (1993) recorded 18 species belonging mainly to the Genus Stickleback, Needlefish, Bullheads, Flatheads, Butterfish, Sand eels and Goby.

Eastern and Northern Baltic

Fresh water fish as well as the marine coastal fish such as Herring and Sea snail dominate in the Eastern and Northern Baltic. Cod, Flounder and Sprat are also still of some significance in the southern region of the Bothnian Sea Gulf and the Gulf of Finland. Fresh water species preferentially live near the coast. In the Bothnian Bay fresh water fish such as Roach, Perch and Pope are the dominant species. .

The major natural structuring factors of the fish fauna in the Baltic are salinity, oxygen, water temperature and depth (Nellen & Thiel 1995).

The fish fauna can be divided into pelagic, demersal and littoral, communities, depending on their habitat.

The pelagic community is dominated by the Herring throughout the Baltic, whereby the Sprat, Salmon and Sea trout are other typical representatives of this group.

The cod, flounder and plaice dominate the demersal community. The flounder is found throughout the entire Baltic whereas the Plaice is not found in the Northern Baltic.

The littoral community is characterised by juvenile representatives of pelagic species. The Bodden Seas and lagoons are important nurseries for both pelagic and demersal species. In these areas at depths below 1,5 m the shallow water communities are dominated by juveniles of the fresh water fish Roach, Perch and Sticklebacks.

Anthropogenic activities, which influence the fish fauna, are primarily the introduction of fertilizer and the resulting eutrophication of the waters, next to fishing. As already described above, the eutrophication in many areas of the Baltic has led to the deterioration of the oxygen levels in the bottom water and in extreme cases even to within the shallower coastal waters (see also chapter I-3.2). Examples of species particularly affected are the Cod and Dab. . Both species require highly saline water, which normally occurs in the lower water column, for the development of their eggs (Temming 1989, Helsinki Commission 2001). Since these zones frequently have oxygen deficiency, a successful development of the eggs is often not possible which has a negative effect on the stock of these species. . The fact that the Dab, which formerly was very common in the area around Bornholm, now only occurs in the West is attributed to oxygen deficiency (Temming 1989).
Fishing also ahs severe effects on the fish stocks. The most severely affected are Cod, Flounder, Plaice, Sprat and herring.
A fishery in the Baltic is concentrated mainly on the Cod and maintains their stocks at a very low level because reproduction rates have dropped. Two stock units have been laid down for the cod: One for the Western Baltic and a second for the remaining regions of the Baltic (Rechlin 1995). Both populations have declined severely since 1983. Since the stock of Cod is highly dependant on the inflow of oxygen rich and saline North Sea water, long periods of stagnation in the exchange of water result in a decline in the population. The longest recorded period of stagnation without an inflow of North Sea water into the Baltic occurred within the period from 1983 to 1993. This is therefore definitely a factor responsible for the observed decline in Cod stocks. In addition, uncontrolled fishing quotas enhanced the process. (Rechlin 1995). This example shows that catch quotas, which are not adjusted to the changed conditions, will have a negative impact on the fish stocks.

I-4 Possible consequences of offshore wind parks on benthic communities

I-4.1 Potential impact pathways

Potential impact pathways for benthic communities have been listed in Table I-6. The impact pathways associated with sound emission and effects on benthic communities have not been listed since they are dealt with in sub-project III (Noise impact from off-shore wind energy turbines.

Table I-6:Potential impact pathways for the benthos and fish, the subjects of protection

Construction phase

Cause / reason	Change of condition	Affected subjects of protection	Impact / Potential endangerment
Preparation of the sea floor, Draw down or construction of foundations or Pile jetting Jetting of cables	Sediment movement, Re-suspension of fine material, Sedimentation of fine material, Enhanced turbidity	Benthic communities (Benthos and demersal Fish)	Changes in the community as a result of habitat alteration.

Operation phase

Cause / reason	Change of condition	Affected subjects of protection	Impact / Potential endangerment
Foundations / piles	Obstruction of sediment surfaces by foundations, Availability of hard substrate in the form of foundations and piles for settlement, Changes in the small and meso scale hydrography as well as sediment composition, erosion around foundations and piles.	Benthic communities (Benthic and demersal Fish)	Changes in the community as a result of habitat alteration and changes in settlement due to alterations of the hydrography.
Transmission of energy through cables	Emission of electromagnetic fields	Benthic communities (Benthic and demersal Fish)	Possible disorientation and disruption of migration patterns
Faulty operation	Emission of toxic substances	Different subjects of protection	Material specific response

Dismantling

Cause / reason	Change of condition	Affected subjects of protection	Impact / Potential endangerment
A accurate assessment of possible impacts of the dismantling phase was not possible due to missing information about dismantling techniques. As a first approach we assume comparable impacts as under construction phase with the condition of complete disposal	As under construction phase	As under construction phase	As under construction phase

The response of benthic communities to changes brought about by construction, operation and dismantling of turbines needs to be taken into account.
In the event of a decline in the stock in a given area, in response to natural or anthropogenic discrete disturbances (e.g. Construction of wind energy turbines, jetting of cables), recruitment potential remains high enough to re stock the area.
Disturbed habitats can be re-settled, not only by dispersion of larvae but also by recruitment post larval and adult forms (Bosselmann 1989).

A high capacity to disperse has been observed in post larval stages of many marine macro faunal species (Heiber 1988; Günther 1992b). The major medium of transport is the water although the dispersal within or on the sediment surface is not to be neglected (Smith & Brumsickle, 1989). The distance traversed during the dispersal depends on size and age of the animals.
The belief of Dauer & Simon (1976) that recruitment in the marine environment is rapid has to be viewed differentially. The environment of a community, age and the frequency of disturbance need to be considered. (Sanders 1968; Dayton & Hessler 1972). According to Boesch & Rosenberg (1981) macro benthic communities in dynamic environments (e.g. estuaries, shallow water areas) behave differently than those in more stable environments (e.g. Deep sea). The former react with more resistance and resilience to strong perturbations than the latter e.g. long-term oxygen deficiency (Arntz & Rumohr 1986, Kröncke & Bergfeld 2001), since they are better adapted to strong fluctuations in temperature, salinity oxygen and frequent perturbations of the sediment. Subsequent to the oxygen deficiency situation in many areas of the German Bight in 1983, there was a strong decline in species numbers and abundance of the benthic community, however, the community recovered from this disturbance within a year (Westernhagen et al. 1986). In a recruitment experiment carried out by Arntz & Rumohr (1982) in the western Baltic at 20 m depth, the experimental surfaces had communities comparable to the surroundings after two to three years.

The spatial and temporal scale as well as the quality of disturbance (physical or another form such as oxygen deficiency) need to be taken into account when investigating the impact of natural or anthropogenic influence. One needs to differentiate between a unique single disturbance within a longer period (e.g. jetting of a pipeline) and repeating short-term disturbances such as heavy fishing with beam trawl in the German Bight and anthropogenic habitat changes such as construction in the marine environment. Repeating disturbances such as fishing with beam trawls can result in similarly permanent changes of the benthic community, as can habitat changes due to changes in hydrodynamic conditions around constructions that result in the establishment of other communities. (Kröncke 1995, Lindeboom & de Groot 1998).

Fishing with heavy bottom gear in the North Sea must be regarded as a severe anthropogenic disturbance (Rumohr et al. 1998). Large areas are thus disturbed at least 3-4 times annually (Rauck 1985 cited in Kröncke & Bergfeld 2001). This results in a permanent change of the benthic community within these areas, whereby the sensitivity between the various macro benthic species differs. Fragile species such as, for example *Echinocardium cordatum*, *Corystes cassivelaunus*, *Phaxas pellucidus*, *Dosinia lupinus*, *Mactra corallina*, *Abra alba*, *Spisula solida* and *Spisula subtruncata* are the most sensitive, whereas the species *Arctica islandica*, *Buccinum undatum* and *Asterias rubens* are less sensitive. The consequence is an increase in short-lived, prolific species at the expense of long-lived, fragile species within the benthic community of the North Sea (Kröncke & Bergfeld 2001).

With regard to potential impact pathways during the construction, Operation and dismantling of offshore wind energy turbines one needs to differentiate between expected small scale (direct vicinity of piles), meso scale (area of wind parks and immediate surroundings) as well as the larger scale surroundings. This is discussed in the following.

I-4.2 Small and meso scale changes

I-4.2.1 Construction phase

A large amount of sediment will be moved and dumped during the construction of a wind energy plant resulting in the local reduction of benthos because of displacement or permanent submergence. (E-connection 2001, Expert discussion- Benthos and Fish 2002). The sediment displacement will mobilise and re suspend large amounts of organic and suspended particulate material, which at specific concentrations is likely to have adverse effects on filter feeders (Kröncke & Bergfeld 2001).

The estimated regeneration time for benthic communities thus affected by physical disturbances in the sub littoral is estimated to be 2 years based on the species composition. However, according to the age and size composition of the perturbed communities the regeneration is estimated to take at least 5 years. (Expert discussion Benthos and Fish 2002; Kenny & Rees 1996, Bosselmann 1988, Boesch 1985, Ziegelmeier 1970). Investigations in connection with sand and gravel quarrying (mentioned in Kröncke & Bergfeld 2001) regarded a regeneration time of 6-8 months for estuarine mud communities, 2-3 years for sub littoral sand communities and 5 to 10 years for communities associated with reef like substrata (e.g. Sabellaria), to be realistic.

Westernhagen et al. (1986) in their investigation on the effects of oxygen deficiency in the German Bight in 1983, found that benthic communities in the affected areas had recovered within 1 year to the extent that the situation after the event had almost returned to that before the perturbation.

Investigations were carried on the benthos, fish and decapods from 1993 to 1995, accompanying the laying of the gas pipeline EUROPIPE in 1994. The pipeline was layed between the Langeoog and Baltrum islands in the “Accumer Ee”. During construction there was extensive displacement of sediment with clearly apparent impacts on the studied biota. However, within a year after the construction there was a clear return of the community structure to that at the onset, before construction began. (Knust 1997) assumes, that the effects pf perturbation within this area would not have been noticeable anymore after two years.

Taking into consideration the current information, the expected effects during the construction phase are likely to be recorded as being very localised and of short to moderate duration (Expert discussion Benthos and Fish 2002).

I-4.2.2 Operation phase

A lasting change, alteration or impairment or a shift in the species composition of benthos and fish can be expected when the hydrography and consequently the sediment structure is permanently disrupted by the wind energy turbines. (Expert discussion Benthos and Fish 2002). There is a strong need to understand the impact of a wind energy turbine on the hydrographic regime in the North and Baltic Seas. However, the hydrographic regimes and sediments in the Baltic and North Seas need to be differentiated because of the environmental and topographic differences.

The localised changes of the current regime in the proximity of piles will result in a change in the sediment grain size distribution and thus change the benthic fauna. Ambrose & Anderson (1990) found that the shift to a coarser median grain size in the sediment surrounding an artificial reef resulted in a change in the occurrences of specific species up to 20 m away from the reef. +In the vicinity of the research platform „Nordsee“ no apparent difference was detectable between 50 and 200 meters away from the platform (pers. com. Dr. E. RACHOR, Alfred Wegener Institute, Bremerhaven). Investigations carried out in 2001 on the benthos and sediment in the direct proximity of a wreck which had sunk in 30 m depth on fine sandy area of the German Bight in 1950, revealed that effects on the sediment and concomitant changes in the benthic community were noticeable up to a distance of a maximum of 50 meters from the wreck. (Fig. I-4) (Knust & Hoek, in prep.)

According to the current state of knowledge, changes in the sediment composition and concomitant changes n the benthic species composition caused by the changes in the hydrodynamic conditions around piles of wind energy turbines can be considered as being locally constrained. It is expected that effects due to changes in the hydrography will not be measurable more than 100 m from the piles (Expert discussion Benthos und Fish 2002; E-connection 2001; SEAS Distribution 2000; Ambrose & Anderson 1990). In this context, it is important to know if several piles will have an accumulative effect, which may also lead to a larger area being affected. (See chapter I.4.3).

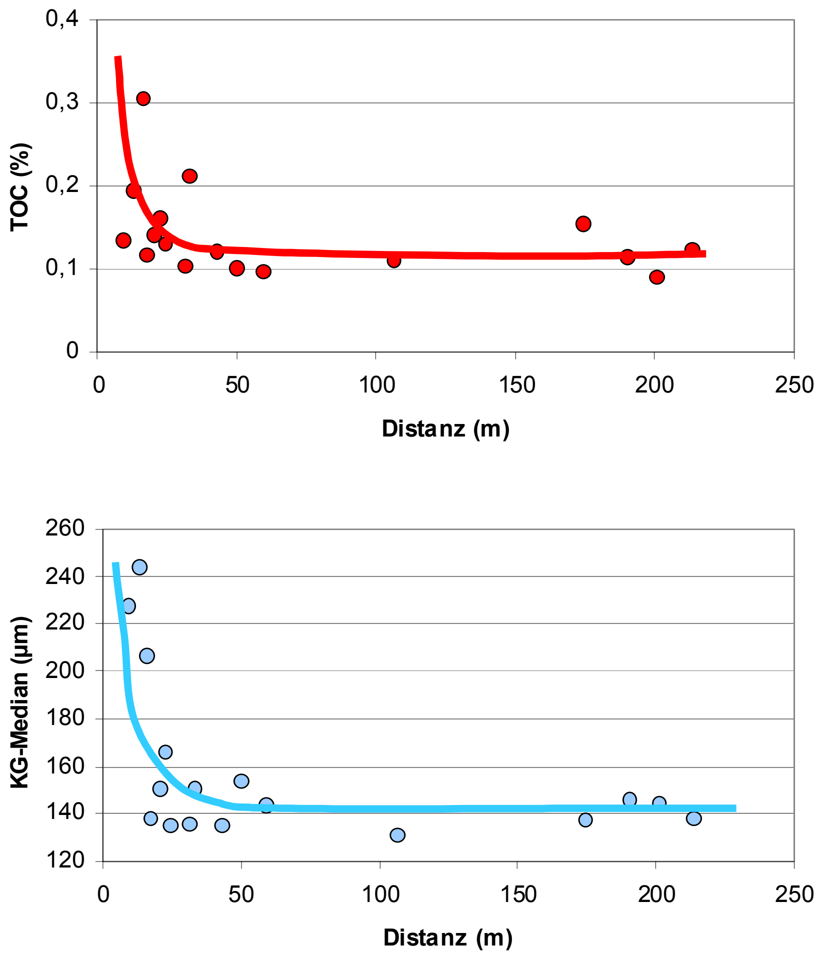


Fig. I-4: Effect of a ship wreck (50 m long in 30 m water depth in the German Bight) on the amount of organic material (TOC) and the median grain size (KG-Median) in the vicinity of the wreck TOC = Total carbon content / KG-Median = Median of grain size / Distanz = distance

The introduction of hard substrates on sandy bottoms will result in the settling of additional; particularly filter feeding species, which prefer hard substrata. (Bombace 1989, Wendt et al 1989). This will lead to an enrichment of organic matter in the immediate vicinity and thus affect the benthic community. Page et al. (1999) describe such effects observed during their investigation on the effect of an oil platform on the distribution of benthos and abundance of crabs. Large-scale effects (e.g. a displacement of pelagic larvae of endo benthic species by filter feeding species which live on hard substrata) are not expected according to the current state of knowledge. (Expert discussion Benthos und Fish, 2002).

An aggregation of fish is expected to occur near the piles. This will tend to be greater with increasing complexity of the structure (Page et al. 1999). Investigations on artificial reefs as well as wrecks and other offshore structures have shown that these have positive effects on various fish populations to the extent that they are used as nurseries by some (Alezion & Gorham 1989, Campos & Gamboa 1989, Hueckel et al. 1989). This is partially due to an increased food supply as well as the protective nature of the structure (Adams, 1994; Bohnsack et al., 1994; Alezion & Gorham, 1989; Anderson et al., 1989). Since the tidal effect creates a littoral zone on the piles a new habitat is created for fish, which lay their eggs on hard substrata e.g. Sea Scorpion, Lumpsucker and Garfish. (E-connection, 2001). There is no indication of a reduction of the in-fauna of the sediment surrounding the piles caused by an increased in feeding pressure by higher fish aggregations. (Ambrose & Anderson, 1990). Davies et al. (1982) could not find any influence in the scour of an artificial reef on the bottom fauna, further than 20 meters from the reef
In addition commercial fishing will not be possible or be permitted in the vicinity of wind energy parks. This secondary effect of the wind energy parks will have consequences for the end and epi-benthic communities. . Many recent investigations have described a shift in benthic community structure in the North Sea during the past decades due to fishing activity as mentioned already in point I-4.1.

These observations are supported by investigations done on the oil platform „West Gamma“ which sank 60 nautical miles north west of Helgoland in 1990 (Tuck et al. 1998). The benthic in-fauna was sampled in and outside an area marked by buoys surrounding the wreck using a 0,1m² van Veen grab between 1992 and 1995. The assumption was that no bottom trawl fishing had taken place within the demarcated area thus permitting a comparison between an un-fished and fished area outside the demarcated zone. There was no fundamental difference between the areas within and outside the demarcation. However, it was observed, during the period of investigation, that the penetration depth outside the demarcation area was less than in the un-fished area within the demarcation. The authors attribute this to the relentless perturbation of the biogenic structures in the top layers of the sediment by fishing gear, which resulted in a recurring turn over of these layers and consequently increased compaction of the surface layers. .

At the same time the benthic community within the undisturbed demarcated area around the wreck, developed in a completely different manner, during the course of three years, than did that outside the buoys where fishing continued. Table I-7 lists the species, which showed clear differences in abundance between protected, and un-protected areas.

Table I-7: Species with different abundances between protected and un-protected areas (Tuck et al. 1998)

Higher abundances in protected areas	Higher abundances in disturbed areas	Class
Amphiura filiformis	Juvenile Ophiuroids	Echinodermata
Thrachythyone elongata		Echinodermata
Leptosynapta inhaerens		Echinodermata
Echinocardium cordatum		Echinodermata
Tellimya ferruginosa	Juvenile Bivalvia	Mollusca
Mysella bidentata		Mollusca
Thyasira flexuosa		Mollusca
Cylichna cylindracea		Mollusca
Cingula vitrea		Mollusca
Callianassa subterranea	Amphipoda	Crustacea
Upogebia spp.		Crustacea
Pectinaria spp.	*Ophelina accuminata*	Polychaeta
Enipo kinbergii	*Spiophanes bombyx*	Polychaeta
	Spio filicornis	Polychaeta
	Phoronis spp.	Tentaculata
Anthozoa spp.		Cnidaria
Nemertini spp.		Nemertini

A multivariate analysis based on the species inventory presented as MDSD plot shows the differences between stations within and outside the area demarcated by buoys (Abb. I-5).

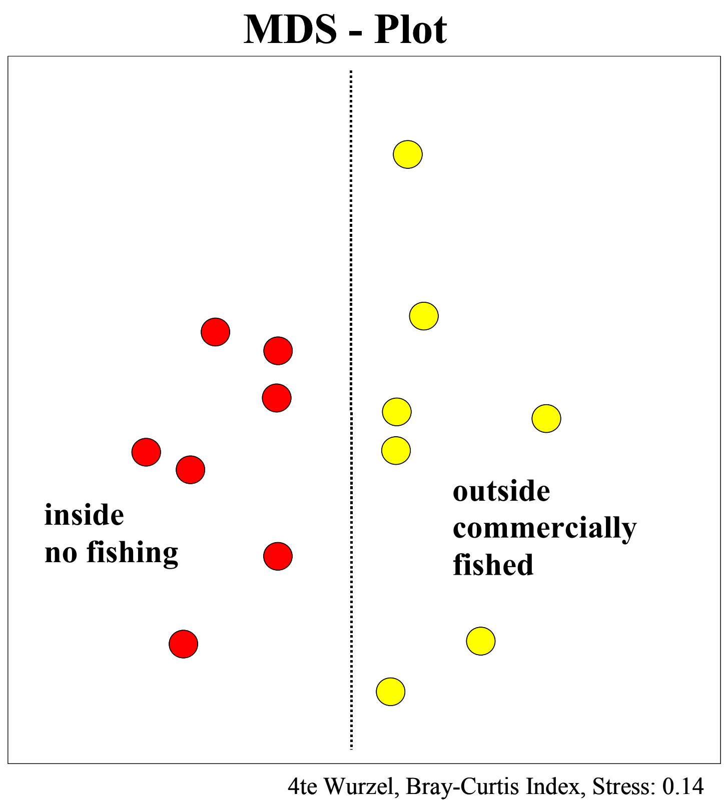


Fig. I-54: Plot of the differences in the benthic community between stations within (no fishing) and outside (commercially fished) area at the Gamma wreck, demarcated by buoys (after Schroeder 1995)

The general comparison of species numbers, abundances and biomass yielded significant differences in species numbers and biomass between the stations within and outside the demarcated areas. With regard to the mean abundance more organism were found within the demarcated area than outside, although the differences were not significant (Fig. I-6).

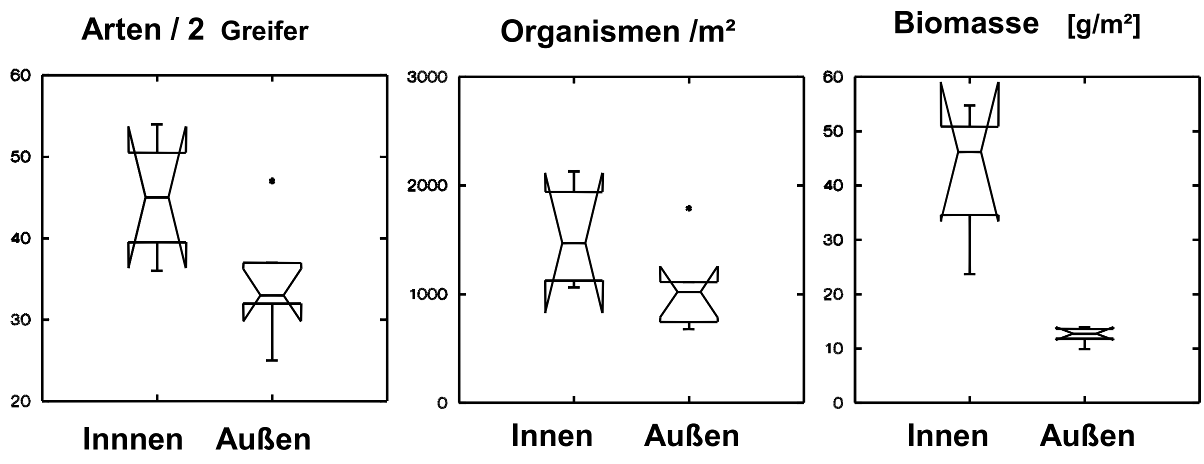


Fig. I-6: **Plot of species numbers, numbers and biomass per m^2 within and outside the areas demarcated by buoys (after Schroeder 1995)**

Arten / 2 Greifer	**= number of species per 2 samples**
Organismen / m²	**= number of organisms per m²**
Biomass2 [g/m²]	**= Total biomass [g/m²]**
Innen	**= inside (no fishing)**
Außen	**= outside (commercial fishing)**

The fact that the results mentioned above clearly show that more fragile species such as the common heart urchin *Echinocardium cordatum*, for instance, were found in the protected area is a clear indication of the effect of heavy bottom trawls. (Tuck et al. 1998, Schroeder 1995). After the fishing ban was lifted in 1995, a sample taken in 1996, a year later, revealed very little difference between the two areas. .

A change in the benthic communities is therefore expected to occur over the years, in areas surrounding offshore wind parks, which have been closed to fishing. This is mainly attributed to the fact that no heavy bottom fishing gear will disturb the benthic in and epi fauna.

There are further indications that larger areas free of fishing may have large-scale positive effects on the development of fish stocks (Hall 1998).

I-4.2.3 Dismantling

It is expected that the turbines will be removed from the system without leaving any visible remains above the sediment surface. In this case the dismantling process is likely to have similar effects as during the construction. . Regeneration of the benthic communities is estimated to take 2 years (species inventory) to 5 years (age and size composition) (Expert discussion Benthos and Fish 2002; Kenny & Rees 1996, Bosselmann 1988, Boesch 1985, Ziegelmeier 1970).

I-4.3 Large-scale changes

I-4.3.1 Construction phase

The likelihood of small and meso scale changes which may occur during the construction phase (see chapter I-4.2.1) does not provide any indication that large scale alterations of the benthic community are to be expected due to the construction. Furthermore, no literature data are available on the effects of similar comparable construction measures.

I-4.3.2 Operation phase

A study on the effects of offshore wind parks on ocean currents was carried out by the university of Hannover (Mittendorf & Zielke 2002). The aim of the investigation was not to determine the change in current speed immediately adjacent and behind the individual turbines (the authors considers this effect to reach nor further than a few meters to decimetres, but a large scale reduction in current speed within and outside the area of the wind park since the park is likely to represent a major resistance factor. Three regions in the German Bight, Borkum, the mouth of the Weser River and the area around Helgoland were chosen to exemplify potential effects. It was shown that the obstruction of large-scale currents by wind parks with several hundred single turbines could be estimated using a hydrodynamic numerical model. The models show that local current and bathymetry produce specific local differences in the currents. . With reference to the three chosen test sites, it was shown that the highest mean percentage reduction in the current speeds would occur in the Mouth of the Weser (2,13%) followed by the area around Helgoland (1,35 %) and the area north of Borkum (0,92 %) (Fig. I-7 and I-8). The authors do not consider this effect to be of any significance for the entire system. Thus changes of this magnitude are not likely to affect for example the sediment structure, which would have a serious large-scale effect on the benthic communities. The authors also conclude, that their observations also apply for the albeit slower current speeds in the Baltic. However, the question of the stability of the water column needs yet to be clarified. Des (See Chapter I-3.2 for the unique hydrographic features in the Baltic).

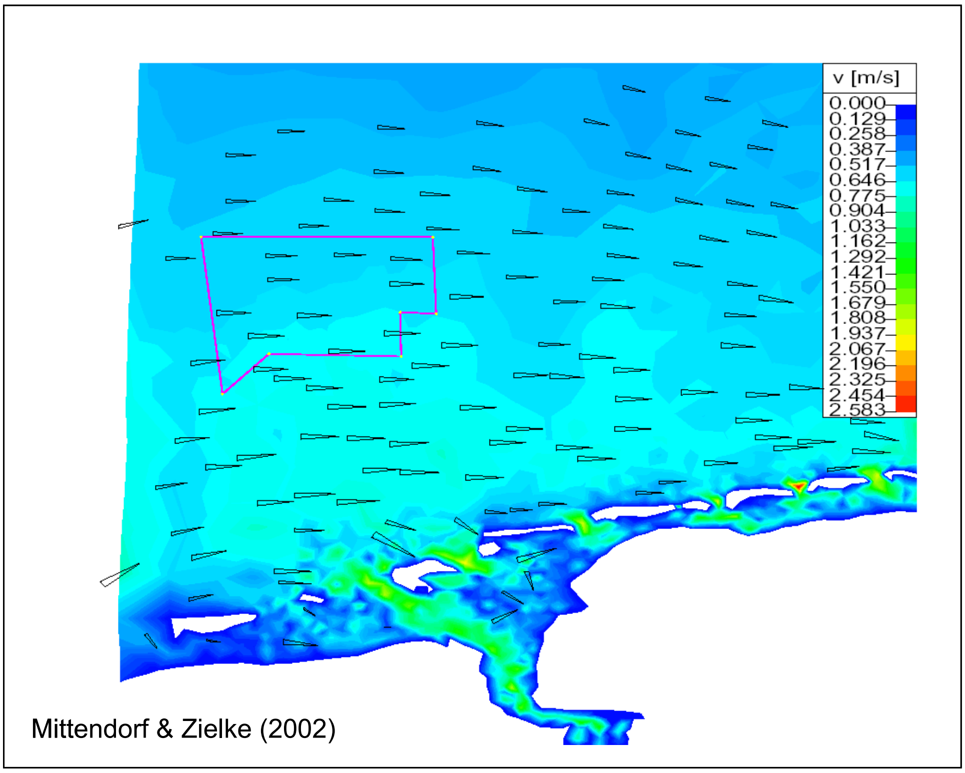


Fig. I-7: **Current speed (meter/sec) and -direction in the North Sea north of Borkum (Mittendorf & Zielke 2002)**

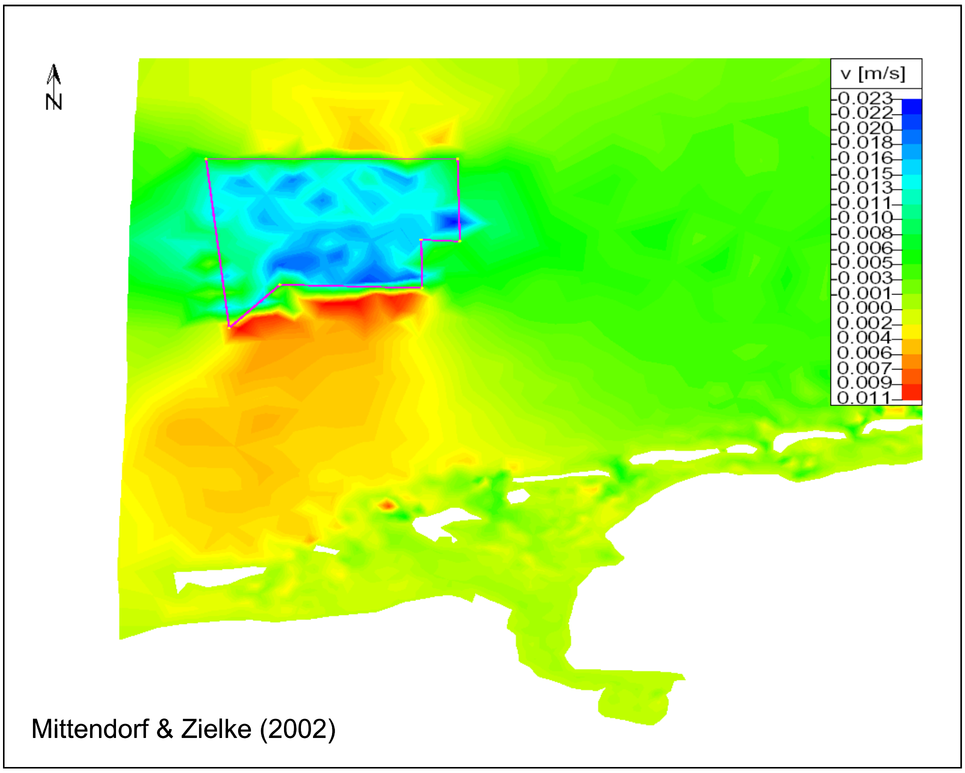


Fig. I-8: **Changes in current velocity caused by a wind park consisting of 833 single turbines north of Borkum (Mittendorf & Zielke 2002)**

I-4.3.3 Dismantling

As described earlier, the observations made with regard to the fact that small and meso-scale effects of the construction do not provide any indication of the large-scale effects. The same applies to the dismantling of the turbines.

I-4.4 Electro magnetic fields

The sediment displacement caused by the laying of cables is comparable to those of the construction of the wind energy turbines. For this reason there is no further reference to the potential effects of sediment displacement and movement.
Up to the present electricity was transmitted over long distances via High voltage direct current (HVDC) cables. (e.g. the mono polar BALTIC-Cable between Sweden and Germany). For this reason most investigations of the albeit few carried out deal with such cables. . The use of cables with direct voltage and direct current primarily produces a continuous magnetic field. The field arises within the insulation of the cable and does not pass through to the outside Sea electrodes are layed together with HVDC-cables in order to use the sea floor as an electrical return. In this case electrical fields arise near the electrodes lying in the water. (Kullnick & Marold 2000).

E-connection (2001) has estimated that the cables layed will produce magnetic radiation of about 5% of the earth's magnetic field. However, Kullnick & Marhold (1999) measured a magnetic field within 1 meter from a sea cable of 450 – 600 Kilowatt and 1600 Amperes to be six times as strong as the earth's magnetic field, whereas it was only a third of the earth's magnetic field, 20 meters away.

With regard to the consequences one needs to differentiate between 1. The effect of electromagnetic fields on orientation or migration, including the "barrier effect": 2. Harmful effects on organisms due to the electro magnetic field; 3. Effect of temperature elevation in the proximity of the cable.

There is evidence that eels use magnetic fields for orientation (Branover et al. 1971; Souza et al. 1988). However other studies do not confirm these observations. Investigations by Westerberg (Talk held on the Workshop „Technische Eingriffe in marine Lebensräume") on eels in the vicinity of the BALTIC-Cable did not reveal any significant effect on the eels when they crossed the cable. There is no information on the reaction of other fish species to cables.

Furthermore there is also no information on the effect of electro magnetic fields on macro zoo-benthos Debus et al. (2000) carried out an investigation on the epi and endo benthos in the proximity of the sea electrode of the HVDC-cable KONTEK layed along the Warnemünde coastline (Connecting Germany with Scandinavia). The investigation did not yield any significant differences between a reference station and those in the vicinity of the electrode. However, further research would be valuable since the mentioned project provided only a snapshot. Avoidance of cables or electrodes by benthic species has not yet been recorded. Harmful effects of electro magnetic fields were only evident under strong fields, which were far above those expected for sea cables. (Kullnick & Marhold 2000).

No information is available on the effect of elevated temperatures caused by cables.

I-4.5 Pollution through wear and tear of the turbines

At this point in time there is no information on operational emissions by the offshore wind parks planned in the North and Baltic Seas. Turbines of this magnitude (3,6 – 5 MW) and with the envisaged technical configuration (e.g. almost complete encapsulation of the gearbox) have not yet been investigated with regard to this question. The first test with land-based prototypes of the 5 MW class have only just begun.

However, the possibility, that filter feeding organisms in particular may be affected by fine particles abraded and released during operation, needs to be considered nonetheless. . Bio/consult A/S (2000) expects a higher copper contamination of the filter feeders since the turbines release about 206 Kg copper per year, based on the experience with existing turbines.

I-4.6 Different foundations for offshore wind energy turbines

- Gravity or weight foundation

The principle of a gravity foundation (Fig. I-9) is based on the exploitation of the gravitational force exerted on the foundation. The tilting moment exerted by the wind and water pressure on the rotor and wind energy pylon (WEP) can only be dissipated to the sea floor via pressure forces, since there is no connective facility to transfer the tensile forces between foundation and sea floor. This results in a high sensitivity to extreme hydrodynamic forces. High shear and tensile forces may arise during strong seas. This effect means that deployment of weight foundations in water depths above 20 m is not only un economical but physical impractical. A further disadvantage of this type of foundation is the comparatively large surface area and thus high degree of sealing.

- Mono pile

A Pile foundation consists of a steel pile with a diameter fitting the requirements and driven into the seabed (Fig. I-10). The pile is driven by ramming, vibration, jetting and or drilling.

These piles transfer lateral and axial forces to the foundation structure on the sea floor. Tensile forces are also transmitted into the seabed by the piles. Currently, piling is carried out to a maximum water depth of 25 to 30 meters. The piling is expected to cause strong sediment movement and displacement as well as high sound emission.

- Tripod

The tripod (Fig. I-11) is a three-legged foundation, which usually consists of a central column supporting a steel frame constituting the three legs. From a steel pile below the turbine tower emanates a steel frame, which transfers the forces from the tower into three steel piles. Pile foundations constitute the end of the legs. . The three pile foundations have small diameters than the mono piles and in contrast, they mainly transfer tensile and pressure forces to the sea floor. . However the depth of the foundations is the same as for the mono piles at 10 to 20 meters. The depth of the piling is dependant on the morphology of the sea floor and tripods can be installed in water depths greater than 30 m although, as with monopiles strong sediment movement and displacement as well as noise emissions are to be expected.

- Jacket

The jacket construction closely resembles the tripod construction in both appearance and carrying capacity. The main difference being the four legged steel jacket construction, which are anchored on four piles. There is no requirement for a massive foundation as has been used in other offshore construction. A further difference to the tripod is the finer structure of the steel frame, which resembles an electrical tower. The single beams have a pipe like profile welded together. The installation of a jacket construction is expected to have the same impact as a mono pile or tripod.

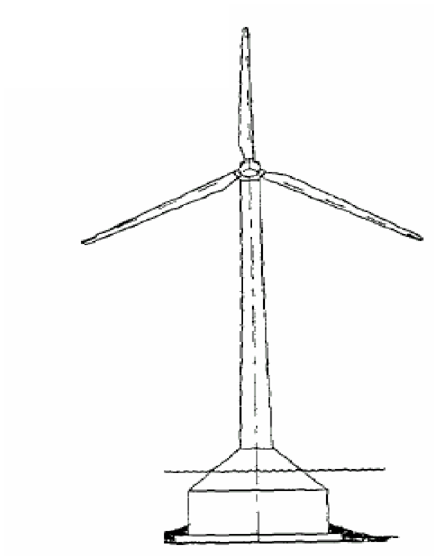


Fig. I-9: Gravity foundation

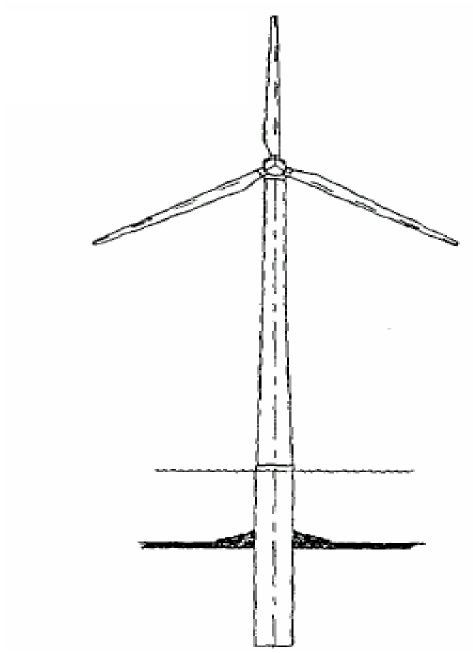


Fig. I-10: Mono pile

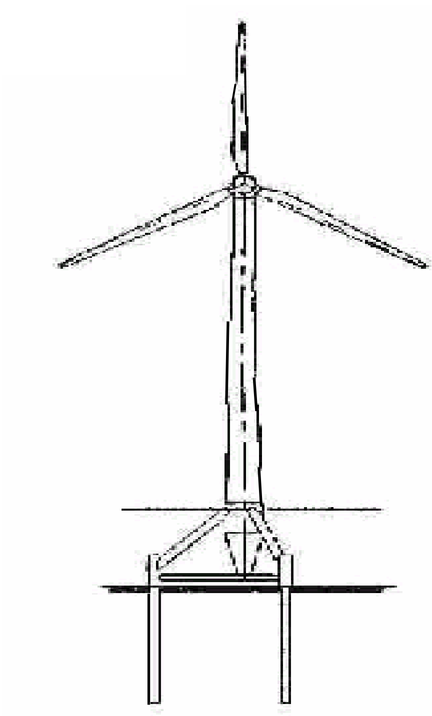


Fig. I-11: Tripod

- Tripile

TheTripile is a combination of the tripod and the mono pile. It has the advantages of a monopile in that it uses the smaller cross-sectional dimensions of the piles. The foundation comprises three monopiles arranged in a triangular formation and connected at the top. This construction can be founded on a steel construction or a concrete slab. However, the offshore construction takes longer than for the other foundations and noise emission as well as the effects on the sediment are considered to be more severe than for the other constructions.

- Prefabrication

All foundation structures are prefabricated on land. The construction of a gravity foundation, however, requires a land based dry dock. Other steel structures can be fabricated in existing shipyards or steelworks.

- Offshore construction

The offshore construction of tripods, jacket and tri piles is expected to be complex. They have to be joined to the heads of the grounding piles on the sea floor. In fact with the tri pile, the connection of the three grounding piles has to be carried out at sea and above sea level.

- Foundation preparation

A levelling of the sea floor and construction of a blinding layer of gravel and lean concrete is required for the gravity foundation.

- Transport

Tripod und Jacket are large complex static structures, which have to be transported individually to the deployment area by barge. Whereas foundation piles of the tripiles and monopiles can be stacked and thus enable the transport of larger quantities by barge. Such rational transport reduces the ship traffic during the construction phase. The gravity foundation is built to float. After flooding of the dry docks, the foundation is stabilized with floats and towed to the deployment point by tug

- Assembly

The gravity foundation does not require any special technical equipment for deployment. It is filled with rubble or lean concrete and lowered. The grounding piles are driven into the sea floor using concrete vibrators, ramming or drilling from jack-up platforms. The choice of the deployment technique depends on the structure of the sea floor and the geometric dimensions of the grounding piles.

- Sealed area

The sealing of the sea floor depends largely on the size of the WET and the resulting size and type of foundation. A gravity foundation results in the largest degree of sealing whereas the monopile has the least. However, even the monopile may result in an area of over 30 m in diameter being sealed. The horizontal dimensions of the scour protection largely determine the extent of sealing.

- Scour protection

In the event of there being no scour protection, the increased current velocity will expedite the erosion of the foundation. The erosion will continue until equilibrium is attained. Since tide direction and swell change continuously an equilibrium scour is not expected to arise.

I-5 Criteria for the evaluation of areas

This section deals with the possibility of establishing evaluation criteria to assess the suitability or non-suitability of a sea-area for the installation of offshore wind energy plants. The established criteria are primarily derived from the discussions on the compartments benthos and fish carried out with foreign and national experts in Bremerhaven in January 2002. (See also Gosselck et al. 1996).

Naturalness: The naturalness of an area needs to be maintained. One condition of this criterion is that an area needs to be free or to a large extent be free of anthropogenic utilization at the time of assessment.

Uniqueness: This entail morphological aspects as well as processes.

- Areas with a unique or specific current regime of importance for exchange or transport processes e.g. the “Elbeurstromtal” in the North Sea and Darß threshold in the Baltic).

- Areas with a unique or special bottom topography or structure and thus specific communities or rare species (red list) (e.g. Helgoländer Steingrund in the North sea as well as stone fields in the Baltic)
- Banks of all forms since these constitute a special habitat compared to their surroundings (e.g. the Stolpe bank and Oder bank plateau in the Baltic and the Dogger bank in the North Sea)

Functional Aspects: Areas which have special functions within the overall system such as for example stepping stones or refuges as well as important of spawning or maturing grounds.

See also in this context the recommendations made in project funded by the Federal Department of Nature Conservation as to areas in the North Sea, worthy of protection (Rachor unpubl.). Regarding the above mentioned aspects, the following areas were regarded as worthy of protection: Borkum “Riffgrund” (unique bottom structure with own community), Amrum “Außengrund” (unique bottom structure with own community), Helgoland and surrounding area with rocky bottom (unique bottom structure with own community), north-eastern area of the Dogger Bank, Muddy area south of Helgoland (unique bottom structure with own community), Areas in the eastern zone of the “Elbe-Urstromtal” (Step stone function, Exchange function) (Fig. I-12).

Additional areas of special ecological significance were identified in the project “scientific fundamentals for the selection and management of marine offshore protected areas in territorial waters and the German exclusive economic zone of the Baltic and the integration into the system of the *Baltic Sea Protected Areas*“, funded by the Federal Department of Nature Conservation. Here too the singularity, representativeness, and high degree of naturalness of the areas were used as criterion for their selection. The following are areas which have been identified as being of special ecological significance where offshore wind energy plants should not be built or construction at least critically reviewed: “Staberhuk, Sagasbank, Walkyriengrund, Kadettrinne, Plantagenetgrund, the Pommeranian Bay with the Oderbank and the Adlergrund” (Gosselck et al. 1998) (Fig. I-13).

If the criteria are applied for example to the “Walkyriengrund” in the Baltic then the following will result according to Gosselck et al. (1998):

Naturalness: The condition of the “Walkyriengrund” is very natural and is not disturbed very much by human activities. Potential interference is only by fishermen’s anchored nets, speedboats and ferries, which have, however, not resulted in heavy disturbances of the protected objects. There is no direct inflow of effluent in the vicinity of the “Walkyriengrund” which could lead to pollution.

Uniqueness / Representability: The “Walkyriengrund” is a shallow water area with strongly structured sediments and the largest shallow area in the Lübeck Bight. It is a specific marine landscape with typical plant and animal communities. The *Laminaria* stocks of the “Walkyriengrund” in the Mecklenburg Bight are singular in their density and extent.

Another example of the application of above criteria to the “Helgoländer Steingrund” in the North Sea yields the following:

Naturalness: The “Steingrund”-Area north east of Helgoland has very diverse Sediments and a very diverse Endo- und Epifauna. The Sediments range from sandy bottoms to large boulders, which are of glacial moraine origin (Kühne & Rachor 1996). The area is very natural and little disturbed by human activity since there is no bottom trawling for example.
Uniqueness / Representability: The “Helgoländer Steingrund” is singular in the German Bight because of its diverse sediments, particularly due to the large boulders as well as due to its extent. Investigations of the benthic macro fauna in the area during 1991 yielded rare species such as the sponge *Leucandra fistulosa*, the sea urchin *Echinus esculentus* and the sea anemone *Haliplanella lineata* (Kühne & Rachor 1996).

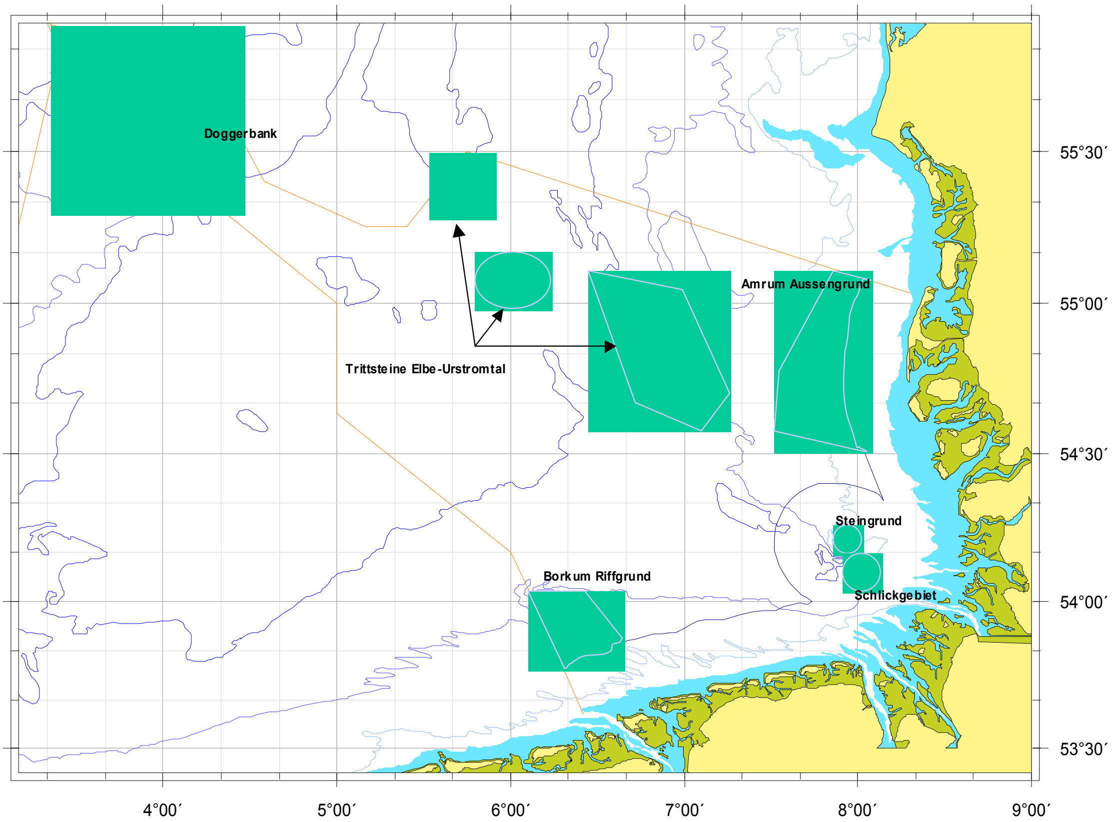


Figure I-12: **Recommendations for areas with benthic communities in the German exclusive economic zone of the North Sea worthy of protection (after Rachor, unpubl.)**

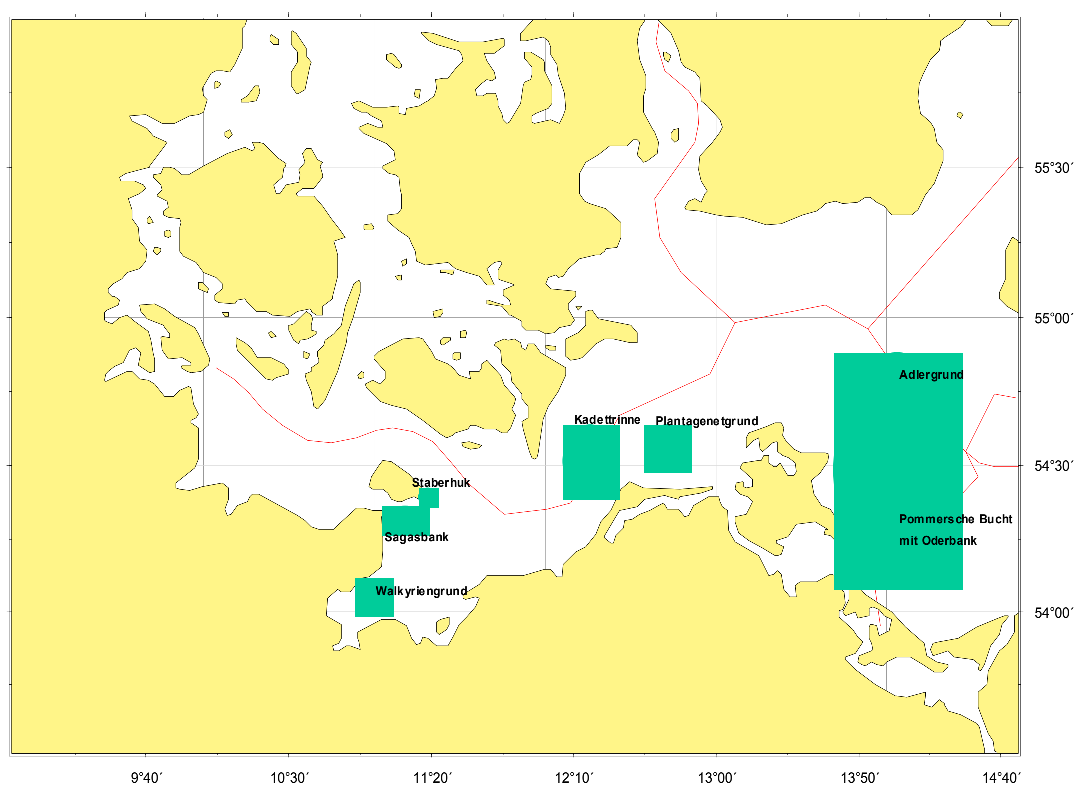


Figure I-13: **Recommendations for areas with benthic communities in the German exclusive economic zone of the Baltic Sea worthy of protection (Gosselck et al. 1996)**

I-6 Measures to avoid and reduce the impacts of offshore wind energy plants on benthos and fish

Essentially, the "Criteria for the evaluation of areas" Point I-5 should be considered when granting permission for planning areas in order to reduce or avoid negative impacts. In other words areas falling under the criteria above criteria should be avoided if possible, when planning wind parks.

Technical variations, which could prevent or reduce the impact of plants on benthic communities, are described below.

I-6.1 Foundations

With regard to the benthic communities, the monopile appears to be the most suitable since it has the least influence on hydrography and lowest areal coverage. However, monopiles have the disadvantage that they can only be constructed to a maximum of 30 meters depth. The dumping of gravel as scour protection around the pylons should be avoided.

Ideally different foundations should be tested in a pilot study in order to assess the effects under realistic conditions.

I-6.2 Construction of the plants

The ramming or vibratory driving of pylons can be considered to be the most appropriate method due to least sediment disturbance. The construction of WEP by grout flushing of piles is considered to be the least appropriate due to large sediment movement and also because it is not feasible in the Baltic because of the structure of the sea bed.

I-6.3 Corrosion protection / Antifouling

Paints containing poison (e.g. TBT) are not to be applied to avoid corrosion or fouling. Should a strong colonization affect the static of a WEP, it is recommended that mechanical cleaning of the pylon be applied. A disadvantage of this method, however, is the increase in organic debris in the immediate surroundings of the piles if no remedial procedures are envisaged to remove the material (Discussion Benthos und Fish 2002).

I-6.4 Cable type / Laying of cables

Since jetting is probably unavoidable when laying cables, modern technology should be used to keep the sediment displacement as low as possible.

In addition, the most appropriate type of cable should be selected (bipolar; Flat-Type), to avoid electrical fields as far as possible, despite the fact that there is little or no information on the effect of electro magnetic fields on benthic communities. However, this should not exclude preventative measures.

It would be appropriate, however, to bundle the energy transmission for parks, which lie in close proximity to each other in order to avoid several cable routings.

I-7 Research needs

The results of this study on the potential effects offshore wind energy plants on benthic communities during construction, operation and dismantling have shown that some questions could not be answered at this point in time. The following questions regarding the impacts of offshore wind energy plants and the necessary cables on the compartments “benthos and fish” have to be addressed:

a) Assessment of the actual sediment transport and displacement during the installation of offshore WEP and their impact on the above mentioned compartments.

b) Investigation of the colonization and species inventory on the piles and their impact on the benthic in fauna and fish communities.

c) Investigations of a potential attraction effect by the plants, on fish.

d) Assessment of the real changes of hydrodynamic conditions surrounding the piles and the associated changes in sediment and faunal composition as well as the spatial extent of these effects.

e) Assessment of a possible large-scale cumulative effect of several WEPs on the current regime.

f) Investigations of the effects of electro magnetic fields on invertebrates and fish.

g) Investigations on the effects of temperature elevation in proximity of cables on invertebrates.

h) Investigation on the exclusion of fishing in the vicinity of offshore wind energy parks.

The points b, c, d, and f are already considered in the framework of the project BEOFINO (Ökologische Begleitforschung zur Windenergienutzung im Offshore - Bereich auf Forschungsplattformen in der Nord- und Ostsee) (FKZ. 0327526) funded by the BMU and co-ordinated by the Alfred-Wegener-Institute

I-8 Summary

It can be expected that the benthic communities and the demersal fish fauna will be affected both in the short and medium-term by the construction of wind energy plants, particularly by the dislodging of sediment. To what extent and areal scale, the construction noise will affect the benthos and fish fauna can currently not be answered.

During operation of the plants, epifauna will settle on the piles, which constitute an artificial substrate. This will result in an increase in the number of species and abundance perhaps even rare species of hard substrate colonizers, particularly in areas with a soft bottom. To what extent the colonization of the piles will affect the soft-bottom communities is currently not known.
The hydrodynamic conditions will change in the immediate vicinity of the piles, which in this area will alter the sediment composition. First results have indicated that the influence will, however, not be noticeable beyond 50 to 100 m away from the pile. Potential cumulative effects of several wind energy parks on the large–scale hydrodynamics have only been assessed in a model simulation. The results have predicted slight changes.

Investigations on oil platforms and artificial reefs provide some evidence that offshore wind energy parks could attract fish, with the result that an increase in abundance of some fish species can be expected. This effect will be larger, the more complex the offshore foundation which is chosen (e.g. Jacket-construction with many cross beams).

The exclusion of fishing from the planned wind energy parks will have an effect on the benthic communities in the area. This could result in an increase of long-lived fragile benthic species in the following years.

Electro magnetic fields as well as an increase in temperature can be expected due to the transmission of electrical power by cable. However, there is no clear evidence of the effect of these on invertebrates and fish.

With regard to the compartments “benthos” and “fish”, for reasons described above, the monopile appears to be the most appropriate construction, despite the fact that its deployment is limited to depths not exceeding 30-35 m. To keep sediment displacement as low as possible ramming of the piles rather than jetting is recommended.

The best available technology should be used to avoid or reduce the effect of electro magnetic fields during transmission of electrical energy (e.g. bipolar, Flat-Type).

II Impact on resting and migratory birds

by Ommo Hüppop & Helmut Wendeln with contributions by Jochen Dierschke, Volker Dierschke, K.-Michael Exo and Stefan Garthe

II-1 Introduction

Wind energy is a renewable energy source which in Germany has begun to be of increasing importance since the 1980's. Although Germany is a world leader in the use of wind energy, the proportion of renewable energy used is still below the goal set by the EU or the German government, which is to double the proportion of regenerative energy between 2001 and 2010 (BMU 2001). Since appropriate locations for wind energy parks on land are limited, the search for intensive large scale sites has recently turned to the offshore area of the North and Baltic Seas. Investment security is provided by the Renewable Energy Act which was passed in April 2000, and which promises benefits for offshore energy plants which are in service by 2006. In the current planning phase, the total area required is estimated to be over 13,000 km², the equivalent to 26,5% of the area of the German Exclusive Economic Zone (EEZ) in the North and Baltic Seas (Hüppop et al. 2002). The size of the planned parks ranges between 80 to 3000 turbines per park. Thus the construction of offshore wind energy parks (WEP) may become the largest technical impact on the marine environment in Europe (Merck & von Nordheim 2000). Since the North Sea and the Baltic Sea are internationally important for foraging as well as migratory birds, it was essential to investigate the potential danger of large offshore wind farms. However, since there are virtually no wind parks of these dimensions anywhere in the world, it is difficult to assess the impact on the marine environment. Investigations on land based wind parks may provide some insight. However, the impact on birds has not yet been satisfactorily investigated (e.g. Breuer & Südbeck 1999, Schreiber 1999, BfN 2000, Isselbächer & Isselbächer 2001). Due to the immense dimensions of the planned wind parks, the larger size and the higher number of individual turbines the risks in the offshore zone are potentially much greater than they are on land.

II-2 Objectives and solutions

The following are potential risks for birds in the offshore area:

- Danger of collisions (bird strike) with wind turbines during all kinds of bird movement (migration, flying between foraging and resting grounds.)
- Barrier effects of the WEP in the migration routes or disruption of flight tracks between foraging and resting grounds.
- Short-term losses of habitats (foraging and resting grounds) during construction and by tenders or helicopters during maintenance
- Long-term losses of habitats (foraging and resting grounds) due to the disturbance effect of WEPs.
- Losses of foraging grounds of benthos feeding ducks due to changes in the sediment structure.

In order to assess the potential impact of offshore WEPs, it is essential to obtain detailed information on the spatial and temporal distribution of birds over the open sea before any conclusion or estimate of risk can be made. It is essential to distinguish between the effects on resting birds or food seeking birds, and migrating birds. Extensive literature surveys as well as a combination of various methods were used to close gaps in our knowledge on the spatial and temporal distribution of resting and migratory birds as well as to gain more precise information on the migratory routes and flight altitudes over the North and Baltic Seas. The accumulated data will serve particularly as a base for an areal assessment but should also facilitate the classification of the importance for individual areas.

Data obtained by high-power radar, in collaboration with the Amt für Wehrgeophysik (Traben-Trarbach), were evaluated. The radars record bird migration (intensity, direction and altitude) over the North and Baltic Seas. Since the military radars do not efficiently cover the lower altitudes, own data were collected by mobile ship radar on Helgoland, Fehmarn and Rügen. These provided additional information on overall flight altitude, distribution and intensity of migration as well as direction. Additional synchronous visual observations on migration provided information on very low altitudes, which were also not obtainable on the ship radar. To complement these studies on migratory activity over the North Sea, use was made of data from long-term observations by the Ornithological Working Group of Helgoland (OAG) and the Institute of Avian Research „Vogelwarte Helgoland". This provided the first long term quantitative observation of offshore bird migration. In addition data from the European Seabirds at Sea (ESAS) project on the temporal and spatial distribution of coastal and seabirds in the North and Baltic Seas were analysed. Complementary cruises were carried out to fill data gaps, particularly for the winter months. A wind energy sensitivity index (WEI) was developed and calculated which takes into account various aspects such as frequency, sensitivity to disturbance and flight capacity of the different species (Garthe & Hüppop in press).

The combined evaluation of all aspects is expected to lead to a method of assessment of sites for wind energy plants in relation to the problem of resting and migratory birds.

II-3 State of knowledge prior to project begin [1]

II-3.1 Importance of the North and Baltic Seas for birds

II-3.1.1 Internationally significant occurrences of sea and coastal birds in the Baltic and North Sea

A comprehensive data set on the spatial and temporal distribution of sea and coastal birds at sea is available due to the international „Seabirds-at-Sea"-Programme (SAS), in which German ornithologists have been involved since 1990 (Garthe & Hüppop 1996, 2000). These have been supplemented by airplane surveys (particularly in the Baltic and Wadden Sea area, by e.g. Skov et al. 1995, 2000, Nehls 1998). The data have been published in several national and international atlases and were used for analyses on the importance of oceanic regions for birds (e.g. Skov et al. 1995, 2000, Stone et al. 1995, Mitschke et al. 2001, Garthe & Hüppop in prep.). Though the data may still be incomplete, at least the most sensitive areas for seabirds in the German Bight and the Baltic are known. Gaps in the data are more extensive for the Baltic than for the German Bight where data are missing in the coastal regions and for the winter months.

According to Skov et al. (1995), two areas can be identified in the German EEZ of the North Sea, which are of international importance for sea and coastal birds and have therefore been designated as „Important Bird Areas" (IBA) by BirdLife International (Skov et al. 1995, Heath & Evans 2000, BfN 2001): The eastern German Bight and the marine areas in front of the East Frisian islands (partly not EEZ). The eastern German Bight, where six seabird species occur regularly in internationally important numbers, has been classified the fifth most important area of the entire North Sea including the Channel and Kattegat. This area, which also comprises parts of the Danish EEZ, houses an average of 24,000 Red-throated and Black-throated Divers, representing 22% of the biogeographic population and thus being the most important wintering zone for divers (Table II-1; Skov et al. 1995).

Table II-1: Importance of the eastern German Bight (North Sea) as a foraging, resting and wintering zone for sea and coastal birds. Listed are the average winter numbers between 1980 and 1993 and the percentage proportion of the biogeographic population (from Skov et al. 1995). Only species which occurred in internationally important numbers, i.e. ≥ 1 % of the respective biogeographic population, were considered.

Red-/ Black-throated Divers	*Gavia stellata / G. arctica*	24,000	21.8 %
Black Scoter	*Melanitta nigra*	190,000	14.6 %
Sandwich Tern	*Sterna sandvicensis*	6,700	4.5 %
Little Gull	*Larus minutus*	2,900	3.9 %
Mew Gull	*Larus canus*	21,500	1.3 %

[1] Modified after Exo et al. (2002)

Red-necked Grebe	*Podiceps grisegena*	1,850	1.2 %

This area is also of international importance for Black Scoter, Sandwich Tern, Little and Mew Gulls as well as the Red-necked Grebe. According to the Ramsar convention an area is classified as internationally important for waterbirds or waders when it regularly harbours more than 20,000 indiviuals or ≥ 1% of the migratory population of a single species (e.g. Skov et al. 1995). The zone adjacent to the East Frisian Islands (Ranking 17th in the entire North Sea) is of international importance as resting area for divers (> 2,100 = 1.9 %, Skov et al. 1995) and according to recent surveys by Heibges & Hüppop (2000), at least at times, for the Black Scoter (up to 40,000 = 3.1 %) and Common Eider (*Somateria mollissima*, up to 120,000 = 4.4 %).

The potential areas for the construction of wind energy parks in the EEZs of the Baltic in many cases coincide with the coastal strips harbouring internationally important bird communities (Skov et al. 2000). These include specifically the Bodden areas of Mecklenburg-Vorpommern with the Stettiner Haff, the Pomeranian Bight as well as the larger parts of the Lübeck-Mecklenburg and Kiel Bights. In the Pomeranian Bight the Slavonian Grebe, Velvet Scoter, Long-tailed Duck, Black Guillemot and five other species are regularly encountered in internationally important numbers (Table II-2). In the Kiel Bight, the Common Eider and Black Scoter need mentioning (Garthe 2000).

Table II-2: **Importance of the Pomeranian Bight (including the Polish parts) as a foraging, resting and wintering area for sea and coastal birds. Listed are the average resting or wintering numbers for 1988 to 1995 and the percentages of the biogeographical populations (from Skov et al. 2000, percentages of the biogeographic populations after Durinck et al. 1994). Only species which occurred in internationally important numbers, i.e. ≥ 1 % of the respective biogeographic population, were considered.**

Slavonian Grebe	*Podiceps auritus*	1,225	24.5 %
Velvet Scoter	*Melanitta fusca*	240,000	24.0 %
Long-tailed Duck	*Clangula hyemalis*	837,000	17.8 %
Black Scoter	*Melanitta nigra*	215,000	16.5 %
Black Guillemot	*Cepphus grylle*	3,975	12.0 %
Red-necked Grebe	*Podiceps grisegena*	1,275	8.5 %
Great Crested Grebe	*Podiceps cristatus*	4,180	4.2 %
Red-breasted Merganser	*Mergus serrator*	3,000	3.0 %
Red-/ Black-throated Diver	*Gavia stellata / G. arctica*	1,875	1.7 %

The current data not only confirm that the North and Baltic Seas are of international importance for a number of sea- and waterbirds and that the marine areas therefore receive special protection (e.g. EU-Bird Directive, see compilation in Mitschke et al. 2001). They also show that different areas harbour completely different species, even within the two seas. Data acquired for one area cannot automatically be applied to other areas because of species-specific differences in habitat requirements or sensitivity to disturbance. This is particularly the case for the extensive shallow areas (< 20 to 30 m water depth) of both seas, which serve as foraging grounds for resting birds but are also for birds from internationally important breeding areas close to the coast (e.g. Sandwich Tern in the Wadden Sea, Heibges & Hüppop 2000, Mitschke et al. 2001). The different occurrence of species as well as the seasonal distributions has to be kept in mind in the selection of areas for pilot studies.

II-3.1.2 Migration over the sea

Several tens of millions of birds annually cross the North and Baltic Seas during spring and autumn migration between breeding and wintering grounds and vice versa. Both seas not only lie in the centre of European bird migratory routes but also in the centre of global migratory routes stretching from northeastern Canada to north east Siberia (breeding grounds) and South Africa (wintering area). This means a special international responsibility for Germany in the context of several agreements and conventions, e.g. in the framework of the AEWA-Agreement for the protection of African Eurasian migratory waterbird species.

Migratory birds usually cross the North and Baltic Seas in a broad front (e.g. Jellmann 1977, Buurma 1987, Alerstam 1990). Some species, however, may choose the coasts or rivers for orientation during special weather situations, more so along the more structured Baltic coastline than along the relatively unstructured German Bight (Jellmann 1988, Alerstam 1990). According to the current knowledge, birds migrate throughout the North and Baltic Seas during both day and night. It is still hardly known at which altitude they fly over the sea (see below). In addition there are regular flights between foraging and resting grounds in the coastal zone.

II-3.2 Potential threats from offshore wind energy plants

II-3.2.1 Bird strike risk

Collision of birds with wind energy turbines is a much-discussed problem. However, quantitative analyses are scarce. On land, the danger of collision with the current deployed and analysed plants, which do not exceed 100 m in height, can generally be regarded as negligible. Occasional exceptions, however, occur in less manoeuvrable soaring species or collisions with plants erected in flight corridors (e.g. Böttger et al. 1990, Winkelman 1990, 1992a-d, Clausager & Nøhr 1995, Colson 1996, Musters et al. 1996, Scherner 1999). In the majority of studies the collision rate amounted to between 0 and 40 birds per turbine and year (see compilation in Clausager & Nøhr 1995). The daily collision rate determined by Winkelman (1985, 1989, 1992a) for two wind parks near the Netherlands coast was estimated to be 0.04 per day in Urk (autumn) and 0.09 in Oosterbierum (spring). Analyses of flying birds approaching an wind energy test plant in Oosterbierum showed that more birds were recorded in proximity to the rotors at night than during the day (Winkelman 1990). Of those birds, which passed in proximity of the rotors considerably more collided with the rotors at night (14 out of 51) birds than during the day (1 of 14). The avoidance was higher when birds had headwind rather than tailwind. The different reactions are probably attributable to the different acoustic recognition of the plants as well as the varying manoeuvrability due to flying speeds resulting from wind direction. Dirksen et al. (1998a) and van der Winden et al. (1999) observed, using radar, that the proximity of flying ducks to wind energy turbnines at Lake Ijssel (NL) under near offshore conditions, was closest during bad visibility. In the offshore wind park Tunø Knob (Kattegat, DK) the number of encounters with ducks was lowest during dark nights (Tulp et al. 1999). However, the ducks did show a higher tendency to fly through the plant at night which means a higher collision risk.

Daytime observations confirm that seabirds fly close to the sea surface particularly when searching for food (<< 150 m, often < 50 m; Krüger 2001, Krüger & Garthe 2002a, Hüppop unpubl.). This is further supported by radar observations of coastal waterbirds and waders, which fly below 150 m during their regular flights between resting and foraging grounds along the coast (e.g. Dirksen et al. 1996, 1998b, van der Winden et al. 1999). It appears that in general migration in the lower altitudes is more intensive closer to the coast (Dierschke 2001b).

Sightings of flight behaviour indicate that migration over the sea during the day takes place at altitudes much lower than over land and thus often lies within the range of WEPs (e.g. Berndt & Busche 1993, Koop 1997, 1999, Bruderer 1997b). Clemens (1978) using radar showed that a large fraction of the migration in the North Sea area takes place below altitudes of 200 m to a maximum of 400 m. However, Jellmann (1979, 1989) during radar observations of nighttime migration altitudes over North West Germany did not register any flights below 150 m. He found median heights between 430 m and 910 m. It should be kept in mind though that the military radar used did not yield reliable recordings below altitudes of 300 m. Despite these observations migration over the sea also takes place at high altitudes, which cannot be detected by eye (e.g. Buurma 1987, Jellmann 1989, Becker et al. 1997). Thus, quantitative estimates of height distribution and the potential impacts of offshore wind energy plants on migration are still very difficult to assess.

Weather, particularly wind direction and speed have a strong influence on flight altitudes. As far back as 1891 Gätke described that birds chose to fly at low altitudes over water when they had strong headwinds. This has since then often been confirmed. Current „Seawatching“ north of the island of Wangeooge indicates that sea and coastal bird species such as Red-throated Diver, Common Eider, Black Scoter, Common Shelduck *Tadorna tadorna*, Sandwich Tern, Common Tern *Sterna hirundo* and Arctic Tern *S. paradisaea* fly close to the water surface, mainly below 10 m; with headwind but at greater heights (> 25 m) when they had tailwinds and at higher speed (Krüger 2001, Krüger & Garthe 2002a). Similar results were obtained by Dirksen et al. (1998a): In the vicinity of coasts, ducks tended to fly at altitudes of up to 75 m, and up to 50 m over open water. With headwinds, the height dropped to 30 m. Koop (1999) observed heights between 40 and 60 m for small birds flying against strong headwinds. There is a danger, particularly with tailwinds, that birds are less able to recognise wind energy turbines while simultaneously being less capable of manoeuvring and thus fly into the rotor areas.

The available information unanimously confirms that both local birds as well as resting and migratory birds are potentially endangered by offshore WEPs. Despite the fact that no collisions have been observed between Common Eiders and an offshore wind park in Denmark (Guillemette et al. 1999), the risk of collision over open water is likely to be higher than on land. In comparison to terrestrial WEPs the offshore ones will be much larger, and the acoustic recognition is likely to be more difficult because of the higher background noise of the open sea. In addition, almost all seabird species as well as many terrestrial birds fly at lower altitudes over water than over land. The highest risk of collision is at night, particularly at moonless ones as well as under unfavourable weather conditions such as fog, rain and strong winds. However, conclusive evidence enabling the quantification of collision risks is as yet unavailable. Quantitative data can only be achieved by using a combination of radar, optical and acoustic data acquisition during investigations at pilot plants.

II-3.2.2 Disturbance and barrier effects

Birds living in open habitats tend to avoid large vertical structures such as those represented by WEPs. Fast moving rotors are likely to cause birds to flee which means that WEPs can indirectly represent large areal losses despite the fact that they only cover a small area. Many investigations carried out on land have confirmed interference and therefore loss of habitat caused by WEPs, particularly for resting species such as waterbirds and waders up to distances between 500 - 800 m around WEPs. Whereby the disturbance increases with size and height, respectively, of the plants (Clausager & Nøhr 1995). The numbers of resting and foraging birds within an area of 250 m around WEPs on land declined by 60 - 95% although there were differences between breeding and resting birds (e.g. Pedersen & Poulsen 1991, Winkelman 1992a-d, Schreiber 1994, Clemens & Lammen 1995, Brauneis 1999, Kruckenberg & Jaene 1999). While breeding birds may become partially accustomed to the plants after a while (not confirmed), migrants or guest species normally do not have the opportunity to do so. Songbirds generally appear to be the least affected according to current knowledge except for possible effects on migration. Recently published data on migration by Stübing (2001) have shown that several small bird species tend to make large detours around WEPs. Amongst the particularly sensitive resting birds are geese, Eurasian Wigeon (*Anas penelope*) und waders, such as Eurasian Curlew (*Numenius arquata*) and European Golden Plover (*Pluvialis apricaria*), which avoid WEPs up to distances of 500 m. An example is given by one of the few quantitative investigations by Kruckenberg & Jaene (1999) who worked on White-fronted Geese (*Anser albifrons*) in the Rheiderland and covered a period before and after the contruction of an WEP as well as affected and unaffected reference areas. The density of grazing geese was less up to a distance of 600 m to within the range of the wind park than in areas of the Rheiderland not affected by WEPs. Even in distances of 400 - 600 m from the WEP, habitat utilization was reduced by roughly 50%. White-fronted Geese were not affected beyond 600 m from the WEP.

The direct reaction of birds to offshore WEPs has up to now only been investigated on Common Eiders. The wind park Tunø Knob (Kattegat, DK) had no effect on the number of resting or feeding Common Eiders. The spatial food distribution apparently had a larger effect on the space utilization by Common Eiders than did the wind park (Guillemette et al. 1998, 1999). However, it cannot be excluded that potential disturbance effects of the wind park was masked by the overlying factor of food distribution. Tulp et al. (1999) reported, for the same park, that landings and starts of Common Eiders were significantly lower within 100 m of the turbines than 300 - 500 m away. The nocturnal activity was lower up to a distance of 1.500 m around the turbines and thus had a clear barrier effect on flying ducks. Dirksen et al. (1998a) also concluded that diving ducks during flight in search for food in the Lake Ijssel (NL) might be hindered by the barrier effect of WEPs. Divers and Black Scoters are particularly sensitive seabirds. They tend to flee from ships several kilometres away. Their occurrence is therefore restricted to areas with little shipping activity (Mitschke et al. 2001). Their sensitivity could thus result in the loss of large areas due to the construction and operation of offshore WEPs. Since many large and particularly sensitive birds occur in the offshore regions and the fact that clearly higher plants than on land are to be erected (up to c. 150 m total height), a higher conflict potential can be expected than for terrestrial plants.

II-4 Standardized surveys on migration during 2001 (by Jochen Dierschke)

II-4.1 Introduction

Standardized observations of bird migration in Germany have been carried out for many years and at various localities (e.g. Gatter 2000). Beginning in the 1930s, an effort was made to create a network of stations to obtain a better understanding of bird migration, however, with limited success (e.g. Drost & Schildmacher 1930a, b). Systematic observations of migrating birds over the sea, have a younger history, since good optics are required to obtain satisfactory results due to the large distance between observers and birds. Along the German North Sea coastline such observations were only carried out at Norderney (e.g. Temme 1989), Wangerooge (Krüger 2001), Sylt (F. Dannenburg pers. obs.) and Helgoland (e.g. Dierschke et al. 1999, 2001, compare chapter II-5). Along the German Baltic Sea coast they were carried out at Rügen (Nehls & Zöllick 1990), Hiddensee (Dierschke et al. 1995, 1997, Helbig et al. 1996) and the Fehmarnbelt (K. Andersen, Results partially published in Berndt & Drenckhahn 1974, Berndt & Busche 1993). Analyses of long-term studies are available from the Netherlands (Camphuysen & van Dijk 1983, Platteeuw et al. 1994), but not from the German coast .

During fieldwork in this project, visual observations of bird migration were carried out in spring and autumn 2001 on Helgoland, Fehmarn and Rügen. The aim was to complement our radar observations by gathering information on species composition, flight altitudes and distance of migrating flocks to the coastline.

II-4.2 Methods

II-4.2.1 Field methods

The most common method, which we also used, was the so-called **„Seawatching“**. This entails the search for migratory birds in the air space over the sea from a fixed viewpoint using a telescope (30 x 80 or 22-60 x 80). In addition, regular spotting of high altitude birds is done using binoculars (10 x 40 or 10 x 42; Dierschke 1991). All migrating birds were noted down or recorded on a dictaphone. The following data were recorded for each single group: Species, number of birds, flight direction, estimated altitude, estimated distance, date, time of day (beginning of every quarter hour) and if possible age and sex.

Passerines are not detectable with this method since their identification usually relies on a combination of voice and jizz. Thus, only passerines (including doves and woodpeckers) flying *over* the observer were registered according to the above parameters.

Raptors are generally can only be identified *visually* since they often fly at relatively high altitudes. We therefore used binoculars to check the air space for flying raptors in the “**raptor observations**” (particularly on Fehmarn). Species identification was obtained by using a telescope for distant birds.

A total of approximately 140,000 individual birds were counted during 484.5 hours of observations in the year 2001. The distribution of the hours over the different stations is shown in the Annex.

Slight methodological restrictions had to be applied to all parameters:

- *Which bird is migrating?* Sometimes it is difficult to establish whether a bird is actually migrating or only flying short distances (e.g. from one feeding ground to the next). Large gulls show flight movements in all directions so that these were considered not to be migrating. Migrating ducks, geese and cormorants are usually easily identified by their “determined” flight behaviour. The same applies to Black-headed Gulls. It is particularly difficult to assess the movement of terns, which often feed while migrating and are thus often not distinguishable from stationary feeding birds. The flying birds/flocks were followed as long as possible so that the data mostly represent birds flying at least several kilometres.

- *Species identification*: Identification of species during Seawatching is usually not difficult for most seabirds up to a distance of 5 to 6 km. Some species such as the Northern Gannet can be identified up to 7 km and more, depending on the light conditions (Camphuysen & van Dijk 1983, Sharrock 1973). Other species such as low flying auks, however, can often only be identified to the genus at large distances.
- *Number*: The further away a flock of birds and the larger the group, the more difficult it is to determine the exact number. The flock size therefore often has to be estimated. Comparisons of bird counts in this project, however, never yielded more than a 20% discrepancy between five different observers.
- *Direction of migration*: The directions were divided into north, northeast, east, southeast, south, southwest, west and northwest, i.e. into 45° sectors.
- *Distance from Land*: This parameter is not relevant when counting passerines and raptors. However, it is important for migration over water, parallel to the coastline. It is often difficult to estimate the distance. However, distances to shipping buoys derived by radar as well as distances to moving objects such as ships or large bird flocks enabled regular calibration of estimated distances. Calibration also took place between the different observers in order to minimize the discrepancies between them.
- *Altitude*: Altitude is the most difficult parameter to estimate. Although some objects may be of help, the estimates can only be done according to coarse categories resulting in four stages:
  a = birds flying low over water, often in wave troughs (ca. 0 to 5 m above sea level)
  b = low flying birds, but flying clearly above wave crests (5 to 10 m above sea level)
  c = birds flying between 10 to 50 m altitude
  d = birds flying above 50 m altitude
  Regular comparisons of height estimates were carried out between the observers. It was usually not possible to compare estimates with the vertical radar because there was seldom any coincidence between the areas of observation.
- *Age & sex*: Accurate observation of these parameters is only possible for small groups, which are not too far away. This is also only possible for a few species. The data obtained were not analysed for this report.

II-4.2.2 Analyses

II-4.2.2.1 Spectrum of species

Because of the necessarily varying methods of observation for the different families, it is not practical to pool data of the systematic observations on seabirds, small birds and raptors to establish the proportion of the different migrating bird families. Furthermore, a comparison between the stations is also not feasible because the studies were not carried out simultaneously, and since changing weather conditions have different effects on the intensity of migration. Since the phenology of most species is known (e.g. LWVT & SOVON 2002, Helbig et al. 1996), we provide only a short characterisation of migration during the field season 2001. A comprehensive summary of all the data obtained at the various stations is provided in the Annex.

The graphical presentation of migratory intensity is based on the mean number of migrating birds per hour and day for the three systematic observation methods (See chapter II-4.2.1). The influence of weather patterns was not presented since this is discussed at length in chapter II-9.2.1.3

II-4.2.2.2 Flock size

Flock size for all data are available, with the exception of a few counts where birds recorded in quarter hourly recordings were grouped. A mixed group consisting of two species, however, yields two data sets with the relevant species number. Species were only considered of which at least 20 flocks were recorded.

II-4.2.2.3 Altitude distribution

For the analysis of flight altitude of sightings, all bird species were classified into 31 groups according to the systematics. Because of their flight characteristics the Common Goldeneye was placed in the same category as the diving ducks and the Eurasian Sparrowhawk with the falcons. Some species did not fit into any category (e.g. Northern Gannet) and are dealt with as single species. Species, which were only rarely recorded such as White Stork, Common Coot, Short-eared Owl, Great Spotted Woodpecker, Bohemian Waxwing, Winter Wren, European Robin, Northern Wheatear, Common Chiffchaff, Willow Warbler, Goldcrest, Blue Tit, Great Tit, Eurasian Treecreeper and Great Grey Shrike (see Annex) were ignored in the analysis. The height distribution of unidentified birds which could belong to different groups (e.g. "duck", "passerine") was also not analysed, in contrast to those which could clearly be categorized (e.g. "dabbling ducks" and "buzzards"). It was differentiated between the following species groups: divers, grebes, tubenoses, Northern Gannet, cormorants, herons, swans, geese (incl. Common Shelduck), dabbling ducks, diving ducks (incl. Common Goldeneye), seaducks, mergansers, falcons (incl. Eurasian Sparrowhawk), other raptors, cranes, waders, skuas, gulls, terns, auks, doves, Common Swift, larks, swallows, pipits and wagtails, Hedge Accentor, thrushes, crows, Common Starling, buntings, finches and sparrows.

All data were divided into spring (= March - May) and autumn migation (August - October) and were statistically analysed using a Bonferroni corrected G-Test on the altitude differences. Since significant differences in flight altitude for some groups were observed in the spring and autumn migration (Table II-4), the results of the groups are presented separately to differentiate between seasons (Fig. II-8). A graphic presentation is only provided for those groups with a sufficient sample size (> 50 Ind./season) and/or of those, which are of particular importance in the North and Baltic Sea. Since in this analysis the significance of the different altitudes for the individual species had a high priority, the analysis was done on an individual basis.

The influence of wind on the flight altitude was also investigated. Data on wind direction and force were obtained from the stations of Germany's National Meteorological Service (Deutscher Wetterdienst, DWD) on Helgoland, in Westermarkelsdorf (Fehmarn) and Arkona (Rügen). Since the birds within a group statistically cannot be regarded independently, this analysis was done on a group basis. The so-called Tailwind Component (TWC) after Fransson (1998) was calculated for each group:

$$TWC = \cos(\varphi) \cdot v$$

Where φ is the angle between wind direction and tailwind for the flying bird or flock and v the wind speed [m s^{-1}]. Negative values mean headwinds and positive values tailwinds. The results only show groups consisting of at least 50 flocks with headwind or with tailwind (see above). Since seaducks are of particular importance in the area investigated, Common Eiders and Black Scoters were presented separately. The altitude distribution was tested for differences between head and tailwinds for all groups using the Bonferroni corrected G-Test for differences. The correlation between TWC and altitude was analysed using Bonferroni corrected Spearman-Rank correlations.

II-4.2.2.4 Distance from the coast

All Seawatch data on the determined distance from the coast for individual species groups are discussed and shown in the graphs (see II-4.2.2.3). Since the limit of ascertainability varies greatly between different species groups (see above), only well recorded species groups are presented. Although the probability of recognising a bird or flock decreases with distance, it was not possible to carry out a distance correction, since a gradient is expected rather than an equal distribution pattern.

II-4.3 Results

II-4.3.1 Species distribution and migratory intensity

During the period of investigation a total of 168 species and 136,000 individuals were counted. A list of all observation periods as well as all species recorded during migration at the three stations is provided in the Annex. The intensity of migration and the species spectrum for each location are shown in figures II-1 to II-3. The daily migratory intensity is shown in figures II-4 to II-6. The following provides a short overview of the daily migration pattern.

Spring migration:
During the March trial phase on Helgoland (6. to 18.3.) it was only possible to carry out standardized surveys on a few days. Red-throated Divers and Black Scoters as well as White Wagtails and thrushes were the main bird species observed. The subsequent visit to Fehmarn (24. to 31.3.) was hampered by very cold weather and easterly storms. Temperatures began to increase on the 27.3. so that strong migration occurred from the 29. to 31.3. Bad visibility, however, only permitted observations of a few hours over the sea. Thus only the migration of raptors and small birds could be followed properly. Dominant species were Common Buzzard, Common Wood Pigeon, Skylark, Meadow Pipit, White Wagtail, Common Starling and Common Linnet. The visit of Rügen in the first half of April (4. to 13.4.) was characterized by divers, seaducks, Red-breasted Mergansers and Common Wood Pigeons. Finally on Helgoland from (16.4. to 2.5.) Little Gulls were observed to rest and migrate in numbers never recorded before. Also Red-throated Divers, Greylag Geese, Black Scoters, Eurasian Curlews and Black-headed Gulls were observed in large numbers. The second visit to Fehmarn (8. to 19.5.) was mainly characterized by migrating raptors (in particular European Honey-buzzards). Dominant among the songbirds were Tree Pipit and Yellow Wagtail. By the end of spring on Rügen (20. to 27.5.) a few Black Scoters and Sandwich Terns were counted, however, migration was not strong.

Autumn migration:
August on Helgoland was characterized primarily by waders, Black-headed Gulls and terns whereas subsequently on Fehmarn the migration was characterized by dabbling ducks, seaducks, raptors, European Golden Plovers, Black-headed Gulls, terns, Yellow Wagtails and large numbers of swallows. Migratory activity on Rügen during September was characterized by large numbers of dabbling ducks and seaducks and on 17.9. by a mass migration of passerines, particularly Tree Pipits and Song Thrushes. At the turn of the month September/October large numbers of Brent Geese, dabbling ducks, Meadow Pipits, thrushes and finches passed Helgoland. The last visit to Fehmarn produced many migrating Common Eiders, Eurasian Sparrowhawks, Meadow Pipits and finches. The end of the season on Rügen was characterized by seaducks, raptors, Common Cranes, Rooks, and various finch species.

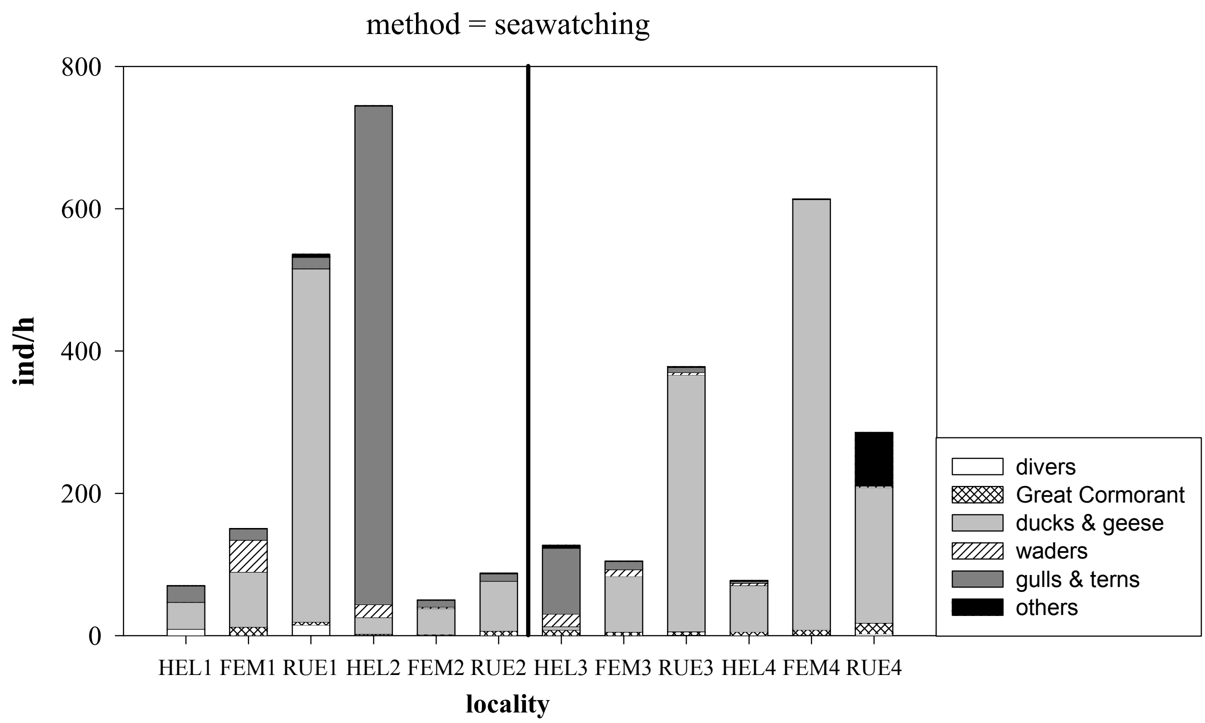
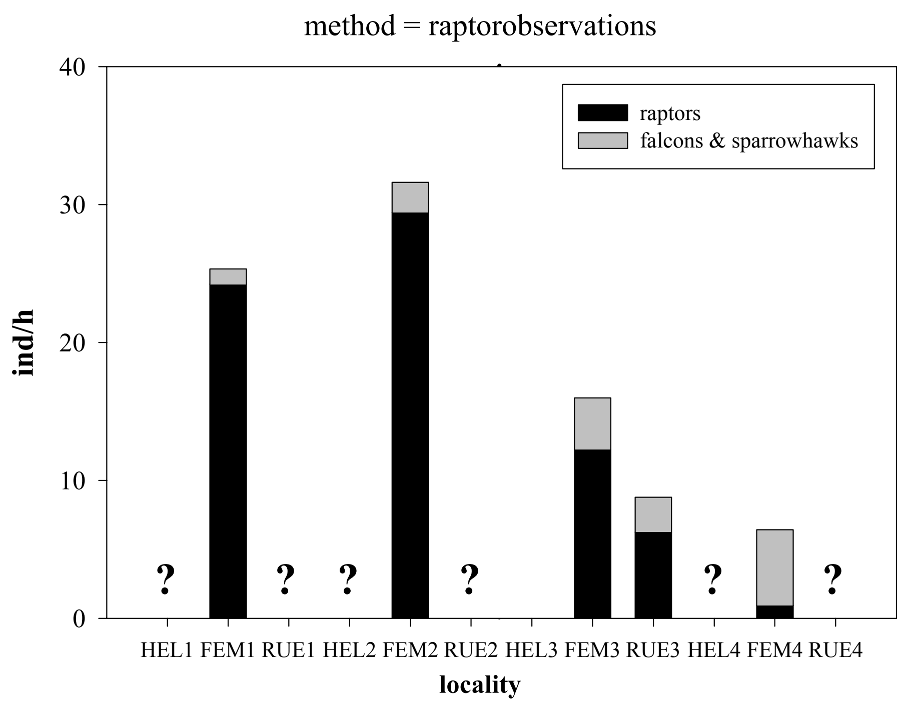
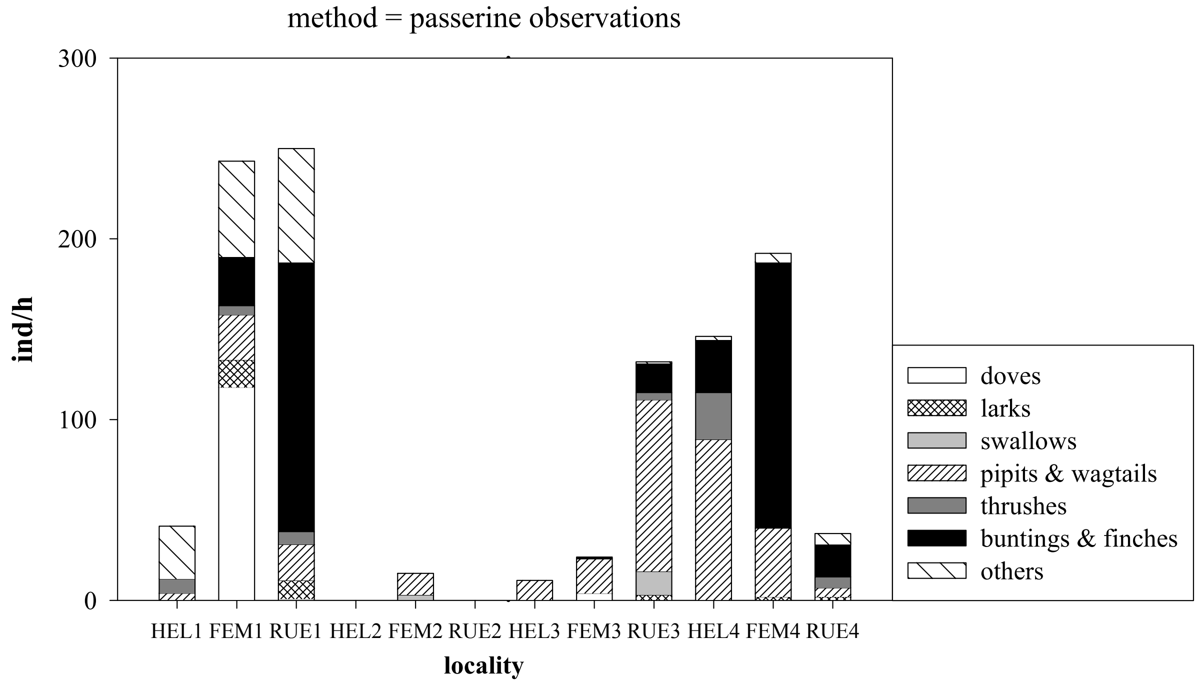
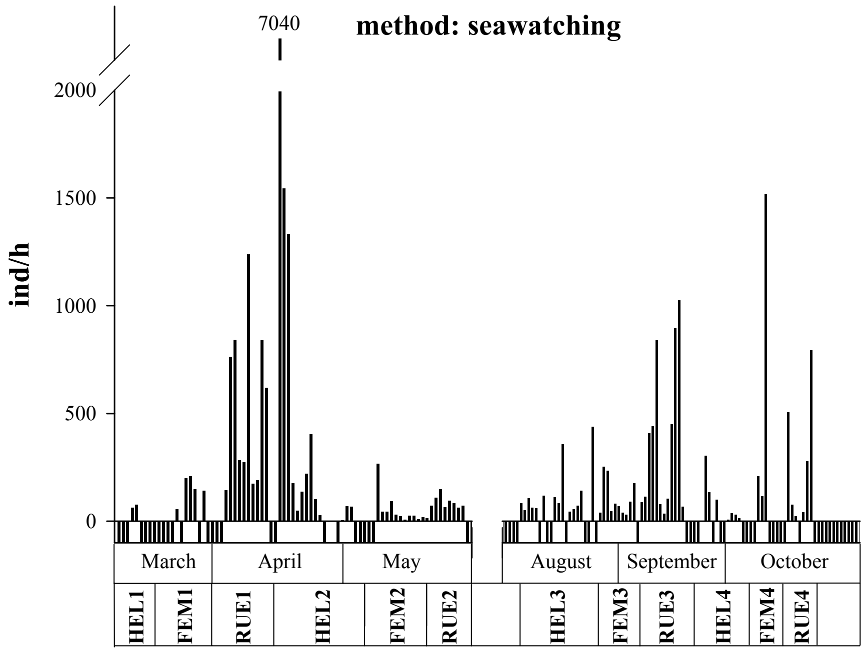


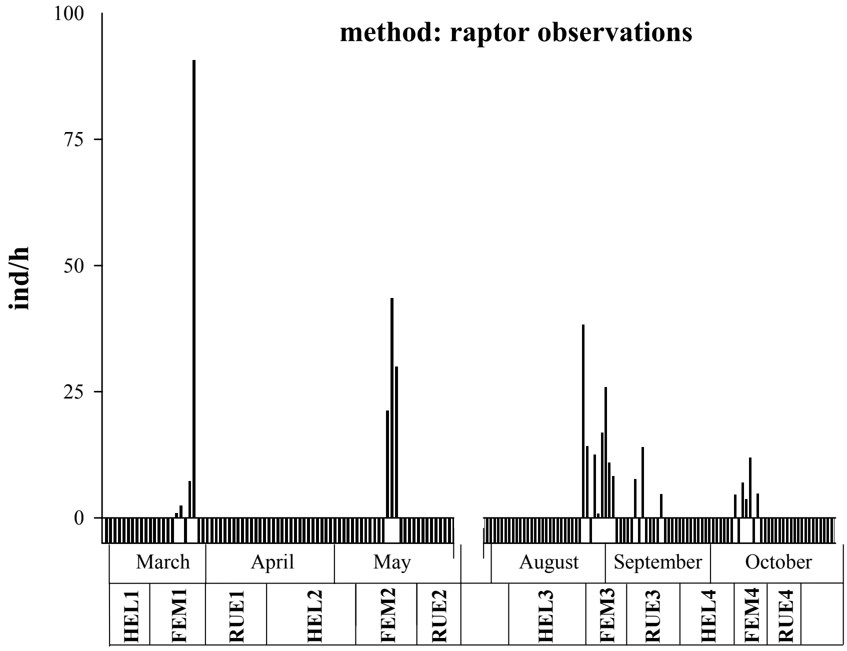
Figure II-1: **Migratory intensity (arithmetic mean of individuals per hour) and species spectrum per visit and location (HEL = Helgoland, FEM = Fehmarn, RUE = Rügen) during Seawatching. The high proportion of Gulls and Terns at HEL2 is attributed to an unusually high number of Little Gulls.**





Figures II-2 und II-3: **Migratory intensity (arithmetic mean of individuals per hour) and species spectrum per visit and location (HEL = Helgoland, FEM = Fehmarn, RUE = Rügen) of standardized raptor observations (top) and passerine observations (bottom). ? = Method was not carried out during the visit.**





Figures II-4 und II-5: **Daily migratory intensity (arithmetic mean of individuals per hour) for the methods sea-watching (above) and raptor observations (below). Bars pointing down mean that the method was not applied on that particular day.**

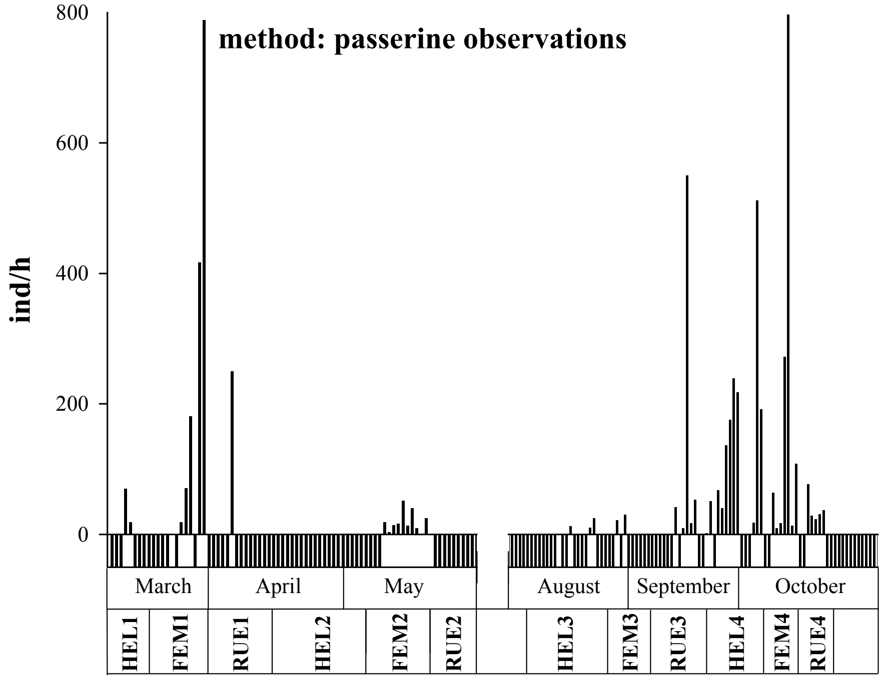


Figure II-6: **Daily migratory intensity (arithmetic mean of individuals per hour) for passerine observations. Bars pointing down mean that the method was not applied on that particular day.**

II-4.3.2 Flock size

Flock sizes of the individual species are shown in Table II-3. Divers and grebes, tubenoses, Northern Gannets, Grey Herons and most raptors and skuas as well as Reed Buntings migrated usually alone or in small groups, while the other species often occurred in larger flocks. Median group sizes of more than 10 Individuals occurred only in Greater White-fronted Goose, Eurasian Wigeon, Common Crane and Common Wood Pigeon.

Table II-3: Distribution of flock size and median (M.) of species on Helgoland, Rügen and Fehmarn during Spring and Autumn 2001.

	Helgoland						Fehmarn						Rügen					
	n	1-5	6-10	10-50	>50	M.	n	1-5	6-10	10-50	>50	M.	n	1-5	6-10	10-50	>50	M.
Red-throated Diver	56	100.0	0.0	0.0	0.0	1							72	100.0	0.0	0.0	0.0	1
Black-throated Diver													276	93.5	5.1	1.4	0.0	1
Red-necked Grebe													53	100.0	0.0	0.0	0.0	1
Northern Gannet	125	100.0	0.0	0.0	0.0	1												
Great Cormorant							99	80.8	10.1	9.1	0.0	2	185	78.4	13.5	7.6	0.5	2
Greylag Goose	33	24.2	15.2	57.6	3.0	14												
Brent Goose	72	37.5	18.1	38.9	5.6	7												
Eurasian Wigeon							86	26.7	18.6	52.3	2.3	11	307	33.2	21.2	40.1	5.5	9
Eurasian Teal							67	26.9	35.8	37.3	0.0	8	126	61.9	15.1	23.0	0.0	4
Mallard													56	75.0	14.3	10.7	0.0	3
Northern Pintail							31	51.6	22.6	25.8	0.0	5	55	65.5	21.8	10.9	1.8	4
Tufted Duck													34	76.5	20.6	2.9	0.0	3
Common Eider	65	41.5	15.4	38.5	4.6	9	565	61.9	17.5	18.1	2.5	4	541	50.6	18.3	27.0	4.1	5
Long-tailed Duck													44	88.6	11.4	0.0	0.0	2
Black Scoter	125	55.2	23.2	21.6	0.0	5	109	67.9	11.9	19.3	0.9	3	3133	57.9	23.7	16.8	1.6	5
Velvet Scoter													74	93.2	6.8	0.0	0.0	2
Common Goldeneye													426	85.2	9.6	4.7	0.5	2
Red-breasted Merganser													237	92.8	6.3	0.8	0.0	2
European Honey-buzzard							140	78.6	10.0	11.4	0.0	2	66	98.5	1.5	0.0	0.0	1
Eurasian Marsh Harrier							51	100.0	0.0	0.0	0.0	1						
Eurasian Sparrowhawk							191	99.5	0.5	0.0	0.0	1						
Common Buzzard							147	89.1	5.4	4.8	0.7	1	36	88.9	5.6	5.6	0.0	1
Common Crane													42	9.5	9.5	45.2	35.7	22
Eurasian Oystercatcher	34	64.7	20.6	14.7	0.0	4												
European Golden Plover	46	84.8	13.0	2.2	0.0	3	41	19.5	2.4	24.4	53.7	100						
Northern Lapwing							43	44.2	20.9	34.9	0.0	9						
Dunlin							46	60.9	21.7	17.4	0.0	4						
Eurasian Curlew	37	54.1	21.6	16.2	8.1	4												
Little Gull	122	29.5	7.4	23.8	39.3	20							98	95.9	2.0	2.0	0.0	1
Black-headed Gull	141	65.2	16.3	18.4	0.0	3	74	82.4	8.1	8.1	1.4	2	36	88.9	11.1	0.0	0.0	2
Mew Gull	49	89.8	10.2	0.0	0.0	2							173	93.6	2.9	3.5	0.0	1
Sandwich Tern	135	91.9	5.9	2.2	0.0	2	112	99.1	0.9	0.0	0.0	1	140	95.7	4.3	0.0	0.0	1
Common-/Arctic Tern	342	75.7	13.5	9.9	0.9	3	90	83.3	11.1	5.6	0.0	2						
Common Tern	128	89.8	8.6	1.6	0.0	2												
Arctic Tern	31	90.3	6.5	3.2	0.0	1												
Sky Lark							74	90.5	5.4	4.1	0.0	2	37	91.9	2.7	5.4	0.0	2
Barn Swallow							49	91.8	0.0	6.1	2.0	1	33	87.9	9.1	3.0	0.0	2
Tree Pipit	58	96.6	3.4	0.0	0.0	1	91	97.8	2.2	0.0	0.0	1	93	60.2	16.1	23.7	0.0	4
Meadow Pipit	1025	78.2	14.3	7.4	0.0	2	350	92.0	5.1	2.9	0.0	2	90	91.1	5.6	3.3	0.0	1
Yellow Wagtail							112	89.3	5.4	5.4	0.0	1						
White Wagtail	40	100.0	0.0	0.0	0.0	1	56	94.6	3.6	1.8	0.0	1						
Song Thrush	104	84.6	5.8	9.6	0.0	2							36	63.9	13.9	16.7	5.6	2
Redwing	90	72.2	20.0	7.8	0.0	2												
Rook													32	84.4	3.1	9.4	3.1	1
Common Starling							33	15.2	21.2	60.6	3.0	18						
Chaffinch	109	58.7	14.7	24.8	1.8	4	75	54.7	13.3	26.7	5.3	3	57	89.5	7.0	3.5	0.0	1
Brambling	44	72.7	25.0	2.3	0.0	2	34	55.9	2.9	35.3	5.9	4						
European Greenfinch							32	68.8	25.0	6.3	0.0	2						
Common Linnet							74	40.5	25.7	32.4	1.4	7						
Reed Bunting	36	100.0	0.0	0.0	0.0	1	52	100.0	0.0	0.0	0.0	1						

Table II-4: **Percentage altitude distribution of various species groups (n = number of individuals) on spring and autumn migration. Bold values denote the highest percentage during a migration period. Differences in t he distribution were tested statistically using a Bonferroni corrected G-Test (df = 3).**

	spring					autumn					G-test)	
spezies group	n	0-5 m	5-10 m	10-50m	>50 m	n	0-5 m	5-10 m	10-50m	>50 m	G	p
divers	724	13.5	34.5	**47.2**	4.7	107	**38.3**	22.4	27.1	12.2	45.1	0.001
grebes	111	**88.3**	9.0	2.7	0.0	36	**100.0**	0.0	0.0	0.0	3.5	n.s.
tubenoses	0					9	**100.0**	0.0	0.0	0.0		
gannets	0					149	**32.2**	31.5	32.2	4.0		
cormorants	535	20.6	23.0	20.0	**36.5**	1,005	33.1	10.2	19.7	**37.0**	56.2	0.001
herons	20	30.0	10.0	25.0	**35.0**	49	28.6	4.1	16.3	**51.0**	0.8	n.s.
swans	175	**48.0**	4.5	22.3	25.1	115	**56.5**	6.1	16.5	20.9	2.2	n.s.
geese	1,262	**34.0**	11.4	23.9	30.6	2,449	21.4	9.8	21.4	**47.4**	111.7	0.001
dabbling ducks	77	24.7	**36.3**	5.2	33.8	9,954	**34.0**	15.0	21.0	30.1	29.6	0.001
diving ducks	81	34.6	19.8	**35.8**	9.9	305	24.3	7.9	**41.6**	26.2	17.1	0.001
seaducks	19,324	36.0	**40.6**	20.5	3.0	21,633	**69.9**	21.2	7.1	1.9	4,959.3	0.001
mergansers	272	39.0	**42.7**	16.5	1.8	416	**43.3**	28.6	15.6	12.5	35.4	0.001
raptors	746	0.0	1.5	4.2	**94.4**	621	1.3	2.4	3.5	**92.8**	10.1	0.05
falcons	76	11.8	7.9	14.5	**65.8**	317	16.4	10.1	18.0	**55.5**	1.9	n.s.
cranes	36	0.0	**58.3**	0.0	41.7	1,833	0.0	0.0	0.0	**100.0**	177.0	0.001
waders	825	13.5	17.6	25.3	**43.6**	25,609	3.4	0.4	1.2	**95.0**	1,863.5	0.001
skuas	0					12	**83.3**	16.7	0.0	0.0		
gulls	14,482	29.3	**51.2**	14.5	5.0	1,159	35.9	19.6	**37.9**	6.6	568.7	0.001
terns	517	15.5	**59.6**	24.6	0.4	3,123	33.4	**55.6**	9.1	2.0	135.6	0.001
auks	14	**50.0**	28.6	21.4	0.0	30	**56.7**	43.3	0.0	0.0	3.7	n.s.
pigeons & doves	1,428	0.0	0.0	16.6	**83.4**	47	0.0	0.0	40.4	**59.6**	17.3	0.001
swifts	55	0.0	10.9	**81.8**	7.3	50	0.0	10.0	**64.0**	26.0	5.6	n.s.
larks	228	3.5	9.2	21.1	**66.2**	144	0.0	16.0	22.9	**61.1**	7.7	n.s.
swallows	76	**54.0**	26.3	13.2	6.6	5,250	26.4	24.1	**32.6**	16.9	31.4	0.001
pipits & wagtails	655	3.8	17.3	**65.3**	13.6	5,891	6.4	**42.0**	25.2	26.5	412.0	0.001
accentors	7	0.0	28.6	14.3	**57.1**	6	0.0	0.0	0.0	**100.0**	0.6	n.s.
thrushes	106	0.9	9.4	33.0	**56.6**	1,210	0.0	1.1	6.0	**93.0**	87.4	0.001
corvids	58	12.0	20.7	**48.3**	19.0	265	21.9	9.4	11.7	**57.0**	47.2	0.001
starlings	767	5.2	12.9	**52.7**	29.2	185	0.0	0.0	37.3	**62.7**	98.2	0.001
buntings	57	0.0	26.3	**68.4**	5.3	110	0.0	3.6	22.7	**73.6**	77.9	0.001
finches	423	0.0	**60.8**	38.3	1.0	4,220	0.4	14.8	34.7	**50.1**	647.8	0.001

II-4.3.3 Altitude

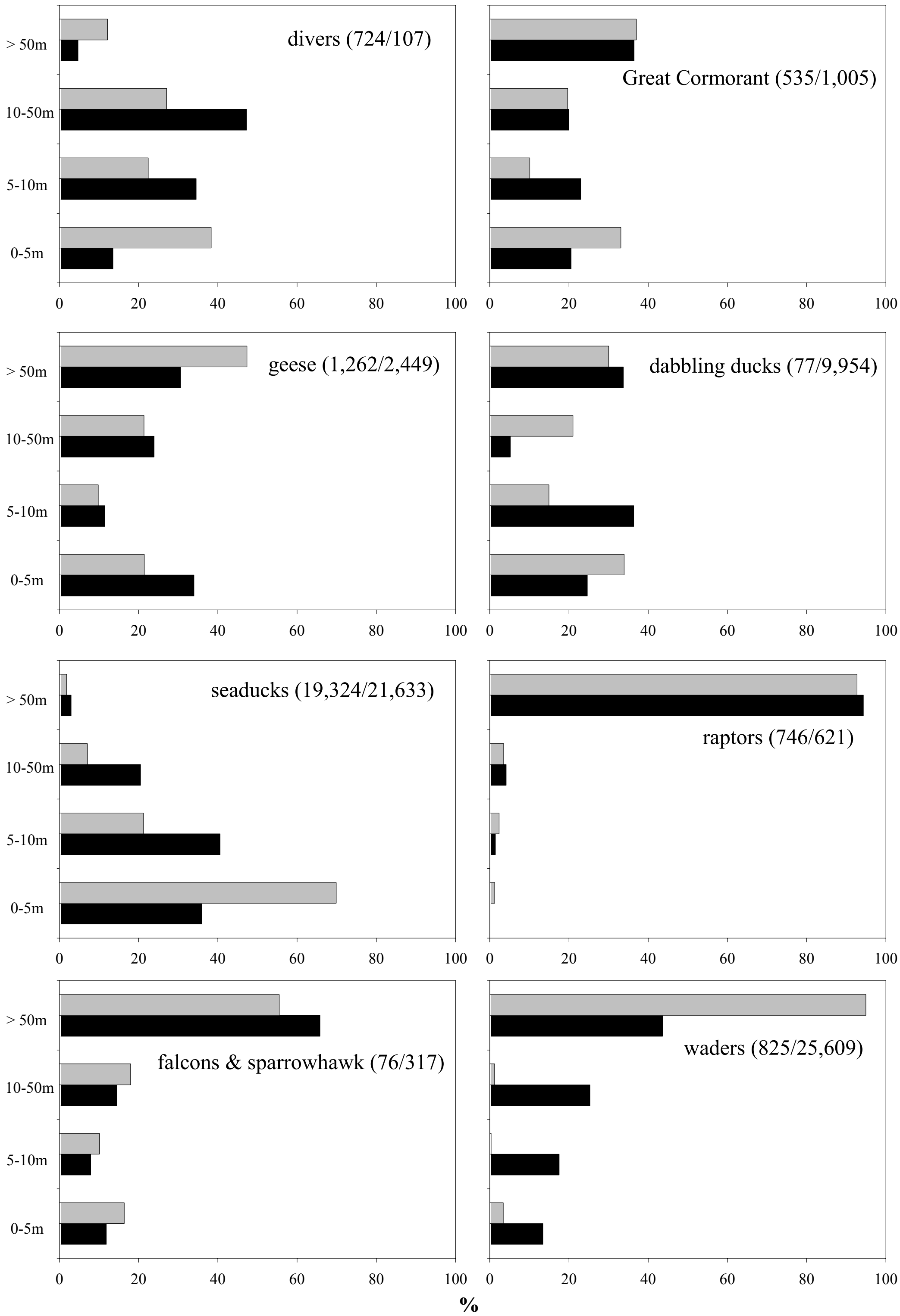
The altitude distribution of the various bird groups is shown in Table II-3. Selected groups are also shown graphically in Figure II-8. No general trend is discernable in the altitude distribution, although significant differences were observed between most bird groups. The various groups can be summarized as follows:

1. Mainly high altitude flyers (mainly > 50m):
   raptors, falcons and sparrowhawks, cranes, pigeons, swifts and Hedge Accentor.

2. Medium to high altitude flyers (mainly > 10m):
   herons, larks, pipits, wagtails, thrushes, finches, corvids, starlings and buntings.

3. Mainly low and medium altitude flyers (mainly 5 to 50 m):
   divers, Northern Gannet, cormorants, swans, geese, dabbling ducks, diving ducks, waders, gulls, terns and swallows.

4. Mainly low flying birds (mainly < 10m):
   grebes, tubenoses, seaducks, mergansers, skuas, auks.


divers (724/107)
Great Cormorant (535/1,005)
geese (1,262/2,449)
dabbling ducks (77/9,954)
seaducks (19,324/21,633)
raptors (746/621)
falcons & sparrowhawk (76/317)
waders (825/25,609)
> 50m
10-50m
5-10m
0-5m
0
20
40
60
80
100
%

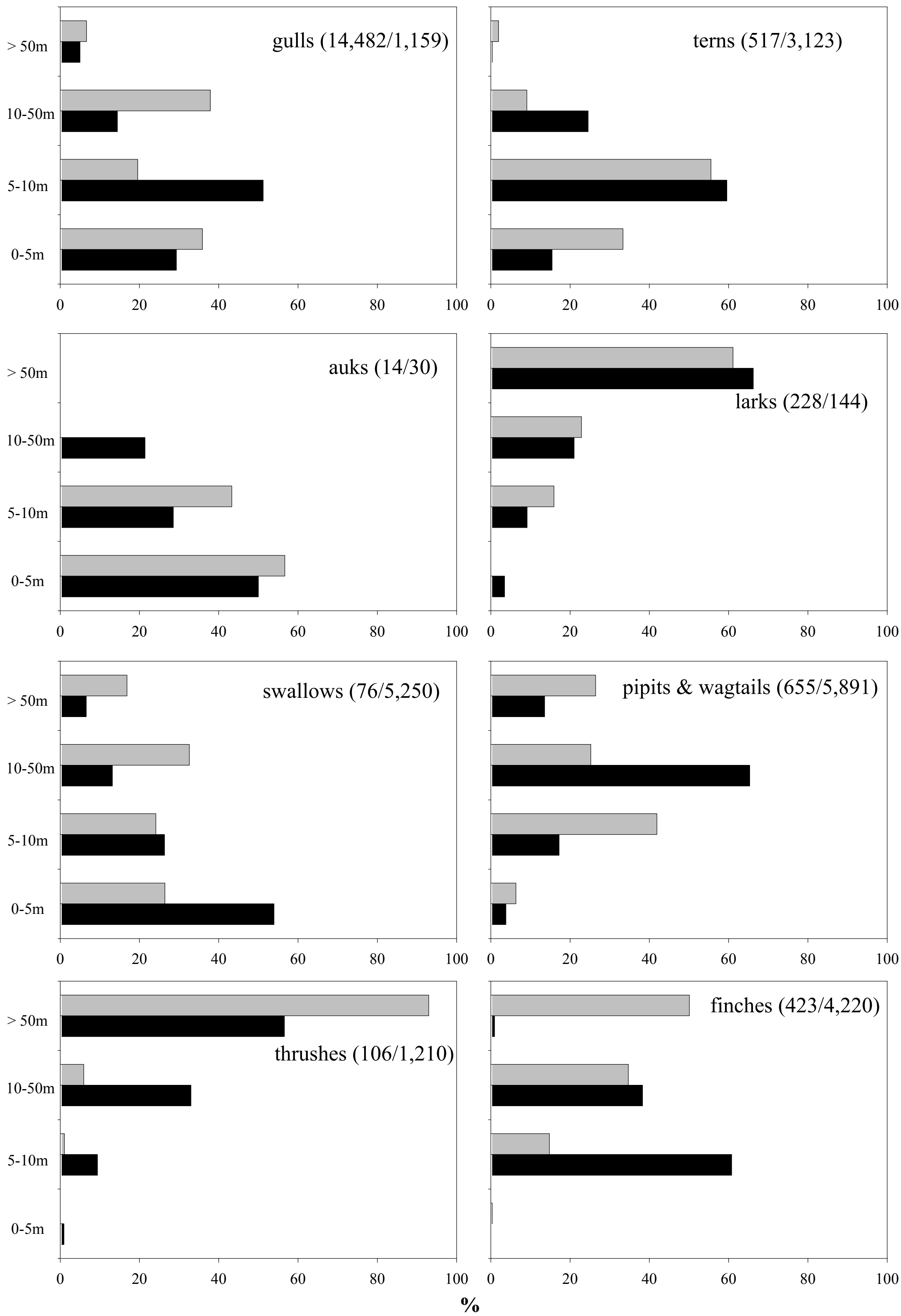
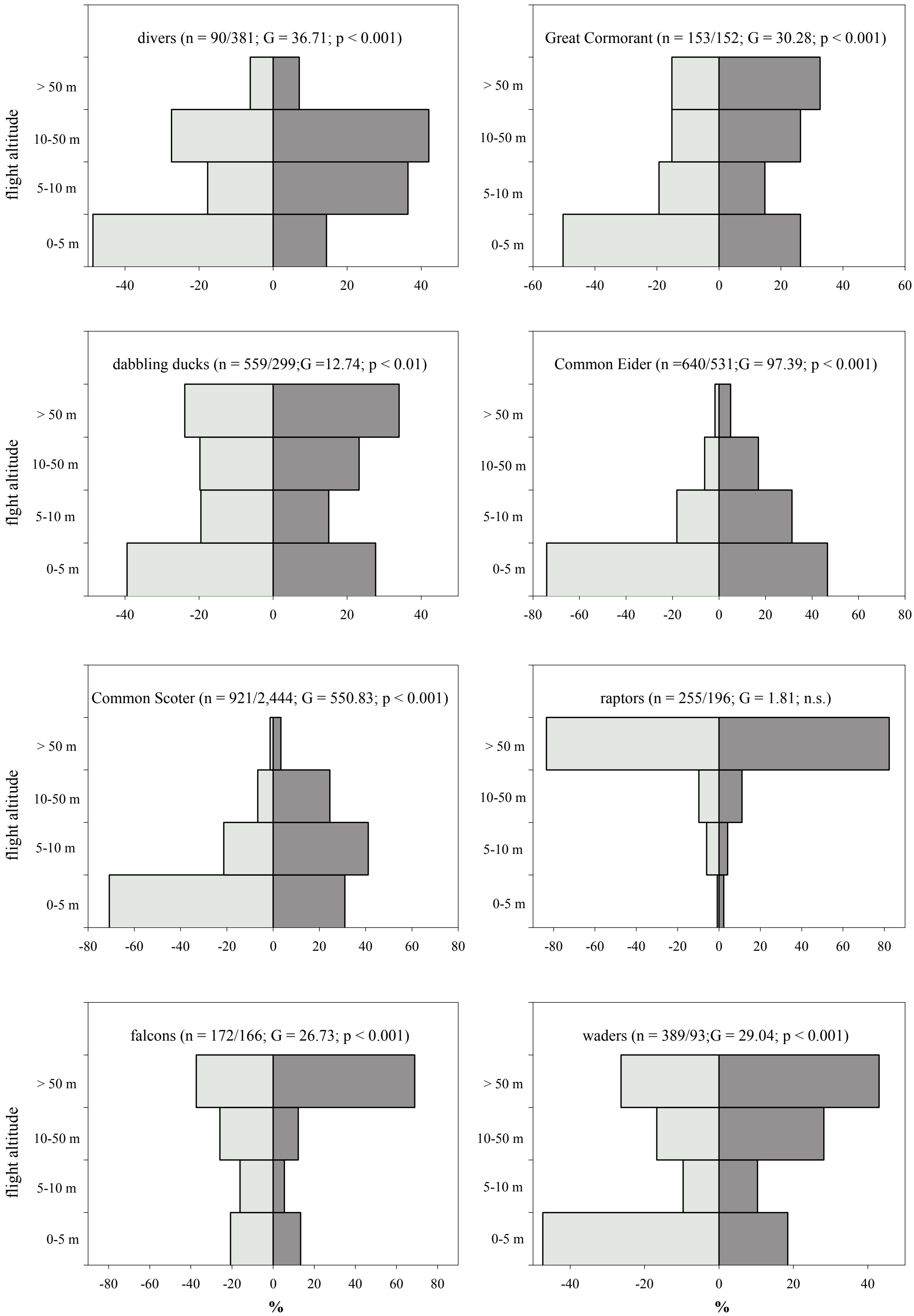


Figure II-7: **Altitude distribution of selected bird groups during spring (black) and autumn migration (grey). Values in brackets denote the number of analysed individuals (spring / autumn). Statistical differences between spring and autumn birds are shown in Table II-4.**

An analysis of the correlation between the „Tailwind Component“ and flight altitude using a Bonferroni-corrected Spearman-rank correlation ($p < 0.05$) did not yield a significant negative correlation for any species group (Table II-5). A significant positive correlation (increase in altitude with increasing tailwind) was only found in the mainly high flying falcons and sparrowhawks. In the medium to high altitude group a positive correlation was only found for larks, pipits and wagtails as well as for finches and sparrows. In the group of mainly low and medium altitude flyers, a positive correlation was found for divers, cormorants, geese, dabbling ducks, waders, gulls and terns while in the group of mainly low flying birds, Black Scoter, Common Eider and mergansers correlated positively (see II-4.3.4) (Table II-5, Figure II-8).

Table II-5: Spearman-Rank correlation (Bonferroni-corrected) between Tailwind Component and Altitude. Only samples with more than 50 individuals were analysed.

species group	n (headwind/tail wind)	r_s	p
divers	90/381	0.271	< 0.001
cormorants	153/152	0.350	< 0.001
geese	110/148	0.232	< 0.001
dabbling ducks	559/299	0.124	< 0.001
seaducks (all species)	1,833/3,218	0.453	< 0.001
Common Eider	640/531	0.408	< 0.001
Black Scoter	921/2,444	0.418	< 0.001
mergansers	143/142	0.299	< 0.001
raptors	255/196	-0.200	0.671 (n.s.)
falcons & sparrowhawks	172/166	0.247	< 0.001
waders	389/93	0.341	< 0.001
gulls	415/354	0.206	< 0.001
terns	804/244	0.360	< 0.001
pipits & wagtails	1,704/248	0.476	< 0.001
thrushes	212/68	0.138	0.022 (n.s.)
finches	463/100	0.241	< 0.001


divers (n = 90/381; G = 36.71; p < 0.001)
Great Cormorant (n = 153/152; G = 30.28; p < 0.001)
dabbling ducks (n = 559/299;G =12.74; p < 0.01)
Common Eider (n =640/531;G = 97.39; p < 0.001)
Common Scoter (n = 921/2,444; G = 550.83; p < 0.001)
raptors (n = 255/196; G = 1.81; n.s.)
falcons (n = 172/166; G = 26.73; p < 0.001)
waders (n = 389/93;G = 29.04; p < 0.001)
flight altitude
> 50 m
10-50 m
5-10 m
0-5 m
%

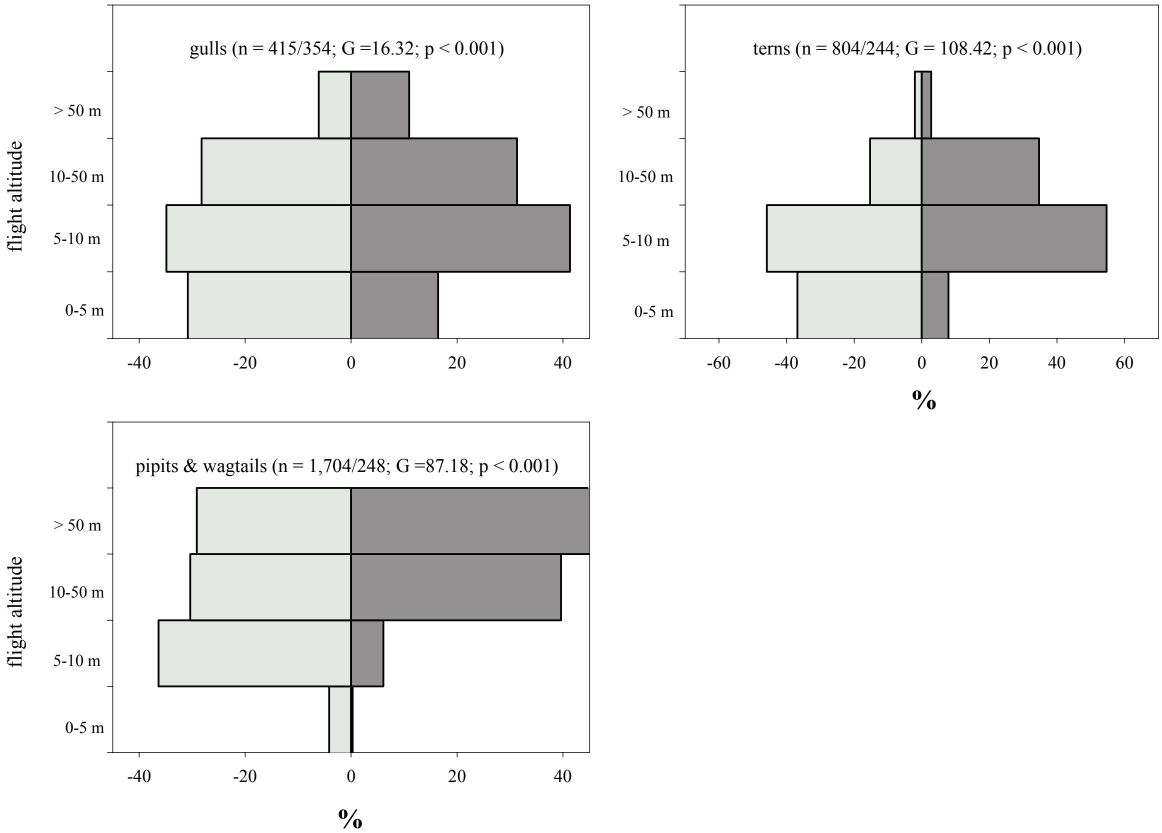


Figure II-8: Percentage altitude distribution of some selected bird groups in headwind (TWC < 0; light grey) and tailwind (TWC > 0, dark grey). Shown is the number of flocks (headwind/tailwind). Statistical test of differences in distribution were made with a Bonferroni-corrected G-Test (df = 3). The results of the Spearman-Rank correlations are presented in Table II-5.

II-4.3.4 Distance from coast

While there was no apparent coastal effect on cormorants, geese and gulls, dabbling ducks and terns almost always kept a distance of at least 500 m from the coastline (Figure II-9). This was even more pronounced in the behaviour of divers, seaducks and auks, where the distance from the coast was usually more than 2 km (Figure II-9).

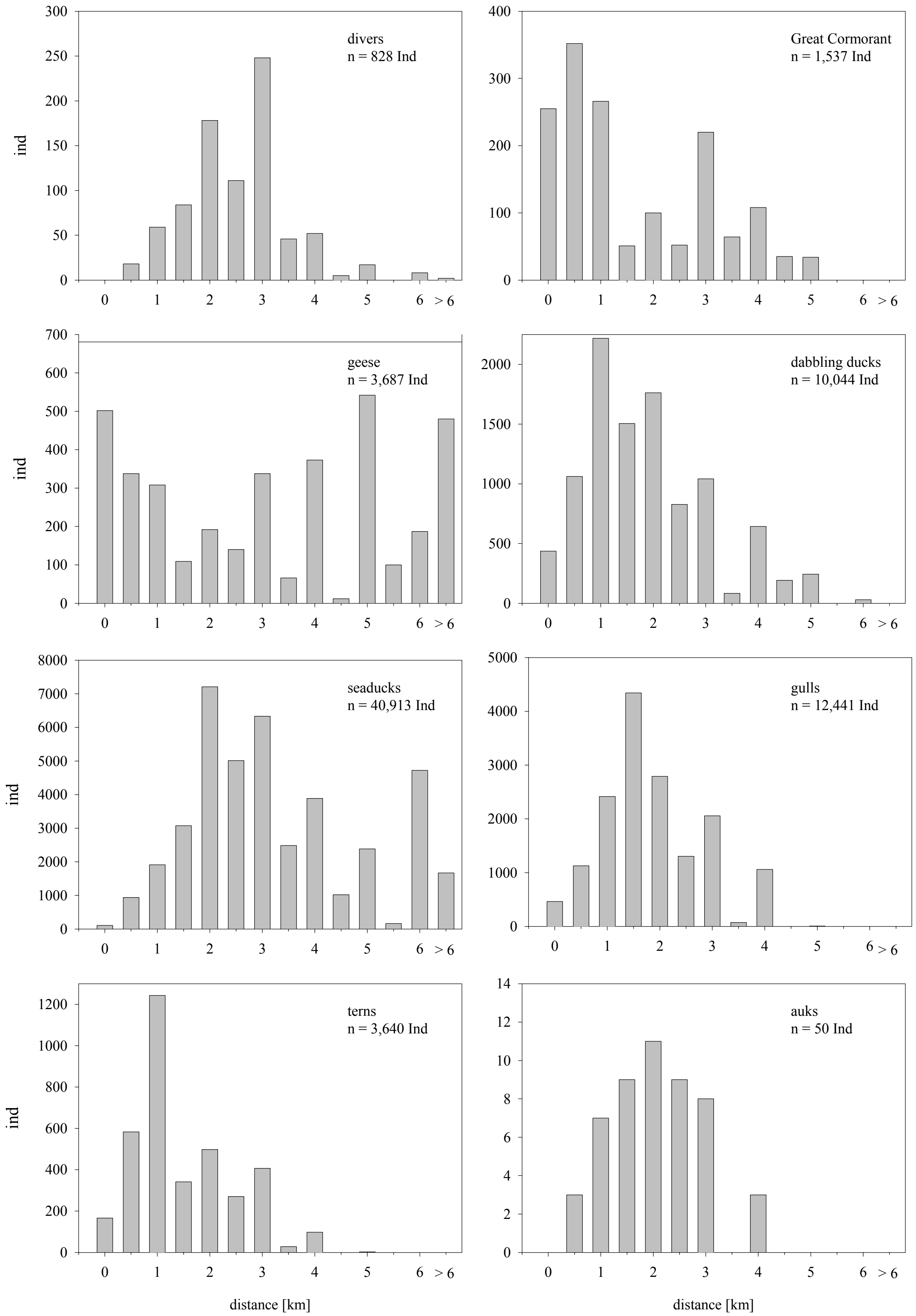


Figure II-9: Distance from the coast of selected bird groups. The decline in frequency with distance does not necessarily represent a gradient, but could also reflect a lower detectability.

II-4.4 Discussion

The radar survey of migratory behaviour, also used in this project, yielded excellent results on flight direction, altitude distribution of flocks and migratory intensity because of its consistency and therefore comparability between different days (e.g. Harmata et al. 1999). The species composition can be estimated from speed of the recorded individuals as well as the shape and size of the radar signal (e.g. Eastwood & Rider 1965). However, this method is limited with regard to details due to high inter- and intra-specific differences (Bruderer 1997a, b, Bruderer & Boldt 2001). Birds flying between 0 and 50m above waves are difficult to record with the vertical radar because of reflection from waves. During strong wave action, the horizontal radar is also affected by wave reflection, so that bird signals are superimposed (chapter II-6.1.1). Visual observations are therefore important to complement the gaps on species composition, flock size and migration intensity of low flying birds.

The surveys could only be carried out for a part of the annual migration. Some species usually show a more intense migration outside the periods of observation (e.g. divers, geese, seaducks, waders) whereas other species migrate mainly at night (e.g. waders, warblers, chats and small thrushes) or at high altitudes (e.g. raptors) and are therefore insufficiently detectable during the surveys.

The seasonal occurrence of different species correlates well with the specific phenologies for the North Sea (e.g. Camphuysen & van Dijk 1983, Platteeuw et al. 1994, Dierschke et al. 2001) and the Baltic Sea (Dierschke et al. 1995, 1997, Helbig et al. 1996). Our random samples can therefore be considered representative. The median flock sizes also correspond well with values determined by Krüger & Garthe (in prep.) on Wangerooge.

The determined altitudes can be regarded as being representative up to a height of about 100 m above sea level. However, they give no indication of the distribution above these heights. The results also correspond well with those obtained by Krüger & Garthe (2002a) on Wangerooge. Wind force generally increases with increasing altitude above sea level (e.g. Geiger 1961, Alerstam 1979b). Jameson (1960) recorded wind velocities of 4 Bft at sea level and 8 Bft, 15 m above. Birds generally tend to optimise their movements to conserve energy and time (e.g. Bruderer 1971, Alerstam 1991). Flying immediately above sea level can be energetically advantageous because of the „ground effects“ (e.g. Withers & Timko 1977).

Some species (e.g. divers, seaducks, auks) maintain a clear distance from the coastline. Should offshore wind energy plants therefore act as landmarks, the birds would require additional energy consuming manoeuvres to avoid these during migration.

The information obtained during migration surveys in this project confirms impressively data, which have up to now only been obtained on land. It was shown that headwinds cause the largest proportion of daily active seabirds to migrate at altitudes below 50 m. The surveys provide additional information to the radar data and are therefore essential in the assessment of potential risks of offshore wind farms.

II-5 Diurnal bird migration on Helgoland (by Volker Dierschke)

II-5.1 Introduction

Ever since the impressive description by Gätke (1891), the German Bight (southeastern North Sea) has been recognised as an important migratory route. Although the significance of Helgoland as a stopover site for migrating birds has been recorded (e.g. Weigold 1930, Vauk 1972), the migration past the island was mostly neglected with the result that incorrect data on the status of some bird species was often published (Vauk 1972, Vauk & Bruns 1983). With the exception of very generalised information (e.g. Gätke 1891, Drost 1928) and despite some efforts to carry out surveys on Helgoland (Drost & Schildmacher 1930a, b, Helbig & Laske 1982) there is very little quantitative information on the number of birds migrating over the sea around Helgoland. However, it is essential to obtain more precise information on migration particularly because of the planned commercial utilisation of the southeastern North Sea and accompanying environmentally friendly planning (e.g. Exo et al. 2002, 2003). Short-term studies only provide momentary information. Long-term observations are necessary because of the high variability of migration, for instance caused by variable weather conditions (e.g.. Dierschke 2001a). Such long-term observations can only be done on Helgoland since other appropriate observation sites are not available in the offshore area. Migration has been followed from there from convenient points of observation, since the 1980's (e.g. Moritz & Stühmer 1985, Stühmer & Zuchuat 1987, Dierschke 1991). Extensive surveys were carried out from 1990 to 2001. Using information on the intensity of migration it is possible for the first time to present long-term quantitative estimates of the migration near Helgoland. Taxonomic groups, which are identifiable from a distance according to body size, were considered.

The collision of migrating birds with offshore structures is a potential danger (e.g. Exo et al. 2002, 2003). In order to determine the vertical distribution of bird migration, flight altitude was also estimated during three years of the survey.

II-5.2 Methods

Helgoland (1,5 km²) is situated 50 km off the coasts of Schleswig-Holstein and Lower Saxony and 45 km off the Wadden Sea island Wangerooge (54° 11' N, 07° 55' E). Members of the Ornithological Working Group of Helgoland (OAG Helgoland) and the Institute of Avian Research „Vogelwarte Helgoland" observed the visible bird migration over the sea between 1990 and 2001 from various stations. During a total of 3082 hours the horizon as well as the airspace visible above and below were checked for migrating birds using a telescope. Higher altitudes (up to at least 200 m above sea level) were monitored with binoculars (more detailed description of methods in Dierschke 1991). The most important stations were between 3 and 20 m above sea level and are shown in Figure II-10. The selection of the observation points was done according to desired direction of observation and shelter from bad weather.

Depending on the location of the observer, only birds, which passed by in the south or north of the island, were recorded. Whereas some bird species were identifiable up to a distance of 10 km, the range of observation for smaller species (e.g. small waders of the Genus *Calidris*) was 5 km less (distance estimated from buoys, Dierschke 1991). Absolute frequency data are therefore only comparable between species of similar size. Irregularities in the observations occurred because of variable visibility with the result that distance of observation was reduced in hazy weather or strong air vibration.

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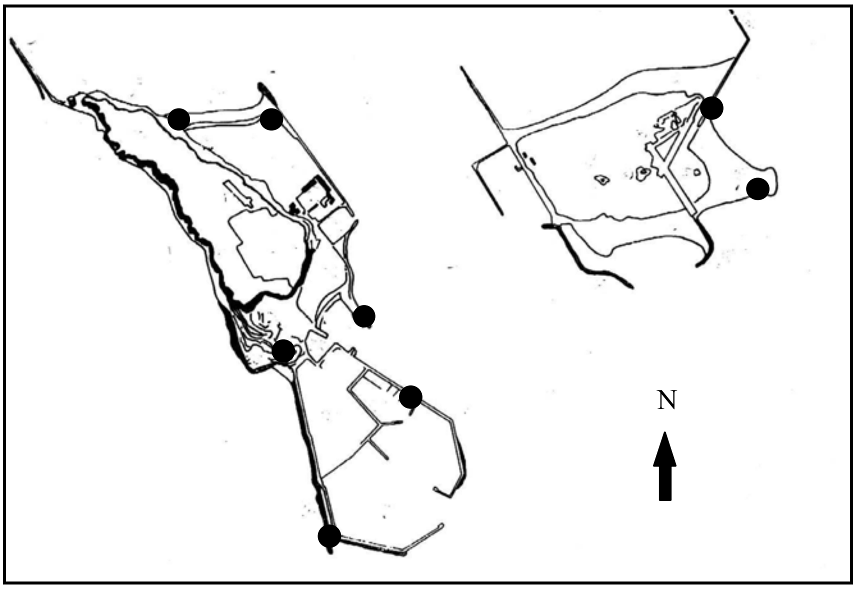

Figure II-10: Map of Helgoland and Dune showing the most important observation points.

Observations were only carried out during a minimum visibility of 3 to 4 km and were interrupted or cancelled during strong rain showers. During the observations (minimum duration of 30 minutes) all recognised flocks or single birds and direction of migration (to the nearest 45°) were noted at 15-minute intervals. During analysis, the sum of observed birds of a single species was divided by the number of hours of observation resulting in the intensity of bird migration as „birds per hour“. All the data were combined irrespective of observation direction (north or south of the island), weather, visibility, daytime or observer. It is probable that because of the vast amount of data, the different factors will cancel out each other and provide a realistic picture of migration.

In order to estimate the total number of migrating birds from random surveys, the migratory intensity was extrapolated using pentade values of the daylight period (sunrise to sunset) and added to produce an annual sum. Since the intensity of migration was determined for the north and south only, the extrapolated values were doubled. This means that the total of migrating birds covered a zone of 10 to 20 km around Helgoland, depending on the bird species. Since this is an estimate no effort was made to correct for daylength or weather. In order to test how realistic the projected data where, they were compared to the highest actually recorded values from all available data around Helgoland for a single year in the period 1990 to 2001. These are all the data from surveys including coincidental observations of migration stored in the data base of the OAG Helgoland and the Institute of Avian Research.

During 1347 hours of observations from March 1999 to 2001, it was determined whether flocks flew above or below 50 m over sea level. The 40 to 60 m high cliffs of the island helped in the estimation of flight altitudes. In most cases it was not difficult to categorize into one of the classes since low flying birds almost always flew at altitudes below 10 to 20 meters above sea level. However, at altitudes between 40 and 60 m small errors were possible, but these were marginal. The proportion of high flying (>50 m) or low flying (<50 m) birds is given only for those birds where at least 40 individuals were recorded. It has to be kept in mind that these data are only provided for the lowest 200 to 500 m of airspace. Many of the species dealt with are expected to fly over the German Bight at altitudes which were not covered with the optical methods available in this study.

In order to determine the effects of wind on altitude of birds, the number of high flying birds was compared to the wind force as well as a combination of wind force and wind direction. This tail wind component (TWC) was determined after Fransson (1998) as follows

$$TWC = \cos(\varphi) \cdot v$$

where φ is the angle between wind direction and the tail wind for the bird (this means exactly opposite the flight direction) and v the wind force (in m s^{-1}). Negative values represent headwind and positive tailwind. Wind force and wind direction data were taken for the times 7.30, 14.30 and 21.30 CET (Germany's National Meteorological Service, weather station Helgoland). All observations were allocated to the closest time slot for weather. Analyses always included the number of individuals and not the number of flocks since the question of number of birds relevant for nature conservation purposes was of primary importance.

All species commonly termed seabirds, waterbirds, waders and coastal birds (members of the order Gaviiformes, Podicipediformes, Procellariiformes, Ciconiiformes, Anseriformes and Charadriiformes) as well as raptors (Falconiformes) were dealt with in this project. Due to the presence of many breeding birds, winter guests or summer residents, the determination of migratory intensity of some species could not be monitored. These were Herring Gull *Larus argentatus*, Lesser Black-backed Gull *L. fuscus*, Great Black-backed Gull *L. marinus*, Black-legged Kittiwake *Rissa tridactyla*, Sandwich Tern *Sterna sandvicensis*, Razorbill *Alca torda* and Common Guillemot *Uria aalge*. In some cases it was possible to distinguish between migrating Lesser Black-backed Gulls and Sandwich Terns from those returning from feeding or to colonies, so that observations on flight altitude could be made.

The observations on flight altitude were made by V. Dierschke (677 h), J.-P. Daniels (410 h), F. Bindrich (66 h), J. Dierschke (60 h), J.O. Kriegs (53 h), H. Schmaljohann (33 h), N. Markones (22 h), S. Jaquier (12 h), F. Jachmann (9 h) and J. Mayer (5 h). F. Stühmer, D. Kratzer, K. Janßen, M. Nickel, G. Teenck and R. Muheim provided additional major contributions to the observation data.

II-5.3 Results

II-5.3.2 Species spectrum, phenology and quantification

Seabirds, waterbirds, waders and coastal birds migrated over the sea of the German Bight throughout the year (Fig. II-11). Numbers of leaving as well as returning migrants were more or less the same, with main migration taking place from February to May and August to November. In the most intensive months over 200 birds passed the islands every hour.

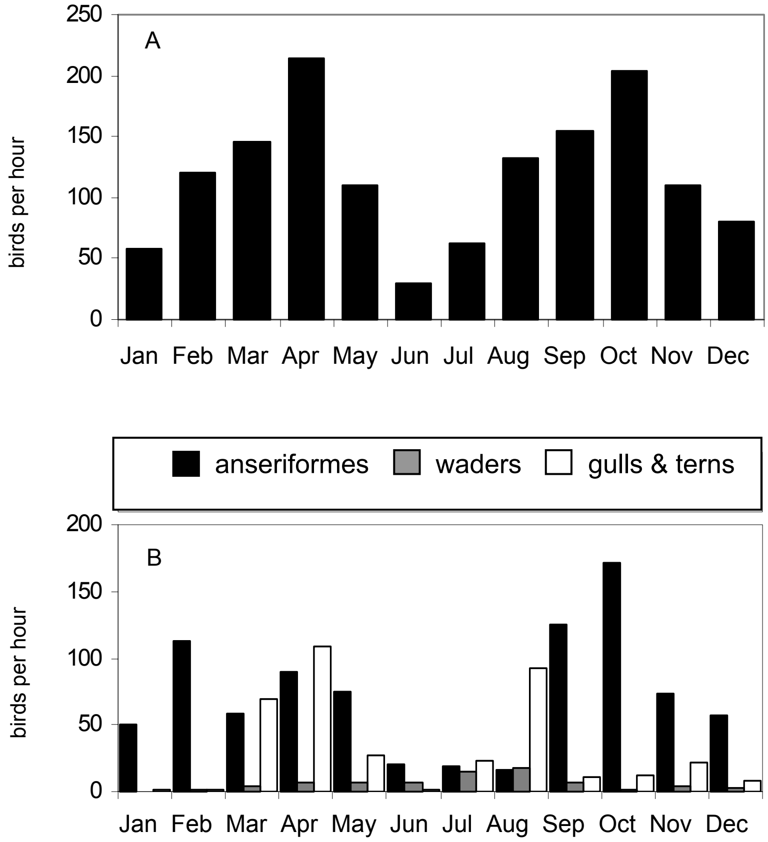

Figure II-11: Monthly migration of seabirds, waterbirds, waders and coastal birds according to surveys from 1990 to 2001. A: All species (except those not counted, see methods), B: Individuals of the main taxonomic groups.

The weakest migration was observed in June, July and January. Over 1 million seabirds, waterbirds, waders and coastal birds migrated through an imaginary zone of 10 to 20 km with Helgoland in the middle and a NW-SE direction, without considering several common species (see methods). An estimated total of 2120 raptors passed this zone annually. See Table II-6 for an overview of projected number of migrants near Helgoland.

Ducks were the dominant representatives of all migrating birds throughout the year, with the exception of July and August. However, gulls and terns contributed considerably to the migrants in March, April and August (Figure II-11). Waders played a minor role with regard to quantity. Their largest contribution was in July and August. A total of 90 seabird, waterbird, wader and coastal bird species were recorded during the period 1990 to 2001. In addition there were seven species, in which observed individuals could not be attributed to breeding or staging birds (see methods). The most common migrants were Black Scoter, Brent Goose and the grouped Common and Arctic Terns, followed by Common Eider, Pink-footed Goose, Little Gull and Black-headed Gull (Table II-7).

Table II-6: Projected annual number of birds migrating in the lower 200-500 m of the air space in a 10 to 20 km wide zone of the sea area around Helgoland.

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species	number of birds extrapolation	highest actual annual (1990 bis 2001)	sum %	year
Red-throated Diver	27220	2700	9.9	1996
Black-throated Diver	596	48	8.1	1998
Red-necked Grebe	472	57	12.1	1998
Great Crested Grebe	224	38	17.0	1996
Sooty Shearwater	574	351	61.1	1996
Northern Gannet	13936	5450	39.1	1996
Great Cormorant	20808	6722	32.3	1996
Grey Heron	972	233	24.0	1998
Mute Swan	318	166	52.2	1998
Whooper Swan	508	143	28.1	1998
Tundra Swan	1212	367	30.3	2000
Bean Goose	240	74	30.8	1993
Pink-footed Goose	65440	18041	27.6	1999
Greater White-fronted G.	314	274	87.3	1993
Greylag Goose	28798	5587	19.4	2000
Barnacle Goose	15430	3463	22.4	2000
Brent Goose	140272	17397	12.4	1994
Common Shelduck	2362	848	35.9	1995
Eurasian Wigeon	26092	17844	68.4	1995
Gadwall	106	13	12.3	1995
Eurasian Teal	4482	651	14.5	2000
Mallard	712	294	41.3	1995
Northern Pintail	5386	1617	30.0	1995
Northern Shoveler	378	118	31.2	1994
Common Pochard	224	165	73.7	1995
Tufted Duck	576	137	23.8	1995
Greater Scaup	170	41	24.1	1992
Common Eider	75968	10938	14.4	1995
Long-tailed Duck	142	12	8.5	1995
Black Scoter	199098	14438	7.3	2000
Velvet Scoter	876	120	13.7	1998
Common Goldeneye	526	65	12.4	2000
Red-breasted Merganser	2934	275	9.4	1996
Goosander	480	81	16.9	1996

Table II-6 (Continued):
Projected annual number of birds migrating in the lower 200-500 m of the air space in a 10 to 20 km wide zone of the sea area around Helgoland.

species	number of birds extrapolation	highest actual annual (1990 bis 2001)	sum %	year
Osprey	110	42	38.2	1993
Eurasian Marsh Harrier	206	75	36.4	1995
Eurasian Sparrowhawk	542	287	53.0	1998
Common Kestrel	250	62	24.8	2000
Merlin	728	203	27.9	1992
Eurasian Oystercatcher	5206	2153	41.4	1995
Northern Lapwing	1278	391	30.6	1996
European Golden Plover	7678	2401	31.3	1994
Grey Plover	8164	1360	16.7	1994
Ringed Plover	266	42	15.8	1998
Bar-tailed Godwit	10566	2857	27.0	1992
Whimbrel	2208	483	21.9	1992
Eurasian Curlew	9638	2002	20.8	2000
Spotted Redshank	134	27	20.1	1993
Common Redshank	2044	419	20.5	1993
Common Greenshank	1352	224	16.6	1998
Green Sandpiper	308	93	30.2	1995
Wood Sandpiper	106	46	43.4	1993
Common Sandpiper	252	59	23.4	1996
Ruddy Turnstone	850	270	31.8	1993
Common Snipe	814	514	63.1	1995
Red Knot	4284	1507	35.2	1993
Sanderling	166	54	32.5	1995
Dunlin	7520	763	10.1	1998
Curlew Sandpiper	166	41	24.7	1993
Ruff	196	30	15.3	1998
Great Skua	126	41	32.5	1998
Pomarine Skua	250	63	25.2	1998
Arctic Skua	1950	1405	72.1	1995
Mew Gull	61348	8610	14.0	1998
Black-headed Gull	65848	8784	13.3	1998
Little Gull	56182	17807	31.7	2001
Black Tern	1714	632	36.9	1995
“Comic“-Tern	106112	21694	20.4	1992
Little Auk	412	632	153.4	1995

Table II-7: Monthly intensity of migration of all seabirds, waterbirds, waders, coastal birds and raptors near Helgoland. Data from 1990 to 2001 (in total 3082 hours of observation)

		birds per hour											
species	n	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Red-throated Diver	8405	5.54	5.10	10.70	4.36	0.54	0.01	<0.01	0.01	0.48	1.65	6.64	11.44
Black-throated Diver	173	0.09	0.02	0.07	0.13	0.17	0.04	<0.01	<0.01	0.02	0.09	0.11	0.06
Great Northern Diver	2			<0.01								0.01	
Red-necked Grebe	175	0.05	0.06	0.18	0.06	0.02		0.01	0.03	0.06	0.09	0.10	0.08
Great Crested Grebe	80		0.07	0.10	0.01			<0.01	<0.01	0.01	0.06	0.07	0.05
Slavonian Grebe	7			0.01	0.01					<0.01	<0.01		
Manx Shearwater	23					<0.01	0.03	0.02	0.01	0.01	0.01		0.01
Balearic Shearwater	7					<0.01	0.01	<0.01	<0.01	0.01			
Sooty Shearwater	314							<0.01	0.06	0.22	0.62	0.04	0.01
Great Shearwater	2									<0.01		0.01	
European Storm-petrel	2							<0.01			<0.01		
Leach's Storm-petrel	11									0.01	0.02		
Northern Gannet	6732	0.06	0.01	0.28	0.15	0.10	1.07	5.53	2.39	3.22	4.76	0.16	0.02
Great Cormorant	8753	0.89	0.15	3.43	3.90	1.02	0.11	0.37	1.22	5.14	10.84	3.09	0.35
Grey Heron	411	0.02	0.01	0.23	0.12	0.07	0.02	0.18	0.18	0.24	0.11	0.01	
Mute Swan	94	0.06	0.01	0.01	0.04	0.08	0.04	0.01	0.01	0.06	0.01	0.09	
Whooper Swan	174	0.02	0.16	0.24							0.03	0.38	0.18
Tundra Swan	418	0.08		0.17							0.46	1.19	0.44
Bean Goose	76	0.03	0.14	0.07		<0.01					0.02	0.20	
Pink-footed Goose	23472	9.26	84.45	1.01	0.72					0.35	24.92	1.79	14.09
Greater White-fronted Goose	113		0.58		0.02						0.08	0.01	
Greylag Goose	11246	0.09	0.83	0.69	8.29	1.22	0.22	0.58	3.03	12.28	3.28	7.54	1.60
Canada Goose	7									0.02			
Barnacle Goose	6264		8.69	1.12	3.29	0.10				1.07	8.05	6.78	0.99
Brent Goose	53158	0.31	2.26	13.06	7.45	56.05	0.61			34.56	62.04	10.20	0.29
Common Shelduck	857	0.19	0.10	0.48	0.33	0.07	0.17	0.23	0.09	0.46	0.15	0.70	0.84
Egyptian Goose	3			0.01									
Eurasian Wigeon	13509	0.05	0.27	0.61	1.08	0.01	0.01	0.02	0.44	26.84	5.01	6.88	1.56
Gadwall	30	0.01	0.04	0.05	0.03	0.01	0.01						
Eurasian Teal	1690	0.08	0.02	0.96	2.07	0.07	0.02	0.02	0.58	1.41	0.26	0.06	0.03
Mallard	247		0.01	0.17	0.02	0.01	0.11	0.04	0.02	0.18	0.12	0.24	0.08
Northern Pintail	2616	0.03	0.04	0.35	0.14	0.02		0.01	0.28	4.78	0.73	1.95	0.32
Garganey	11					<0.01				0.03			
Northern Shoveler	177			0.04	0.08	0.04		0.01	0.04	0.24	0.07	0.04	
Common Pochard	117			0.01	0.01	<0.01	0.02			0.27	0.02	0.01	0.01
Tufted Duck	238		0.02	0.06	0.13	0.11		0.02	0.04	0.24	0.10	0.01	0.06
Greater Scaup	65	0.02			0.01	<0.01		<0.01		0.05	0.04	0.14	0.06
Common Eider	33937	2.73	3.88	4.86	8.80	0.30	0.57	0.80	2.67	24.78	46.73	19.78	10.55
Long-tailed Duck	42	0.04	0.02	0.05	0.02	<0.01	0.02				0.01	0.03	0.05
Black Scoter	64304	35.94	10.94	33.53	55.46	16.53	18.56	17.51	8.53	17.39	18.24	13.80	24.49
Velvet Scoter	268	0.19	0.07	0.12	0.19	0.03		<0.01	<0.01	0.07	0.08	0.28	0.42
Common Goldeneye	177	0.02	0.01	0.14	0.12	0.01				0.02	0.14	0.23	0.21
Smew	4				0.02								
Red-breasted Merganser	977	0.52	0.21	0.87	0.76	0.14	0.05	0.02	0.01	0.20	0.72	0.72	0.20
Goosander	148	0.02	0.06	0.16	0.18						0.01	0.18	0.18
Ruddy Duck	1						0.01						
Osprey	52				0.02	0.03			<0.01	0.10	<0.01		
European Honey-buzzard	25					0.03		<0.01	<0.01	0.04			

Table II-7 (Continued):
Monthly migratory intensity of all seabirds, waterbirds, waders and coastal birds near Helgoland.

		birds per hour											
species	n	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eurasian Marsh Harrier	105				0.03	0.03		<0.01	0.03	0.19	0.01		
Hen Harrier	29				0.01	0.02				0.02	0.02	0.05	0.01
Montagu's Harrier	1								<0.01				
Northern Goshawk	1										<0.01		
Eurasian Sparrowhawk	236			<0.01	0.05	0.02			0.03	0.23	0.30	0.16	
Common Buzzard	14			<0.01	0.02					0.01	0.02	0.01	0.01
Rough-legged Buzzard	1				<0.01								
Common Kestrel	103		0.01	0.01	0.03	0.04		<0.01	0.02	0.14	0.06		
Eurasian Hobby	11					<0.01			<0.01	0.02	0.01		
Merlin	266		0.01	0.01	0.11	0.27			0.01	0.24	0.23	0.01	
Peregrine Falcon	20			<0.01		0.01				0.03	0.02	0.01	
Eurasian Oystercatcher	2356		0.01	0.05	0.12	0.60	0.36	1.15	2.91	0.28	0.05		0.06
Pied Avocet	11			<0.01	<0.01				0.02				
Northern Lapwing	476	0.01	0.23	0.88	0.03	0.01	0.06	0.14	0.06	0.03	0.25	0.06	
European Golden Plover	3503		0.01	0.32	0.17			1.10	3.74	0.86	0.55	1.93	1.91
Grey Plover	2008			0.02	0.02	2.97	2.61	0.12	0.90	0.60	0.21	0.10	0.28
Ringed Plover	136		0.01	0.04		0.03		0.06	0.16	0.02		0.02	
Black-tailed Godwit	10			0.01	<0.01			0.01	0.01				
Bar-tailed Godwit	4655		0.01	0.32	0.23	1.42	0.07	3.01	3.41	2.82	0.01		0.02
Whimbrel	1000				0.03	0.32	0.12	1.13	0.73	0.03			
Eurasian Curlew	3074	0.01		0.26	5.29	0.18	3.01	0.97	1.16	0.47	0.08	0.11	0.05
Spotted Redshank	50					0.01	0.03	0.03	0.02	0.04			
Common Redshank	935				0.06	0.21	0.15	0.92	0.81	0.04	0.01	0.01	
Common Greenshank	563				0.07	0.16	0.11	0.66	0.36	0.03			
Green Sandpiper	153				0.03	0.01	0.01	0.17	0.09	0.04	<0.01		
Wood Sandpiper	47					0.02		0.07	0.02	0.01			
Common Sandpiper	118					0.04		0.15	0.06	0.03			
Ruddy Turnstone	433			<0.01		0.04		0.55	0.30	0.06			
Red-necked Phalarope	5								0.01				
Eurasian Woodcock	23			0.06	0.01						0.01	0.01	
Jack Snipe	5									<0.01	0.01		
Common Snipe	446			<0.01	0.01	<0.01		0.09	0.31	0.60	0.06	0.01	0.01
Red Knot	1960	0.01	0.86		0.13	0.21		2.10	1.22	0.37	<0.01	0.11	0.21
Sanderling	74		0.01	0.01	0.01	0.01		0.03	0.09			0.03	
Little Stint	28							0.02	0.01	0.03	<0.01		
Temminck`s Stint	3					<0.01		<0.01					
Purple Sandpiper	6				0.01			0.01					
Dunlin	3272		0.23	1.77	0.19	0.42	0.05	2.46	1.79	0.67	0.37	1.45	0.21
Curlew Sandpiper	89					<0.01		0.11	0.07	0.01			
Ruff	83			0.01	0.01	0.02	0.02	0.02	0.07	0.06	0.01		
Great Skua	54	0.02						0.03	0.02	0.03	0.04		0.02
Pomarine Skua	101	0.01	0.01		0.01	0.04		0.02	0.06	0.06	0.04	0.03	0.08
Arctic Skua	982	0.02		0.03	0.06	0.03	0.02	0.07	0.85	1.13	0.19	0.06	0.02
Long-tailed Skua	14								0.02	0.02			
Mew Gull	17877	0.50	0.22	36.75	17.35	1.46	0.10	2.76	1.24	0.78	2.13	10.76	7.26
Mediterranean Gull	7			<0.01			0.01	<0.01		<0.01	0.01		
Black-headed Gull	23538	0.48	0.89	31.60	7.74	4.58	1.12	9.05	7.84	4.67	7.03	9.43	0.44
Little Gull	21173	0.24	0.23	0.55	79.15	3.96		0.11	0.10	0.40	2.98	1.93	0.67
Sabine's Gull	23								0.01	0.04	0.01	0.01	
Black Tern	900				<0.01	0.20		0.50	0.36	1.17			
"Comic"-Tern	52222			0.01	4.88	16.79	0.17	10.07	83.29	4.03	0.12	0.05	
Little Tern	15				<0.01	<0.01		<0.01	0.01	0.02			
Black Guillemot	29	0.02	0.02	<0.01	<0.01	<0.01		<0.01	0.01	0.01	0.04		
Little Auk	175	0.03						<0.01			0.45	0.19	0.03
Atlantic Puffin	2							<0.01				0.01	
total	382171	57.7	121.0	146.5	213.7	110.5	29.7	63.1	131.8	154.1	204.2	109.8	79.9

Table II-8: Proportion of birds migrating above an altitude of 50 m (only species with n > 40). Only birds flying below 200 to 500 m are detectable with optical methods.

species	n	flight altitude <50 m	light altitude >50 m	proportion (%) >50 m
Red-throated Diver	3183	2921	262	8.2
Black-throated Diver	90	72	18	20.0
Northern Gannet	347	305	42	12.1
Great Cormorant	3383	2530	853	25.2
Grey Heron	176	132	44	25.0
Whooper Swan	41	24	17	41.5
Tundra Swan	223	176	47	21.1
Pink-footed Goose	6189	3859	2330	37.6
Greater White-fronted Goose	86	76	10	11.6
Greylag Goose	4950	3104	1846	37.3
Barnacle Goose	2927	1979	948	32.4
Brent Goose	15637	12763	2874	18.4
Common Shelduck	273	247	26	9.5
Eurasian Wigeon	4155	3420	735	17.7
Eurasian Teal	839	803	36	4.3
Mallard	71	64	7	9.9
Northern Pintail	770	535	235	30.5
Northern Shoveler	44	41	3	6.8
Tufted Duck	89	87	2	2.2
Common Eider	10135	9806	329	3.2
Black Scoter	27636	27057	579	2.1
Velvet Scoter	75	75	0	0.0
Common Goldeneye	99	88	11	11.1
Red-breasted Merganser	393	373	20	5.1
Goosander	61	46	15	24.6
Eurasian Sparrowhawk	122	103	19	15.6
Common Kestrel	45	38	7	15.6
Merlin	121	109	12	9.9
Eurasian Oystercatcher	930	653	277	29.8
Northern Lapwing	69	21	48	69.6
European Golden Plover	1140	924	216	18.9
Grey Plover	844	231	613	72.6
Ringed Plover	59	39	20	33.9
Bar-tailed Godwit	1123	635	488	43.5
Whimbrel	172	117	55	32.0
Eurasian Curlew	1678	929	749	44.6
Common Redshank	271	186	85	31.4
Common Greenshank	187	87	100	53.5
Green Sandpiper	40	14	26	65.0
Common Sandpiper	49	14	35	71.4
Ruddy Turnstone	104	68	36	34.6
Common Snipe	43	8	35	81.4
Red Knot	538	310	228	42.4
Dunlin	1077	1001	76	7.1
Arctic Skua	114	112	2	1.8
Mew Gull	7708	6634	1074	13.9
Lesser Black-backed Gull	53	43	10	18.9
Black-headed Gull	9343	8210	1133	12.1
Little Gull	18481	17927	554	3.0
Black Tern	60	60	0	0.0
“Comic“-Tern	17622	17424	198	1.1
Sandwich Tern	782	739	43	5.5

II-5.3.2 Flight altitudes

Many of the observed birds mainly migrate at altitudes below 50 m over sea level (Table II-8). This was particularly noticeable for divers, grebes and the petrels, shearwaters and fulmars, diving ducks, mergansers, skuas, gulls, terns and auks with less than 10% of individuals flying higher than 50 m (Table II-9). Relatively large proportions of highflying birds (20% of individuals) were observed in cormorants, herons, swans and geese and particularly waders (37 %, Table II-9).

Table II-9: Proportion of birds flying over 50 m according to taxonomically and ecologically relevant groups.

species groups	n	flight altitude <50 m	flight altitude >50 m	propor-tion (%) >50 m
divers (3 Species)	3275	2995	280	8.5
grebes (3 Species)	62	62	0	0.0
shearwaters (3 Species)	31	31	0	0.0
gannets (1 Species)	347	305	42	12.1
cormorants (1 Species)	3383	2530	853	25.2
herons (1 Species)	176	132	44	25.0
swans (3 Species)	301	231	70	23.3
geese (7 Species)	30089	22039	8050	26.8
dabbling ducks (6 Species)	5888	4872	1016	17.3
diving ducks (3 Species)	127	125	2	1.6
seaducks (5 Species)	37958	37039	919	2.4
mergansers (2 Species)	454	419	35	7.7
raptors (10 Species)	386	320	66	17.1
waders (28 Species)	8476	5347	3129	36.9
skuas (3 Species)	150	144	6	4.0
gulls (6 Species)	35585	32814	2771	7.8
terns (5 Species)	18464	18223	241	1.3
auks (2 Species)	24	24	0	0.0

In the air space below 200 to 500 m the flight altitude of most species is dependant on the tail wind component comprising wind direction and wind force. The stronger the head wind or the weaker the tail wind, the higher the proportion of birds flying below 50 m (Figure II-12). This pattern is particularly evident in cormorants, geese and waders, whereas seaducks and terns are not or hardly affected.

Wind force alone also has an effect on flight altitude. It has been observed for many species that flight altitude decreases with increasing wind force, whereas the proportion of birds flying above 50 m increases with weak winds (1 to 3 Bft.). This is particularly evident in cormorants, waders and gulls. Red-throated Diver and mergansers however, appear to react indifferently to wind force (Figure II-13).

II-5.4 Discussion

Significance of the sea area around Helgoland as a migration route for seabirds, waterbirds, waders and coastal birds

The sea around Helgoland to a distance between 5 and 10 km and the airspace up to an altitude of 200 to 500 m which is observable with the available methods is annually traversed by more than one million migrating seabirds, waterbirds, waders and coastal birds, according to projections. The number of individuals involved is probably half as high due to a double passage in spring and autumn migration. Since the observed activity of actually recorded birds under incomplete coverage of season or daytime corresponds well with the projections, these can be regarded as being realistic (Table II-6). These data for the first time enable an estimate of how many birds cross the southeastern North Sea during migration. It should be kept in mind that the actual numbers of most species are considerably greater since only a portion of the individuals can be recorded with the available optical methods and birds migrating at higher altitudes cannot be detected.

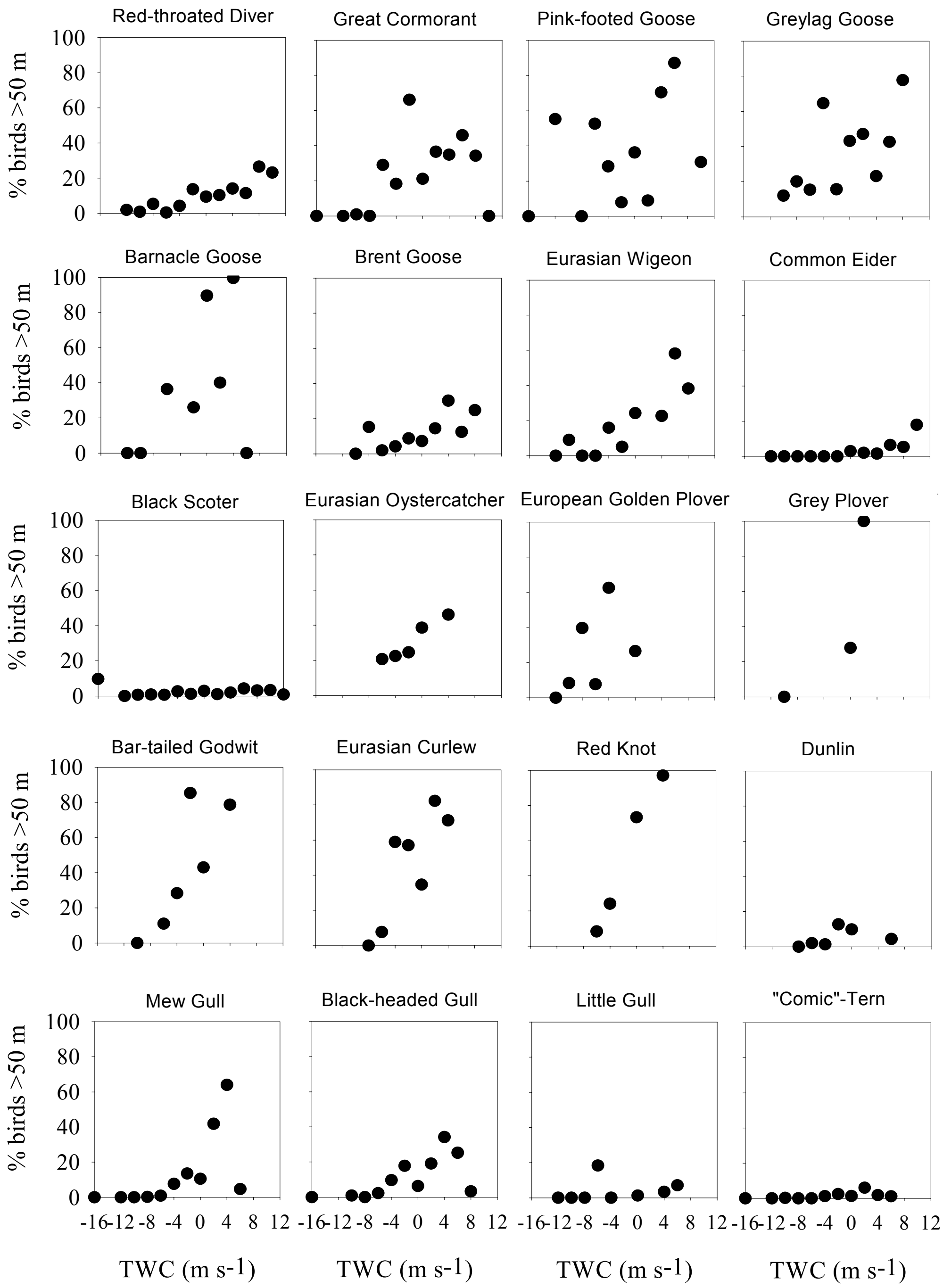


Figure II-12: **Dependence of flight altitude on the tail wind component (TWC). Only TWC-classes à of 2 m s^{-1} with n > 50 birds were considered.**

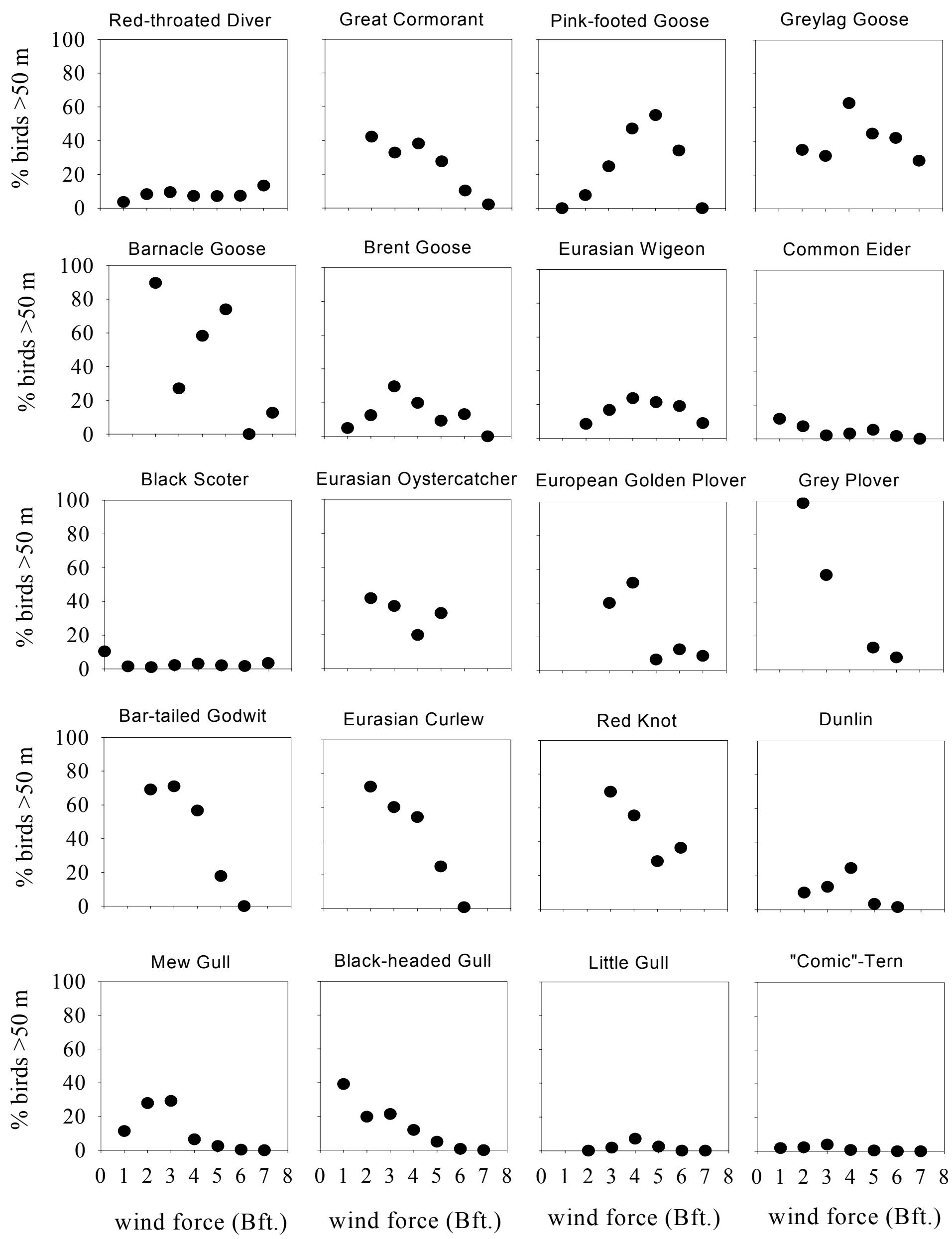


Figure II-13: Dependence of flight altitude on the wind force. Only wind force-classes of 1 Bft with n > 50 birds were considered.

Large proportions of the total biogeographic populations of some species pass over the sea around Helgoland. In 19 species the proportion exceeded 1% of their biogeographic populationd (Table II-10), according to the Ramsar Convention's international importance of resting areas (e.g. Rose & Scott 1994). This particularly applies to the Pink-footed Goose of which almost the entire Spitsbergen breeding population passes Helgoland during cold flights in winter and of which and over 16.000 individuals or 45% of the population do so during normal autumn migration in September/October (Table II-10). The Little Gull migrates past Helgoland with half of its population during spring migration. Over 10% of the biogeographic populations of Red-throated Divers, Greylag Geese, Brent Geese and Black Scoters were also recorded (Table II-10).

The high significance of the sea area around Helgoland for migrating birds is explained by the fact that the island is in the centre of important migratory routes, which birds breeding in northern Eurasia traverse en route to their winter quarters between western Europe and West Africa. Particularly the central location between the northeastern and southwestern part of the Wadden Sea which is an important staging site for the birds (Meltofte et al. 1994), as well as the important resting areas for divers and Black Scoters adjacent to the Wadden Sea (Skov et al. 1995, Nehls 1998, Heibges & Hüppop 2000, chapter II-11), are likely to be responsible for the large number of migrants near Helgoland. Since the birds dealt with here are not attracted to the island itself, possibly with the exception of some raptors, the observed migration is considered to be representative for large areas of the inner German Bight. Near the former research platform „Nordsee" in the German Bight, which was situated further off the coast, the intensity of migration was considerably lower at least in summer (May to August). On the other hand for some species migration along the coast was even higher than over Helgoland (Dierschke 2001b). Should it become evident, that some bird species react sensitively to constructions in the offshore area or are particularly endangered by collisions, the protection of these species needs to be taken into account in the planning stages. This applies particularly to those species of which considerable proportions of the entire population traverse the German Bight on their migratory flights.

Table II-10: Species, which pass the Helgoland sea area in projected numbers of more than 1% of their biogeographic population. AM = autumn migration, SM = spring migration, WF winter escape flight. Sources: A = Monval & Pirot 1989, B = Pirot et al. 1989, C = Smit & Piersma 1989, D = Lloyd et al. 1991, E = Durinck et al. 1994, F = Rose & Scott 1994, G = Madsen et al. 1999.

species	number at Helgoland during strongest migration	period of-migration	size bio geographic population	source	proportion of biogeogr. pop. at Helgoland
Red-/Black-throated Diver	15670	AM	110000	E	14.2 %
Red-necked Grebe	240	SM	15000	E	1.6 %
Great Cormorant	13380	AM	320000	F	4.2 %
Whooper Swan	260	AM	25000	A	1.0 %
Tundra Swan	1020	AM	17000	A	6.0 %
Pink-footed Goose	35120	WF	37000	G	94.9 %
Greylag Goose	20710	AM	200000	G	10.4 %
Barnacle Goose	8430	AM	267000	G	3.2 %
Brent Goose	75530	SM	300000	G	25.2 %
Eurasian Wigeon	24470	AM	750000	A	3.3 %
Northern Pintail	5000	AM	70000	A	7.1 %
Common Eider	62290	AM	3000000	B	2.1 %
Black Scoter	99730	AM	800000	B	12.5 %
Red-breasted Merganser	1730	SM	100000	A	1.7 %
Grey Plover	6300	SM	168000	C	3.8 %
Bar-tailed Godwit	8610	AM	815000	C	1.1 %
Eurasian Curlew	5190	AM	348000	C	1.5 %
Mew Gull	46150	SM	1600000	D	2.9 %
Little Gull	51700	SM	90000	F	57.4 %

Flight altitudes of migrating birds

The results on the distribution of flight altitude near Helgoland correspond well with those determined for the East Frisian Islands using the same method (Krüger & Garthe 2002a) and chapter II-4. Some of the species, which fly over the Helgoland sea area, fly at very low altitudes, almost exclusively below 50 m and often only a few meters above sea level. Of the species, which are represented by a considerable proportion of their geographic population such as Red-throated Divers, Brent Geese, Black Scoters and Little Gulls, at least 80% fly in the lowest 50 m. This means that a considerable proportion of the over 1 million seabirds, waterbirds, waders and coastal birds would be affected by offshore structures such as wind energy plants. For species in which a large part of the total population is involved, this could have influence on the species' protection. This is of particular significance during migration in strong headwinds when flight altitude is generally lower than when flying under weak winds or with tailwinds. The results presented here concerning wind conditions and flight altitudes are in agreement with investigations using various methods (Able 1970, Bruderer & Liechti 1998a, b, Gatter 2000, Krüger & Garthe 2002a, chapter II-4 and II-7) and can therefore be regarded as being representative.

II-6 The use of radar in the detection of bird movements

II-6.1 Ship radar

II-6.1.1 Localities and types of radar

In this project, ship radars were used to record bird movement. Since we did not have the possibility of using ships or other fixed structures at sea, we used exposed localities on islands (Figure II-14): 1. Helgoland (54° 10.201‘ N, 07° 53.456‘ E), 2. Fehmarn (54° 30.425‘ N, 11° 12.314‘ E) and 3. Rügen (54° 38.955‘ N, 13° 14.065‘ E). Every site was visited twice each spring and autumn. The exact recording periods are given in Table II-11.

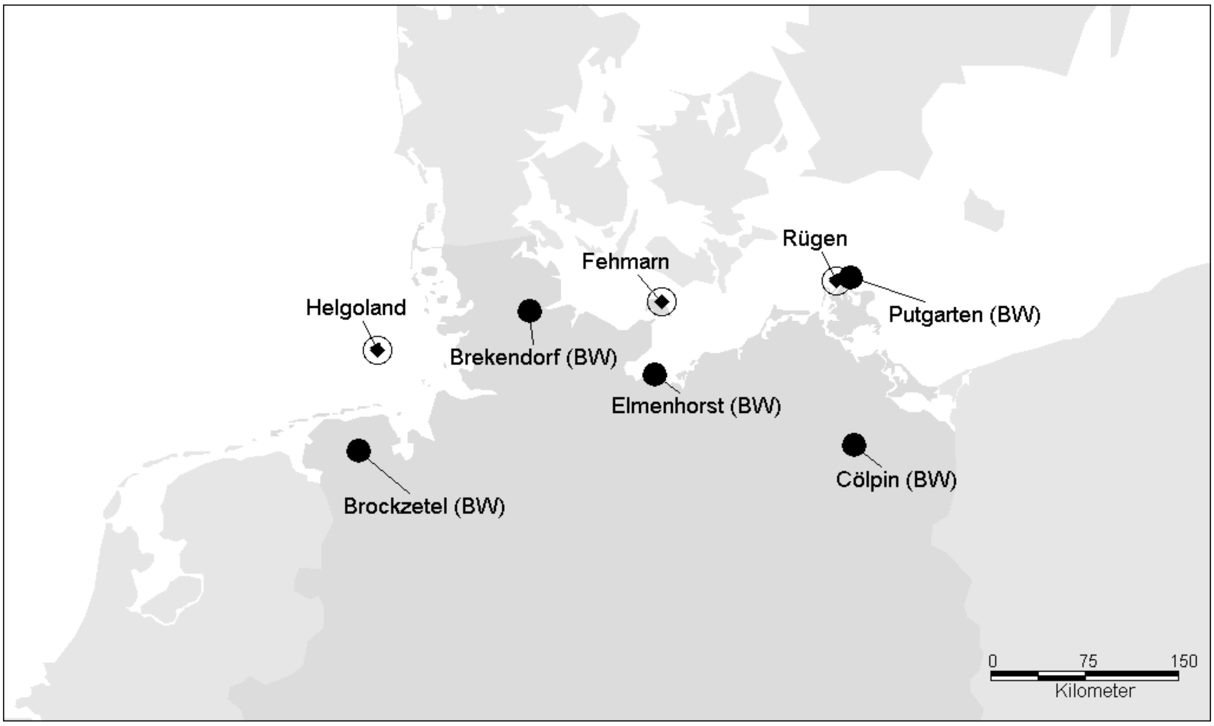


Figure II-14: Localities of large range surveillance radars of the German Army (black dots) and locations of own ship radar measurements (cycled dots).

Table II-11: Recording times of ship radars as well as times of use and peak power of horizontal radar at the various localities. The measurement campaigns are listed chronologically with the result each site is repeated four times (twice in spring and twice in autumn).

site	abbreviation	period	power of horizontal radar
Helgoland	HEL1	12.03. - 15.03.01	-
Fehmarn	FEM1	23.03. - 31.03.01	-
Rügen	RUE1	04.04. - 13.04.01	10 kW
Helgoland	HEL2	18.04. - 03.05.01	10 kW
Fehmarn	FEM2	07.05. - 19.05.01	10 kW
Rügen	RUE2	19.05. - 27.05.01	10 kW
Helgoland	HEL3	07.08. - 23.08.01	10 kW
Fehmarn	FEM3	27.08. - 07.09.01	-
Rügen	RUE3	07.09. - 19.09.01	-
Helgoland	HEL4	24.09. - 05.10.01	-
Fehmarn	FEM4	08.10. - 15.10.01	4 kW
Rügen	RUE4	15.10. - 24.10.01	4 kW

On Helgoland, local electricity could be used so that measurements were carried out continuously. Because of the possible danger for persons, the access to the southwest jetty had to be closed during measurements. On weekends with high frequency of tourists measurements were interrupted from Saturday morning to Sunday evening. On Fehmarn and Rügen the radar and other electrical equipment were powered by a HONDA EU10i power generator, which had to be serviced after every 300 hours of work. Thus it was not possible to carry out continuous measurements. Emphasis was placed on night time, whereby efforts were made to obtain several 24-hour recordings at each locality in order to cover all hours of the day. The duration of recordings for every day as well as the number of analysed digital photographs are shown in figure II-15. The antenna of one radar rotated horizontally (horizontal radar) and the antenna of the other vertically (vertical radar). The horizontal radar recorded the spatial distribution of signals, particularly the direction of bird flight. The vertical radar covered the space above the instrument with an opening of 25° (angle of the beam, see below). A total of 25,120 photos taken by vertical radar (running time: 1,792 hours) and 13,897 by horizontal radar (running time: 1,158 hours) were analysed.

During our first visit to Helgoland and Fehmarn we only had one radar which was used between 24.08.2001 and 11.10.2001. The recording of altitude was given priority over the flight direction so that one radar was always rotating vertically, meaning that during periods of failure, no horizontal measurements were made.

The radar instruments were fixed to the southwest jetty on Helgoland. The instruments could be turned to a vertical position by tilting it. A camping mobile was used to carry the radar on Fehmarn and Rügen as well as to live and work in. At these localities we used a wooden structure to mount the vertical radar and a wooden board on the ground to place the horizontal radar on (Figure II-16).

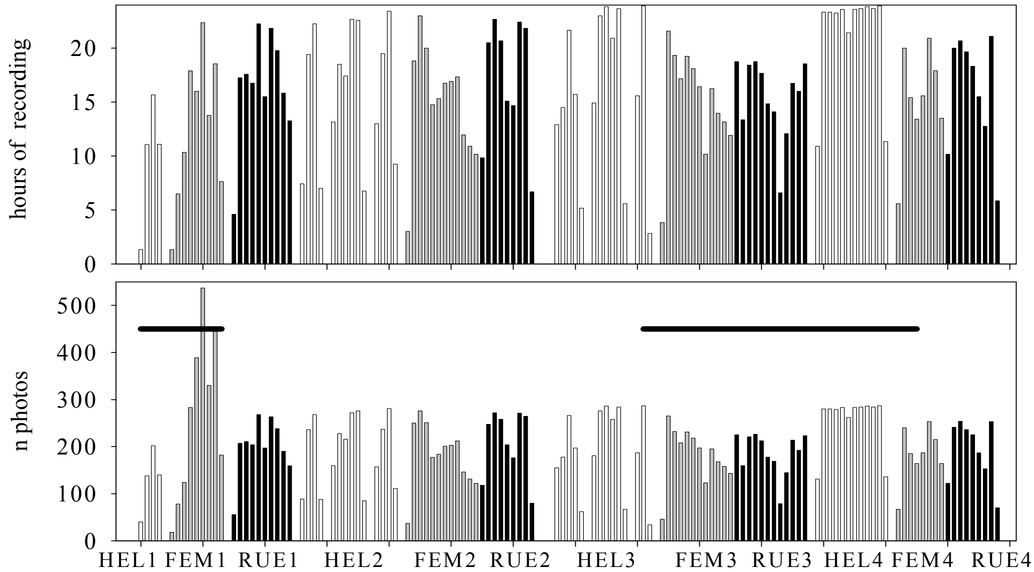


Figure II-15: Hours of recording (upper graph) and number of digital photos (lower graph) for the vertical and horizontal radar on different days. The horizontal bars denote the times during which the horizontal radar was not deployed. Vertical radar: 1.792 hours; 25.120 photos; Horizontal radar: 1,158 hours, 13,897 photos. The various measuring campaigns are shown using the abbreviations in Table II-11 (HEL=Helgoland, open; FEM=Fehmarn, grey columns, RUE=Rügen, black columns)

Both structures were levelled with a bubble level. The radars were generally directed vertically to the coast line in order to cover flying ways of the birds. On Helgoland the direction was adjusted to follow that of the jetty).

Figure II-16: Vertically (right) and horizontally (left) rotating radar at Fehmarn.

We used a Raytheon Radar RL 80C with a 183 cm rotating scanner (open array, horizontally polarized; 24 RPM) and a 10 kW transmitter („peak power output"); a second 10kW- and 4kW-instrument, respectively, was used from 11.10.2001). All radars work within the X-band with a transmission frequency of 9410±30 MHz and a wavelength of 3 cm.
The radars have a vertical beam angle of 25° and a horizontal angle of 1.1° (Range: Table II-12)

Table II-12: Ranges and physical characteristics of the radars (PRF=Pulse Repetition Frequency)

range (nm)	pulse length (µS)	PRF (MHz)	bandwidth MHz	used instruments
0.75	0.15	3000	12	Horizontal radar 4 kW
1.50	0.35	2000	3	Vertical radar 10 kW
3.00	0.45	1600	3	Horizontal radar 10 kW

Ships radars use pulsed beams. Generally a low pulse length is correlated to a high pulse repetition frequency (PRF) similar to the relationship wavelength/frequency in the propagation of light. This results (at a constant width of the radar beams) in a low pulse volume which enable a high resolution and objects are displayed more clearly and there is less probability that several birds are displayed as a single object. Such a high resolution is, however, only possible when the range is low. The technical details concerning „radar ornithological“ applications are provided by Eastwood (1967) and by a more recent review by Bruderer (1997a, b).

It is important to maintain constant and reproducible settings on the instruments in order to facilitate quantitative assessments and comparisons of data. This is particularly important in the vertical radar resulting in a permanent setting of a range of 1.5 nautical miles (1 nm = 1852 m). This setting was a compromise between high resolution and a larger range over the sea. The position of the radar on the radar-screen was placed in the left hand corner in order to obtain maximum distance over water (ca. 2 nm; see Figure II-17).

Quantitative measurements were seldom possible with the horizontal radar because sea clutter covered a large portion of the screen preventing an evaluation in this area. The data therefore only represent random samples. It was therefore justified to change the range of detection from 3nm in the 10 kW-instrument (large range) to 0.75 nm in the 4 kW radar, after it was discovered that the detection of birds with a 3 nm-setting was unsatisfactory. The 4 kW radar delivered excellent results in the 0.75 nm range (the 4 kW instrument became necessary as a replacement for a defect 10 kW radar).

Time is given as UTC (Universal Time Code, equivalent to GMT; the difference to CET is 1 hour, and to CEST, 2 hours). The time was standardized for the daytime hours to account for the changing sunrise and sunset times during the course of the year. The standardized time refers to a 12 h day (light period: 06:01 to 18:00, dark period: 18:01 to 06:00; for methods see Flore & Hüppop 1997).

II-6.1.2 radar settings

It is possible to permanently adjust filters and settings of the radars to the current situation. Such permanent adjustments are desirable in projects limited by time and space. However, problems arise when different localities or recording times need to be compared since the results depend on individual settings and on the type of radar used. Therefore, we chose constant settings, which resulted in optimal comparability of data between varying conditions. Table II-13 provides an overview of the functions and settings used. The adjustment of the gain, which was set at 76 %, is important here. A higher gain resulted in an interference, which hampered the recognition of bird signals. The track-function enabled the separation of current (yellow points) and “old” echoes (blue tracks). The echoes lasted on the screen for 22 seconds (setting: “medium”). A radar is only able to display the signal in two dimensions: the direction and distance of the signal. In the horizontal radar these adjustments enable the calculation of distance and flight direction whereas in the vertical radar the altitude can also be measured.

Table II-13: Settings on the radar instruments

key	command	function	setting
GAIN	GAIN	Enhancement of the echo	76 %
	SEA	Reduction of swell-echos	OFF
	RAIN	Red. of close rain/snow-echos	OFF
	FTC	Red. of distant rain/snow-echos	OFF
TARGETS	STRUNG	Echos from interference	ON
	EXPANSION	Echos of target expansion	OFF
	TARGET TRACK	Echos from wake	medium
MULTI	TUNE	Fine tuning of receiver	AUTO

II-6.1.3 Recording of radar data

II-6.1.3.1 Methods

The recording of radar data was performed by photographing the radar screen at intervals of 5 minutes using a web cam (Philips ToUCam Pro, Resolution: 800x600 Pixel; during the first visit to Fehmarn an interval of 2.5 minutes was used, see Figure II-15). The web cam was run by a notebook using the free software „IrfanView" for image sampling. It was not possible to obtain a continuous record of the screen due to limited disc space.

Photographs with bird signals were analysed using the free image analysis program „ImageTool" and a specially designed protocol (Figure II-17). The bird signals and wave reflections can merge for low flying birds causing problems with identification. All the measurements are based on the screen co-ordinates of the digital photographs. The horizontal water surface served as a reference line for the vertical radar. Two points of this line were clicked with the cursor: the location of the radar (= centre) and the sea surface at a distance of 1 nm. The signals were then subsequently marked by clicking on the blue part of the signals (old, after glowing signal) and then the actual yellow signal. If a signal was displayed as a clear line, but did not contain a yellow spot, it was also registered as being a bird signal, however, twice on the same spot since there was no directional information available. Signals with only one point but no target track (birds flying perpendicularly to the radar beam) were treated similarly. The programme transfers the coordinates of each measured point to a data file.

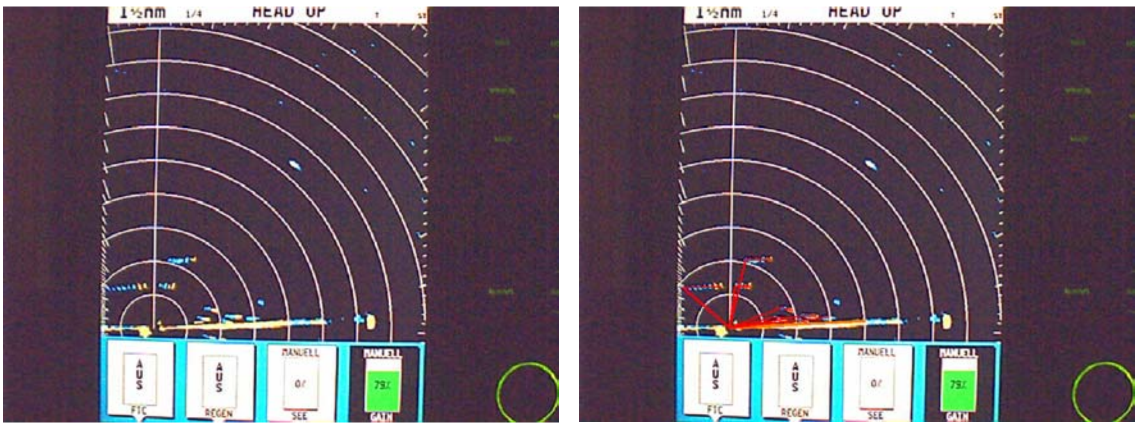


Figure II-17: Example of the analysis of a radar photograph. Left: Original photo of a screen showing bird signals on the vertical radar flying from the left to the right. Right: Analysed signals.

A frequency of 1 photo every 5 minutes results in 1) that every signal of following photographs is from different birds or flocks and 2) that not every bird / flock is recorded („missed" signals between photographs). Half hourly video sequences with an interval of 10 seconds between images, were taken to estimate the number of „missed" signals between photographs. These signals were counted and compared with those obtained at 5 min intervals. The video recordings had an average of 5.5 ± 1.1 times (Mean ± sd, n = 34 Video sequences) more signals than the single photos, whereby the numbers of both methods showed a highly significant correlation (linear regression: Number of signals on photos as function of the number of video images: $y=0.185x+0.644$; $p<0.001$, $R^2= 0.963$). This clearly shows that the photographs taken permanently at 5 min intervals give a very representative description of the actual flight activity.

II-6.1.3.2 Calculated parameters from raw data

The screen co-ordinates were used to calculate the following parameters using the statistic programme SPSS (Janssen & Laatz 1999):

Vertical radar:

- *Altitude*: Height of the signal above sea level
- *Distance from radar*: direct distance of signal from the radar
- *Distance to land*: Distance of the radar from the vertical projection of the signal onto the sea surface
- *Length and direction of „tracks"* enables a *rough estimate of the direction of bird movement*, the flight angle relative to the position of the radar. A track is only produced if the distance of the bird from the radar changes. A bird which does not change its distance from the radar (crossing the beam vertically) does not cause a track, but only a yellow point.
- *Inclination of the track*: This value indicates whether a bird is increasing or decreasing its altitude. It was only calculated when the track length had at least 10 pixels as otherwise inaccuracy is too high; this represented an actual flight distance of between 80 and 160 m.
- *Migratory intensity*: All the photographs of the vertical radar were used to calculate the migratory intensity, including those without any bird signals (= no migration). The intensity is represented by the number of echos per photo and was calculated on an hourly and daily basis (mean number of echos per photo and day; seasonal migratory intensity).

Horizontal radar:

- *Flight direction*: Flight direction was determined for every signal, which had a target track and a yellow dot. The flight direction was determined by the individual flight direction and the influence of the wind vector (see Liechti 1993). For the determination of the mean flight direction only those signals were considered which could be attributed to migration activity. For the spring migration the direction was 45±90° (NE), and for the autumn migration it was 225±90° (SW). All other directions, which were possibly attributed to foraging flights or reverse migration, were not included in the calculation.
- *Flight speed*: The speed of movement is derived from the length of the target track (flight distance) and the time required. This calculation, however, is only useful when the complete target track is visible on the screen (in other words when the traversed distance is known). A systematic determination of the migration speed from the radar photos was not possible because it was not always possible to decide whether target tracks were complete. The individual signals merge when birds fly slow and they cannot be separated. Further, the tracks are often very short near the limits of recognition since the tracks only appeared briefly on the radar screen. It was not possible to determine the speed while the radar was running due limited manpower. Also, this would have biased the data because of subjective selection of signals. We therefore refrain from providing actual speeds and only show *relative speeds as length of target track in m*. Here, we have the same problems as above. However, the error in the various campaigns is the same so that data are compara-

ble. Thus within this project data from different localities as well as between night and day are comparable.
- *Distance from radar*: Direct distance between radar position and signal.
- *Direction of signal:* Determination of the spatial distribution relative to the radar.

The radar data do not provide any information on the following:

- *Number of birds*: It is not possible to differentiate between individual birds or flocks. A large signal can be the result of a single large bird or a flock of small birds.
- *Species spectrum*: It is not possible to identify the species of bird. Only the flight speed may provide an indication of the bird. However, the speed can be similar between species and depends strongly on the wind conditions (see chapter II-8.2.1.2, and e.g. Bruderer & Boldt 2001)

II-6.1.4 Detectability of birds: distance correction

The detectability of a bird depends on many factors of which the most important are mentioned below (for more information see Eastwood 1967 and Bruderer 1997a, b).

- *Flight altitude*: The detectability of birds flying low is only partially possible with the vertical radar, since the signals merge with the reflection from the sea surface and thus make differentiation impossible (s. Figure II-17). In the radar used and with a distance setting of 1.5 nm this was the case within a height interval of 0 to 50 m. The maximum altitude detectable with the radar used depended on factors described below - we recorded signals up to an altitude of 3,795 m. The number of actually observed echos in the lower height category of 0 to 100 m is therefore higher than shown in the figure. An arrow in the lowest height category indicates this underestimation of low flying birds.

- *Size of the birds*: Under constant conditions (distance, angle) the detectability and signal strength increases with an increase in bird size (with increasing radar cross section, see Eastwood 1967). However, it is difficult to differentiate between large single birds and flocks of smaller birds.

- *Angle of the radar beam*: Different angles can result in different reflections of identical birds on the radar screen. The strongest signal is obtained in lateral view, whereas front and hind view result in 20 times smaller signal (Bruderer 1997a). To account for this effect, it is important to know the flight direction and thus have information on the angle.

- *Distance of bird from radar*: The used radar scanners have a nominal beam angle of 1.15° x 25°. Thus the volume detected by the beam increases with distance. On the other hand the energy of the emitted beam decreases by the factor $4\pi R^2$ (R = distance). The equivalent loss of energy takes place with the beam reflected by the bird. This twofold reduction leads to the so-called „4^{th} power law", which states that the energy decreases by the power of 4 between radar and bird (see Eastwood 1967 for the radar formula). Close up reception is further reduced because of the following reason: (1.) The energy is too high - the antenna reduces the reception for reasons of self-protection, and (2.) The antenna is both transmitter and receiver, which means that the minimum time is dependant on the time it takes to switch from transmitter to receiver. These restrictions result in a distance-dependant detectability which initially increases with distance, then attains an optimal range of detection and thereafter decreases again with increasing distance. If the sum of the vertical radar echos is plotted in a 100 m by 100 m matrix (Figure II-18), the highest sensitivity becomes apparent between 500 and 1200 m.

In order to justify the distance–dependant sensitivity in quantitative statements (e.g. altitude distribution) it is necessary to correct appropriately by the number of recorded echos. We chose not to calibrate the radar experimentally for example using a model plane. Instead we used an empirical approach based on the assumptions confirmed by direct observations, which showed that (1.) there was no land/sea gradient in density of birds on Helgoland and (2.) the flight directions within the distance covered by the radar was evenly distributed. A correction for the detectability in the altitude range between 50 and 150 m was carried out after Buckland et al. (2001) using the program „Distance 3.5“ (http://www.ruwpa.st-and.ac.uk/ distance/index.html). The altitude range of 50 – 150 m was chosen since (1.) it is the range of high bird density and (2.) the angle of detection is almost equal to the horizontal. Thus errors due to the different radar cross sections of the birds resulting from the dependence on the azimuth can be minimized (e.g. Figure 3.3 in Eastwood 1967).

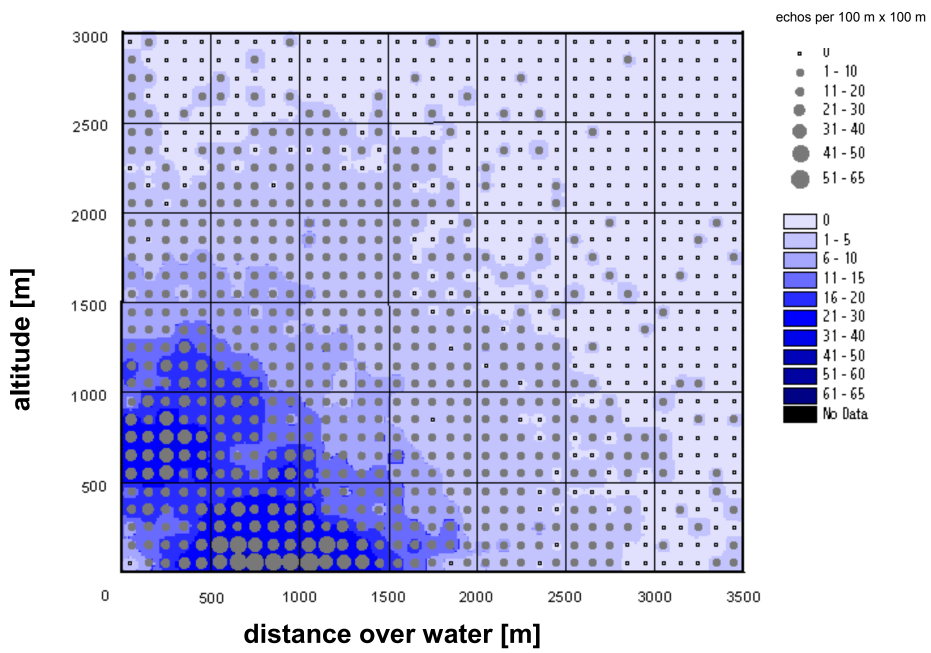


Figure II-18: Totals of the echos recorded with the vertical radar per 100 m x 100 m field from the Helgoland SW-jetty. This demonstrates the distance dependant detection probability (measuring campaign Helgoland 2 to 4, compare Table II-11)

A Half Normal model with Cosine series expansion (Buckland et al. 2001) was used with three estimated parameters (a_{1-3}), which was determined using the Akaike Information Criterion:

$$y = e^{(-x^2/2\, a_1^{\,2})} \cdot (1 + \sum_{j=2}^{3} a_j \cdot \cos \frac{j \pi x}{w})$$

with (± Standard error):
X = Distance from radar [m]
Y = Detection Probability
a_1 = 956.0 ± 41.13 SE
a_2 = - 0.6995 ± 0.0681 SE
a_3 = - 0.1048 ± 0.0711 SE
w = 2500 m

The results of the model are shown in figure II-19. The sum of the echos was correspondingly corrected for distance dependence.

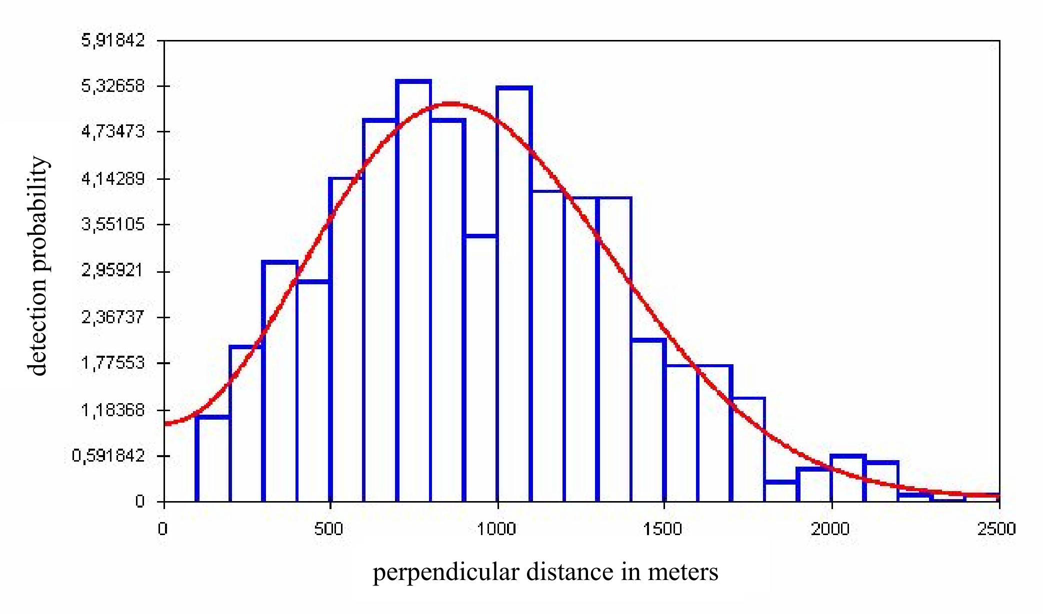


Figure II-19: Detection probability of a bird in dependence of the distance over the sea. All echos from the measuring campaign Helgoland 2 to 4 (compare Table II-11) for altitudes between 50 and 150 m above sea level. Original-Output of the Programme « Distance 3.5 »

II-6.1.5 Visual verification of radar signals

Radar signals could be attributed to actual bird movement by observations carried out simultaneously to the radar recordings. It was checked whether visually observed birds were recorded on the radar as a signal. Birds not recorded on the radar were usually flying low or a long distance away (Figure II-20). Approximately 40% of the birds flying below 50 meters (22 of 55) were not detected within the detectable radar range of 150 to 1800 m, whereas only 8% (4 of 53) of the birds flying above 50 m were not recognized. Thus the number of signals in the lower altitude category is larger than determined with the radar (bird signals merge with the reflection of the waves, see chapter II-6.1.3 and Figure II-17). The shown percentage values can only be an approximation since a distance correction would also be required to determine the exact numbers also in visual observations (see chapter II-6.1.4). However, this is not possible due to the low number of random samples and an uneven distribution of signals with distance from the coastline. We therefore stick to the statement that for all the presented altitude distribution values in this report the values of the lowest altitude category (0 to 100m) are always underestimates (see arrow).

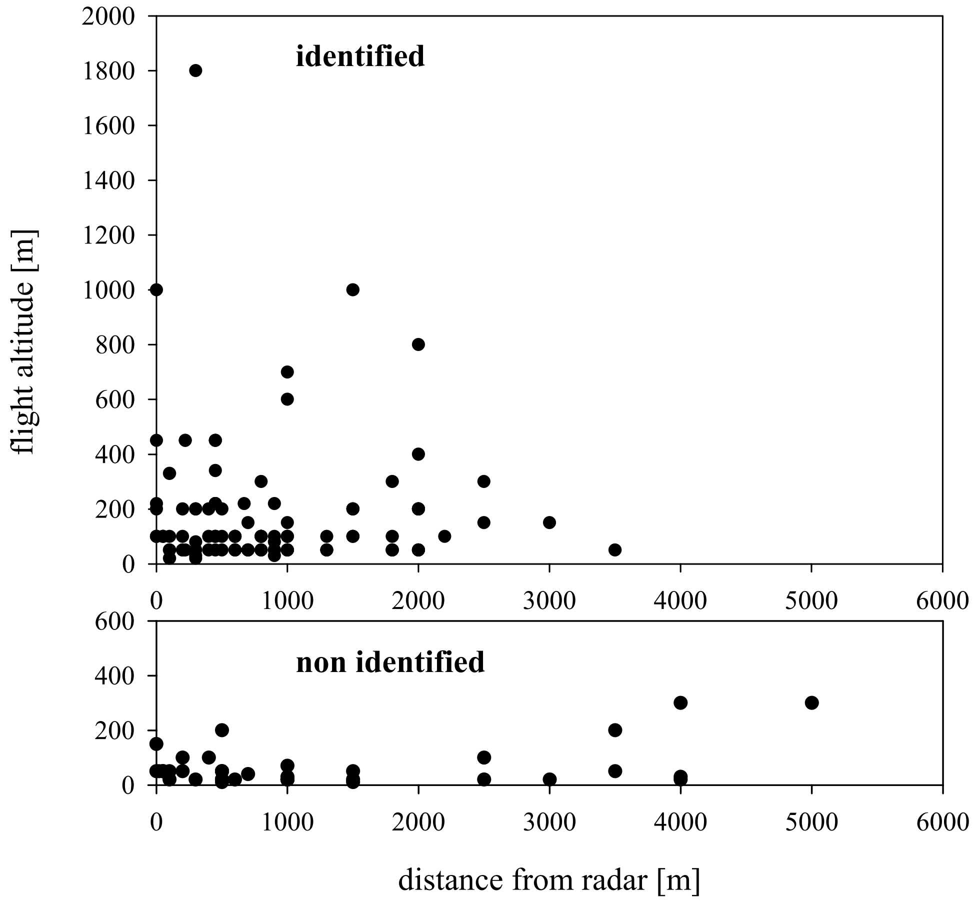


Figure II-20: **Recognition of bird signals as a function of altitude and distance from radar (measured over sea surface). The birds were identified visually and the appearance checked on the radar screen. Top: birds identified (n = 128); bottom: birds not identified (n = 44)**

II-6.2 Military radar

II-6.2.1 Locations and radar device

Data obtained from 5 large range radars belonging to the German Army were used for this report (Figure II-11). These were located in North Germany at Brockzetel (53° 28.1' N, 07° 40.0' E), Brekendorf (54° 26.5' N, 09° 39.7' E), Elmenhorst (54° 00.1' N, 11° 06. E), Putgarten (54° 40.5' N, 13° 23.3' E) und Cölpin (53° 30.6' N, 13° 26.1' E). The different aged instruments record in the 10 cm wave band (S-Band) and record echos of objects up to more than 180 km away. No further technical details are available due to military secrecy. A basic description, however, is provided by Jellmann (1977). In contrast to Jellmann we were not able to keep the filter and amplifier settings constant so that quantitative recordings as for example obtained by Buurma (1995) were not possible.

II-6.2.2 Time frame and data volume

The data analysed in this study were for the main migratory months March to May and August to October of the year 2001. After removing duplicate data (see below) 32 million data points from spring and 24 million data points from autumn remained. The amplifier and filter data were not provided due to military secrecy.

II-6.2.3 Method of data analysis

The Amt für Wehrgeophysik supplied all the data as binary coded raw data on CD-ROMs. The data were filtered, i.e. aeroplane echos were removed but the geographic coordinates, altitude, time (UTC) for every registered echo were retained. The coded data were decoded with a specially developed programme (Virtual Pascal 2.1) and converted to ASCII. Some parameters were recalculated and repetitive values, which were obviously reflections from fixed points, eliminated. The ASCII data consisted of the following variables: longitude, latitude, year, julian day, UTC, altitude, distance and angle to radar station.

II-6.2.4 Conversion of data to maps

Since the filter data and amplifier settings were not available, much of the envisioned analysis was not possible. As with the ship radar the likelihood of observing a bird or flock is distance dependant, too (chapter II-6.1.4). However, the amplification or muting can be altered for different circumferences around the station. Thus the spatial comparison between echo densities becomes impossible. The initial intention of computing adaptive functions was therefore not possible despite a time consuming procedure and large computing effort. Hence, we had to modify the procedure of data analyses.

To determine the *spatial distribution of migratory intensity* we used the distance-dependant probability of discovery. Although this may change due to modification of the instrument settings, the relative number of echos in a constant distance around the station remains comparable. We therefore placed transects in a GIS as sections through the outermost rings of the stations Brockzetel, Elmenhorst, Putgarten and Cölpin in which the probability of discovery changes minimally. This allows the selection of quantitative north-south and west-east profiles. According to the justified assumption that a general migratory route exists from northeast to southwest (opposite in spring) and an additional west-east component near Fehmarn and the Polish coast, this analysis delivers almost the same results on spatial migration as do maps. After all for the first time it was possible to obtain a large-scale areal quantification of bird migration over the German Bight and the western Baltic.

In order to determine the *direction of migration* and the *local hot spots* of bird movement, we chose a visualization of the tracks. This was done by using special scripts to plot the echos chronologically (partly funded by the BfN project „BIMOS“) using the statistics and graphic software „R“ (http://cran.r-project.org) as „animated“ charts. This visual analysis is, however, subjective.

II-6.3 Weather data

The flight altitude in a particular situation strongly depends on local weather conditions. The large-scale weather is also of importance with regard to the migratory intensity. Since we did not have the opportunity to obtain comprehensive large-scale weather analyses within this project, we concentrated on the effects of weather on the locally measured flight altitude and treated the influence on flight intensity exemplary and descriptively.

Weather data were obtained from Germany's National Meteorological Service. The single weather parameters are often correlated (Table II-14). E.g. visibility is often low at low cloud altitude and high cloud cover. Cloud altitude and cover are negatively correlated, which results in the fact that a high cloud cover is correlated with low-lying clouds. Air pressure (particularly changing pressure) may be regarded as indicator and integrating parameter of „good“ and „bad“ weather: Visibility was high during high pressure, high clouds and low cloud cover, high temperatures as well as low likelihood of precipitation. During precipitation, cloud cover is high and clouds lie low.

Table II-14: Correlation of different climate parameters (r = Pearson correlation coefficient, p = Probability, n = number of hours). Data: Germany's National Meteorological Service

		visibility	cloud altitude	cloud cover	air pressure	temperature
cloud altitude	r	0.128				
	p	**0.000**				
	n	2,126				
cloud cover	r	-0.335	-0.550			
cloud cover	p	**0.000**	**0.000**			
	n	2,126	2,126			
air pressure	r	0.225	0.311	-0.395		
	p	**0.000**	**0.000**	**0.000**		
	n	2,129	2,126	2,126		
temperature	r	-0.033	0.090	-0.008	0.075	
	p	0.126	**0.000**	0.728	**0.001**	
	n	2,129	2,126	2,126	2,129	
precipitation	r	-0.082	-0.232	0.242	-0.344	0.062
	p	0.116	**0.000**	**0.000**	**0.000**	0.232
	n	369	369	369	369	369

The following climate elements were applied:

a) To compute the effect of the Tail Wind Component (TWC, tail wind / head wind) on flight altitude/migratory intensity: wind direction (°), wind speed (m s^{-1})

b) For the comparison of flight altitude and migratory intensity between following groups:
   - „Hours without precipitation“ / „Precipitation in the hour before“
   - „Air pressure low “ (below 1004.3 hpa); „Air pressure medium“ (between 1004.3 and 1015.4 hpa); „Air pressure high“ (over 1015.4 hpa); Group divisions: Equal distribution of air pressure during periods of observation (comparison only of flight altitude)

c) Effect on flight altitude: Cloud altitude (m), Cloud cover (%)

d) Effect on migratory intensity: Temperature (°C), wind speed (m s^{-1}), wind direction (°), precipitation (mm)

As presented in chapters II-4 and II-5 the TWC was calculated after Fransson (1998). Relationships between flight altitude and TWC as well as flight intensity were of particular interest. These data are derived from the vertical radar. However, since no migratory direction was detectable on the vertical radar (essential for the computation of the TWC), the TWC was determined from the horizontal radar, which was operated concurrently, and applied to the vertical data. A TWC was computed for every signal of the horizontal radar with the exact migration direction and subsequently averaged for the corresponding hourly interval. Only those values were included, which corresponded to the seasonally appropriate direction of migration (spring NE ± 90°; autumn, SW ± 90°). These mean TWC values, determined from the horizontal data, were then applied to the vertical data obtained simultaneously, whereby only the data from the lower 400 to 500 m were used. This was made in order to avoid possible effects of differing wind speeds and directions at greater heights.

II-7 Flight altitudes

II-7.1 Introduction

In order to determine the potential hazard of offshore wind energy plants for resting and migratory birds, it is essential to know the flight altitude of birds. As shown in chapter II-3 most of our knowledge on flight altitude in birds is derived from recordings on land and in coastal areas. There is very little information for offshore areas. While a rough estimate of flight altitude is possible by visual observations (chapters II-4 and II-5), the use of radars provide more concrete measurements of flying birds, particularly at night. This is of great importance since many bird species migrate at night (e.g. Berthold 2000) and the potential of collisions with wind turbines is considered to be very high (chapter II-3). The dependence of flight altitude on weather conditions is an additional factor in the assessment of collision risks.

II-7.2 Results

II-7.2.1 Altitude distribution

All references to flight altitude are based on data which were corrected for distance (see chapter II-6.1.4). The data are therefore restricted to a height of up to 1800 m. Table II-15 shows all the echos above 1800, based on data not corrected for distance: they contribute about 3.1 % of all echos and range from 1.3 (Rügen in spring) and 5.1 % (Helgoland in spring). The maximum recorded altitude was 3795 m.

Table II-15: Altitude distribution of echos (%) according to season and location in different altitude groups (corrected for distance, up to 1800m) incl. maximum altitude and proportion of echos above 1800m (without correction for distance)

	with distance correction				without distance correction		
	% echos			n	% echos	max.	n
	below 200m	201 to 400m	401 to 1800m	echos, corrected	above 1800m	flight altitude (all data)	echos, not corr.
total	26.5	13.7	59.8	45,857	3.1	3795	32,218
spring, total	28.6	15.4	56.0	29,886	2.6	3795	21,051
autumn, total	23.3	10.9	67.7	15,970	4.0	3733	11,167
Helgoland, total	19.6	13.3	67.1	8,666	4.7	3733	6,176
Fehmarn, total	28.3	14.5	57.2	24,320	2.7	3795	17,161
Rügen, total	27.9	12.2	59.9	12,871	2.7	3532	8,881
Helgoland/spring	16.7	11.6	71.7	5,576	5.1	3104	4,009
Helgoland/autumn	22.9	15.1	62.0	3,090	3.9	3733	2,167
Fehmarn/spring	32.4	17.4	50.2	18,390	2.2	3795	13,070
Fehmarn/autumn	17.0	7.0	76.0	5,930	4.1	2780	4,091
Rügen/spring	28.8	13.1	58.1	5,920	1.3	2830	3,972
Rügen/autumn	27.1	11.4	61.5	6,951	3.9	3532	4,909

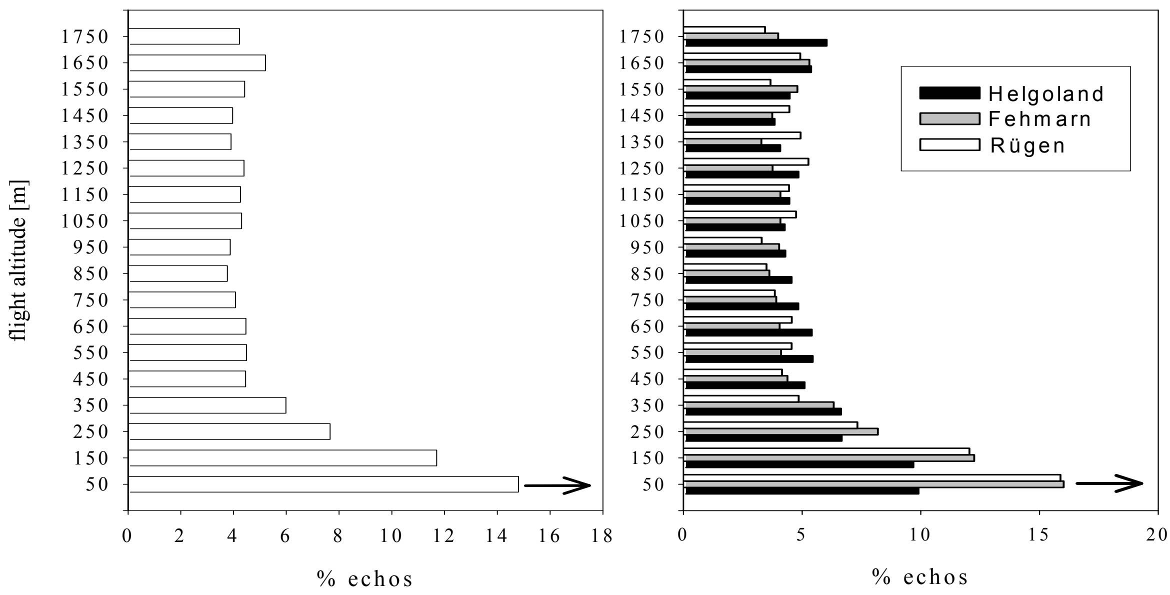


Figure II-21: Flight altitudes (% echos) in 100 m intervals (interval media). Left: All locations together; Right: Single locations. The sample size is shown in Table II-15. The arrows denote an underestimation of the lowest altitude class (see chapter II-6.1.5)

The overall distribution of altitudes is shown in figure II-21. Most echos were recorded in the lowest 200 m (total of 26.5 %, Table II-15). The subsequent 200 m had 13.7 % echos and der remainder (59.8 %) were located between 400 and 1800 m.

A comparison of the locations (Figure II-21) showed that Helgoland had the lowest number of low flying birds (19.6 % below 200 m compared to 28.3 % on Fehmarn and 27.9 % on Rügen, Table II-15). A comparison of the spring and autumn migration shows that there are relatively more signals in the lower altitudes during spring (28.6 %, Table II-15 and Figure II-22), whereas the higher altitudes are preferred during autumn (67.7 % compared to 56.0 % in spring).

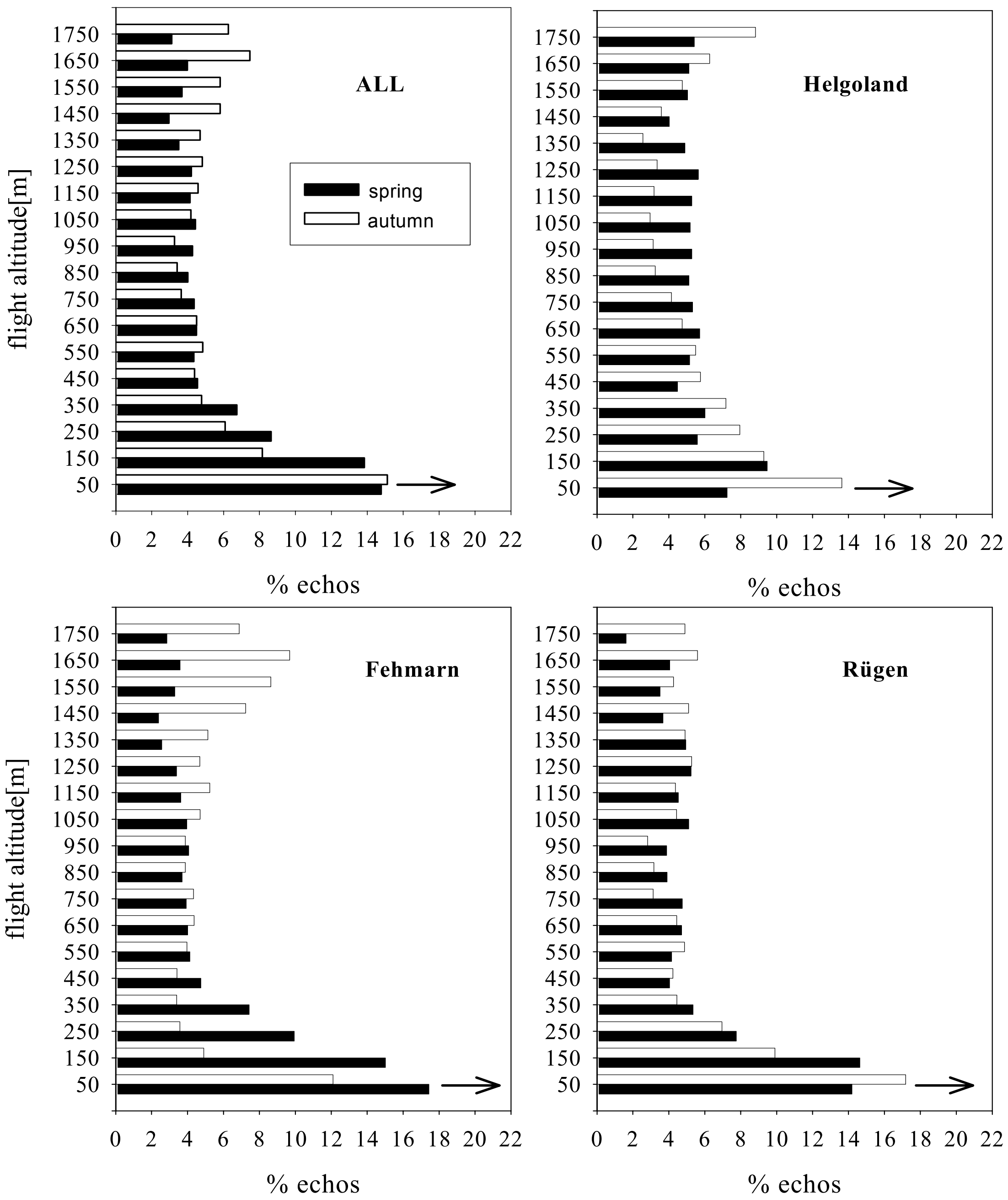


Figure II-22: Flight altitudes (% echos during spring and autumn for all locations together (top left) and for the three locations seperately: Helgoland (top right), Fehmarn (bottom left) and Rügen (bottom right; shown are interval middles; n see Table II-15). The arrows denote an underestimation of the lowest altitude class (see chapter II-6.1.5)

Namely during spring there was a low concentration of echos below 200 m on Helgoland (16.7 % of all signals; figure II-22). On Fehmarn the spring migration took place in lower altitude levels (below 200 m: 32.4 %) than in autumn (below 200 m: 17.0 %). In autumn it was conspicuous that a high proportion of echos occurred in higher altitudes (76.0 %) and few in the middle layer of 200 to 400 m (7.0 %). On Rügen there were no obvious differences between the spring and autumn migration. The proportion of low flying birds was high during both periods (below 200 m: in spring 28.8 %, in autumn 27.1 %).

II-7.2.2 The diurnal course of migration

The flight altitude showed clear diurnal variations (Figure II-23; standardized time). It was lowest during the afternoon hours, increased steeply after sunset and reached the highest levels 2 hours after sunset. After that the altitude began to decrease and remained low in the second half of the night. During the hour after sunrise, a second peak is attained and thereafter it decreases continuously until the early afternoon. However, every hour is characterized by a high variability.

The altitude distribution of day/night echos corresponds to the diurnal pattern (Figure II-24). During the day the proportion of echos in the lower 200 m was very high (37.7 % of all echos; night: 23.0 %), whereas concerning the total data set, the number of echos in higher altitudes were always higher than during the day. On Helgoland, however, there were relatively few night signals in the lowest 200 m (15.7 %), whereas on Fehmarn and Rügen the proportion of lower night signals was higher (Fehmarn: 24.8 %; Rügen: 24.9 %), but always clearly lower than the daytime values (Fehmarn: 38.4 %; Rügen: 35.5 %).

Since the data are presented as percentage distribution it is important to consider the diurnal migratory intensity when interpreting the data (chapter II-9.2.1.2). They show that the main migration takes place at night.

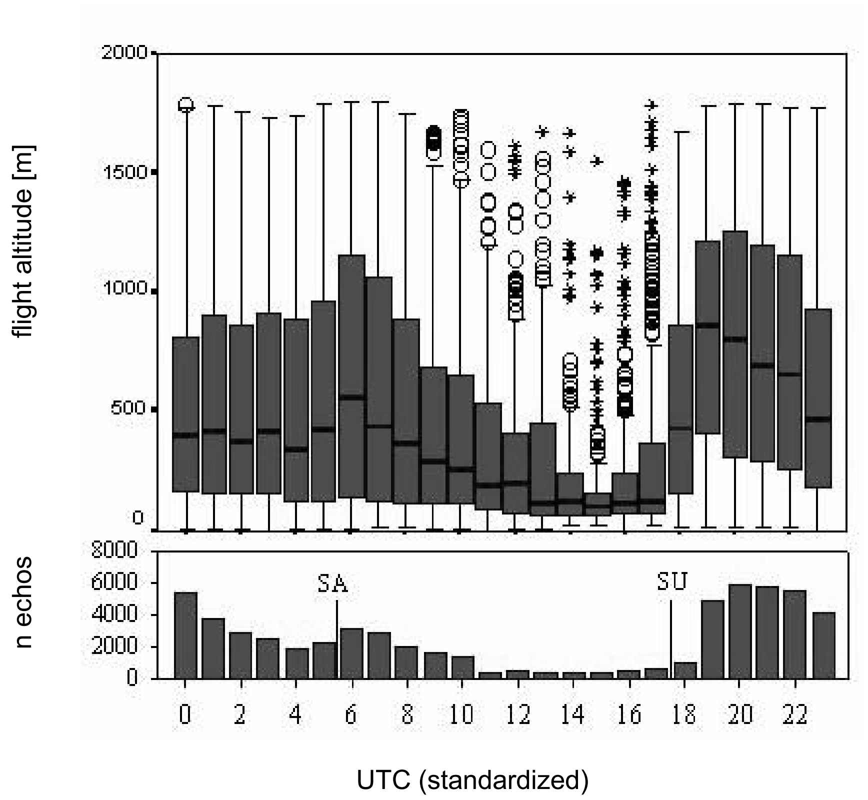


Figure II-23: Flight altitude as a function of time (UTC, standardized). Box plots show: bar=median, box=25/75% percentile, circles=outliers (1,5 to 3 times distance from top box end), stars=extreme values (more than 3 times distance from top box end), whiskers = maximum values (without extremes or outliers). N per hour is shown underneath the figure. The time shown corresponds to following time slots: Example 8 =8:00-8:59 hrs 9=9:00-9:59. SA = sunrise; SU = sunset

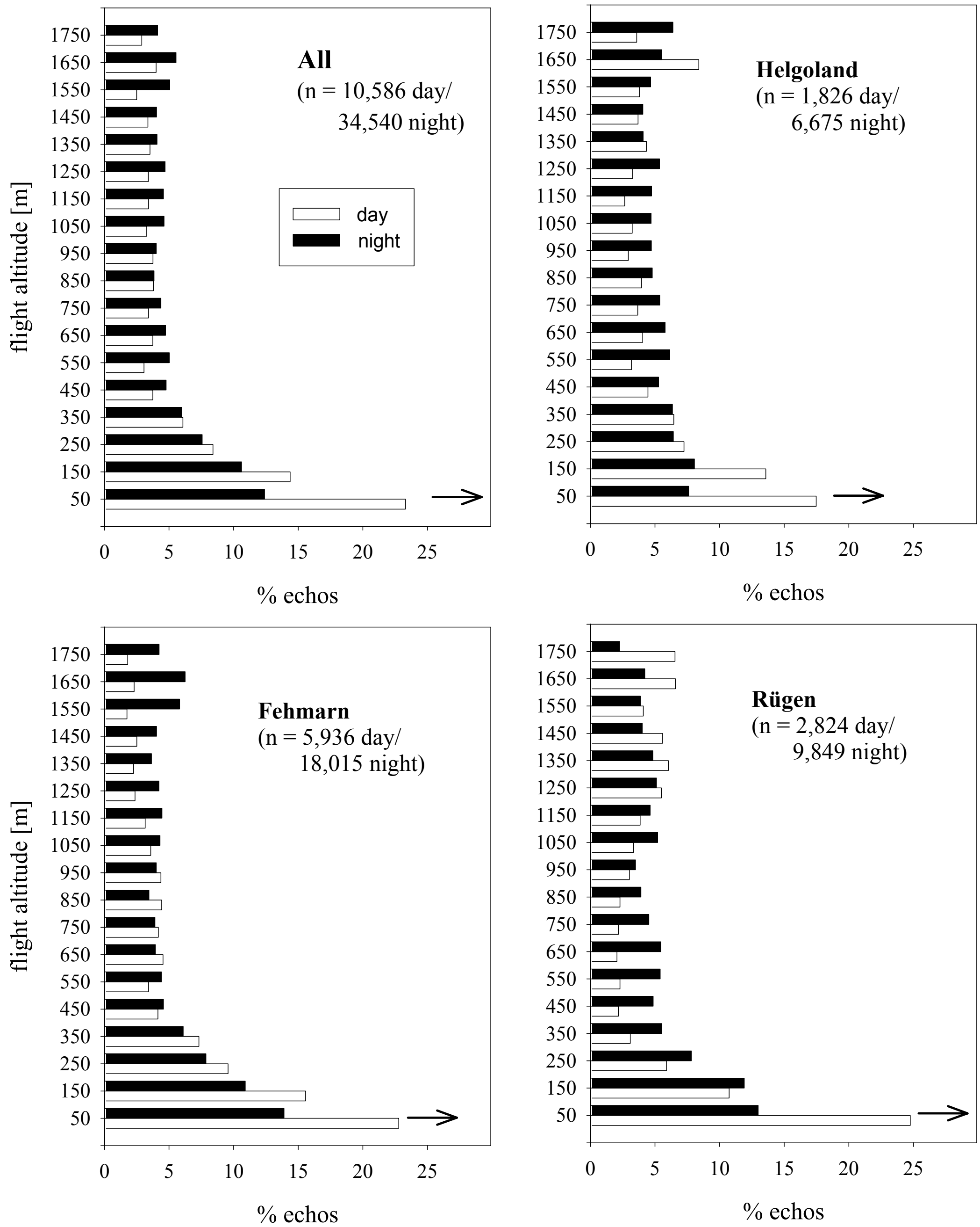


Figure II-24: Flight altitudes (% echos) during day and night of all data (top left), Helgoland (top right), Fehmarn (bottom left) and Rügen (bottom right). The arrows denote an underestimation in the lowest altitude class (see chapter II-6.1.5).

II-7.2.3 Influence of weather

The influence of precipitation on flight altitude becomes clear when the diurnal course of flight altitude in dry weather is compared with that during precipitation (Figure II-25a). Whereas no differences are apparent during the day, the increase in flight altitude after sunset is markedly less expressed when it rains than in dry weather. When it rains, the birds fly at much lower altitudes during the entire night than when it does not rain.

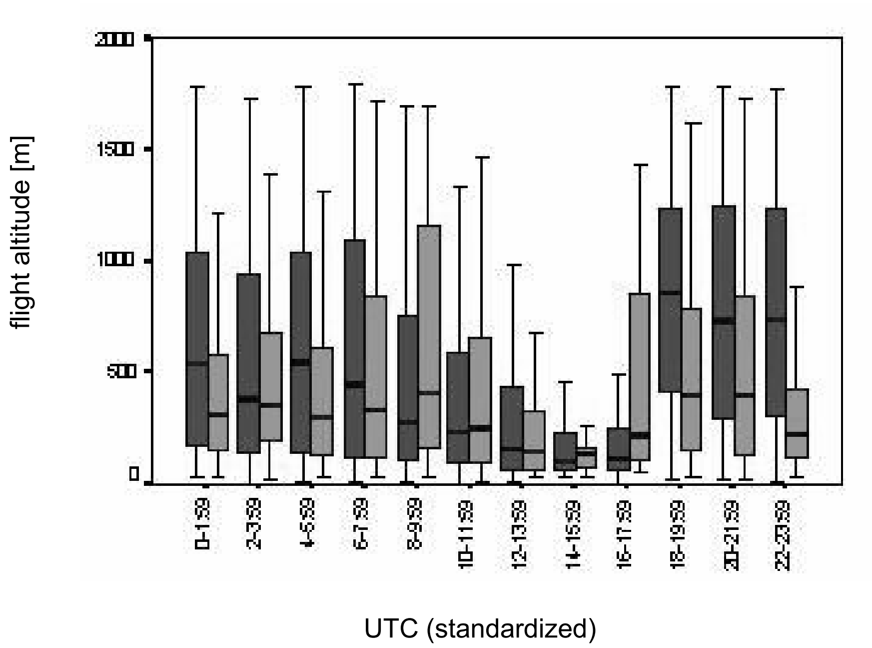


Figure II-25a: **Flight altitudes during dry weather (dark boxes) and rain (rain an hour before, grey boxes) as a function of daytime (standardized time, sunrise=6:00, sunset=18:00). Box plots show: bar=median, box=25/75 % percentile, whiskers=maximum values (without extreme values and outliers). N (dry/rain): 00:00-01:59 hours (4248/2909), 02:00-03:59 hours (3441/626), 04:00-05:59 hours (2058/330), 06:00-07:59 hours (2508/420), 08:00-09:59 hours (2438/301), 10:00-11:59 hours (795/343), 12:00-13:59 hours (651/26), 14:00-15:59 hours (483/57), 16:00-17:59 hours (576/123), 18:00-19:59 hours (3517/446), 20:00-21:59 hours (7512/424), 22:00-23:59 hours (6039/1459)**

The distribution of flight altitude immediately before and after a strong rain shower demonstrates clearly the direct effect of rain on the flight behaviour of migrating birds. On 30.03.2001 there was strong migration (see chapter II-9)and strong showers occurred in the hour from 22:00 to 23:00 (Sunset 17:07). The comparison before and after the shower shows that the altitude distribution shifted to the lower altitude level (Figure II-25b) and the proportion of birds flying below 200 m doubled from 9.2 % to 18.5 %.

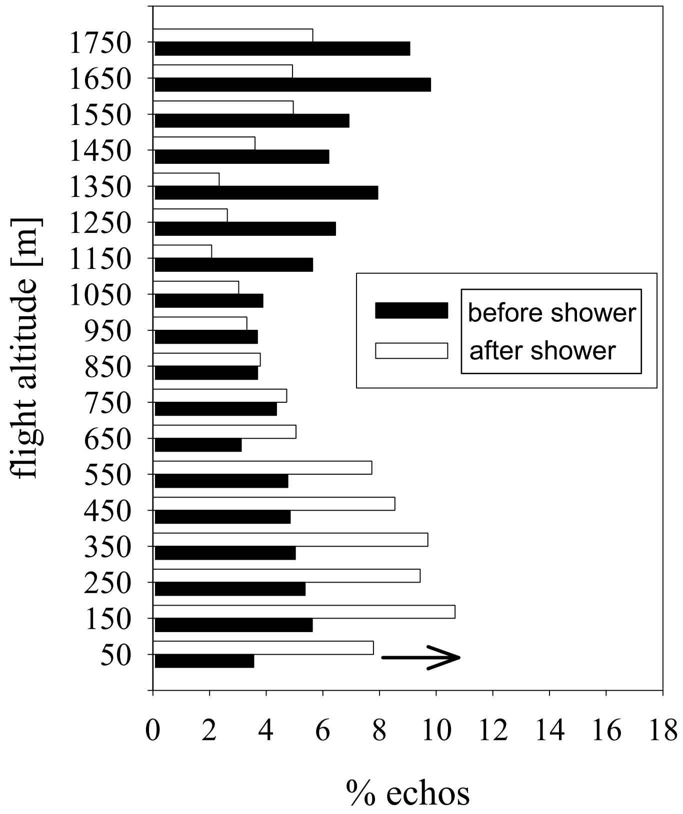


Figure II-25b: Flight altitude (% echos) before and after a 1 hour rain shower (n before rain=473, n after rain=1067; the middle of 100 m ntervals are shown). The arrow indicates an underestimation of the lowest altitude class (see chapter II-6.1.5)

Air pressure was another parameter investigated. For this purpose the entire range of air pressures was divided into 3 equally distributed groups: low, middle, high (see figure II-26 top). The bottom part of figure II-26 shows the flight altitude as a function of air pressure. It shows that lower altitudes are preferred during low pressure, particularly in the 4 hours before midnight. Under high pressure the flight altitude starts to decrease later. During the morning hours (4:00 to 8:00; dawn at about 5:00; sunrise: 6:00) this relationship is the opposite. Here there is a tendency for the birds to fly at higher altitudes.

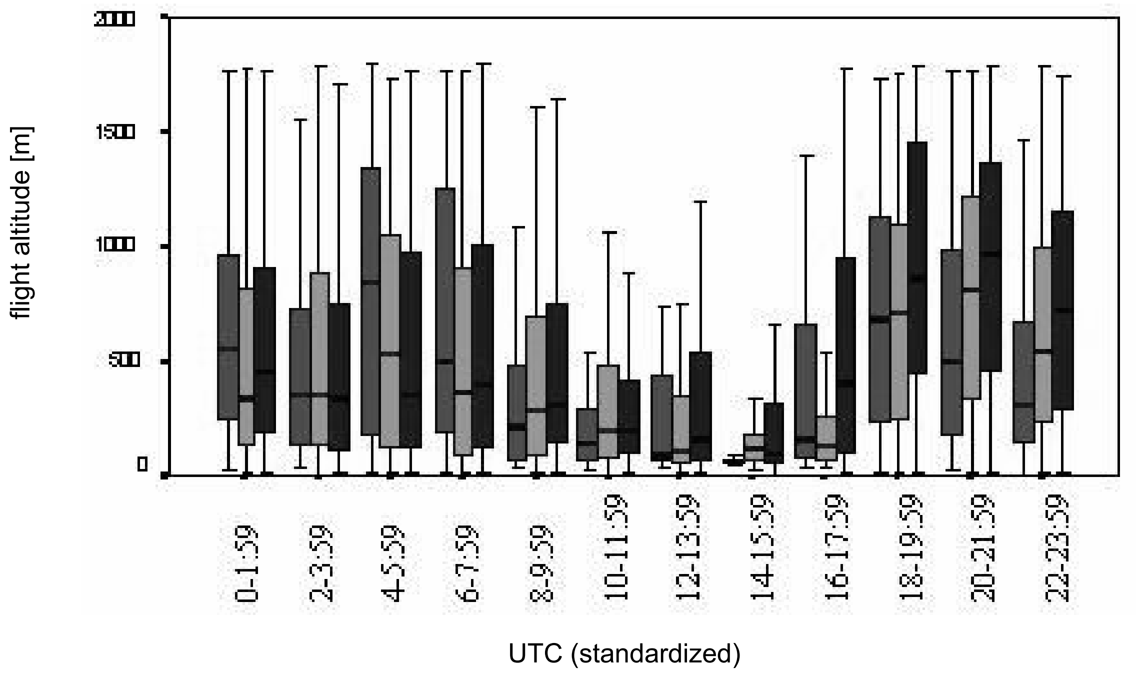


Figure II-26: **Diurnal flight altitude as a function of air pressure (within the individual time slots from left to right: „low“ - dark boxes, „middle“ - grey boxes, „high“ - light grey boxes) (standardized time, sunrise=6:00, sunset=18:00). Box plots show: bar = median, box=25/75 % percentile, whiskers = maximum values (without extremes and outliers). n (low/middle/high): 00:00-01:59 (562/4596/3517), 02:00-03:59 (253/2868/1309), 04:00-05:59 (579/2628/1763), 06:00-07:59 (462/1616/2564), 08:00-09:59 (200/1034/1877), 10:00-11:59 (61/518/558), 12:00-13:59 (34/430/246), 14:00-15:59 (41/481/165), 16:00-17:59 (195/704/465), 18:00-19:59 (1029/2677/2118), 20:00-21:59 (3555/5942/4201), 22:00-23:59 (3114/4117/3321).**

For the presentation of flight altitudes as a function of wind direction/wind speed (both combined in the Tail-Wind-Component, TWC) we used only the distribution of echos in the lowest 400 m since (1.) weather data from the lower near ground levels were used (wind speed and direction may vary with altitude) and (2.) the direction of migration used to compute the TWC is based on the horizontal radar which only registers low flying birds (radar opening angle above ground level is 12.5 °, i.e. birds are recorded up to an altitude of 400 m when flying at a distance of 1 nm. During head wind there were more echos in the bottom 100 m than during tail wind (Figure II-27; 44.6 % compared to 34.3 %).

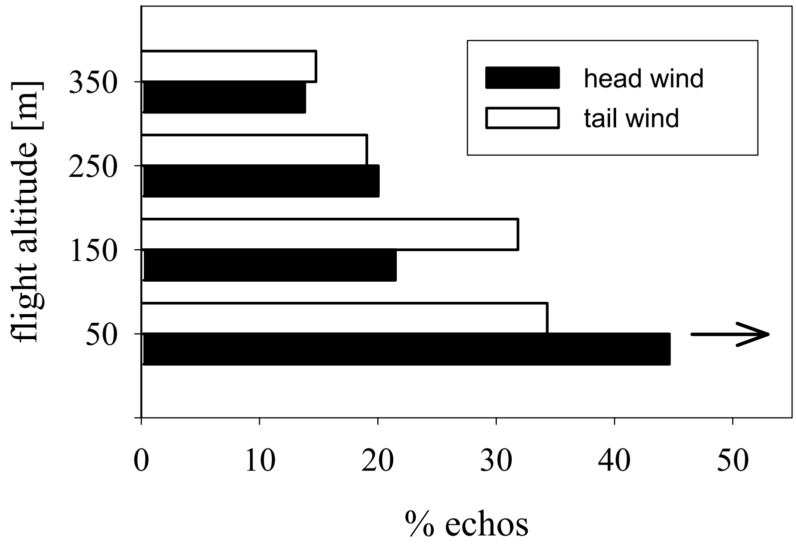


Figure II-27: Flight altitude (% echos) in the lower 400 m as a function of the Tail Wind Component (head winds = TWC < -2; tail wind = TWC > 2); shown are middles of intervals , n 'head wind' = 734, n ´tail wind`" = 1,014 echos). The arrow indicates an underestimation of the lowest altitude class (see chapter II-6.1.5)

The effect of cloud altitude and the degree of cloud cover on the flight altitude distribution during the night and the first 4 hours of daylight are shown in figure II-28. It is apparent that cloud cover was high during low altitude of clouds and that the cloud cover decreased with increasing cloud altitude (see also Table II-14).

This presentation again shows the general change in flight altitude during the night, particularly during clear weather or low cloud cover and high altitude clouds (in this case over 660 m). It is worthy to note the high number of samples in this group, which indicates that this situation was most frequent. Initially the birds flew relatively high (only few numbers in lower altitudes), and subsequently decreased altitude in the second half of the night.

When clouds were very low the altitude distribution was very constant (e.g. from 02:00 to 03:59). During the hours 22:00 to 23:59 there were only very few echos (50) in this cloud category so that the results for these hours need to be treated with caution. After sunrise (06:00) there was a clear change of echos to higher altitudes when clouds were very low. When clouds were at a medium height it was very apparent that during the early hours of the morning, a large proportion of echos (up to 50%) occurred in the lower altitudes. This means that the birds avoided the cloud cover. In the second half of the night the shift to lower altitudes was not that distinctive as during high cloud cover. Generally there were also echos within cloud layers although we did not have any information on the density or altitude of the clouds. Thus we cannot definitely say that birds actually flew through the clouds.

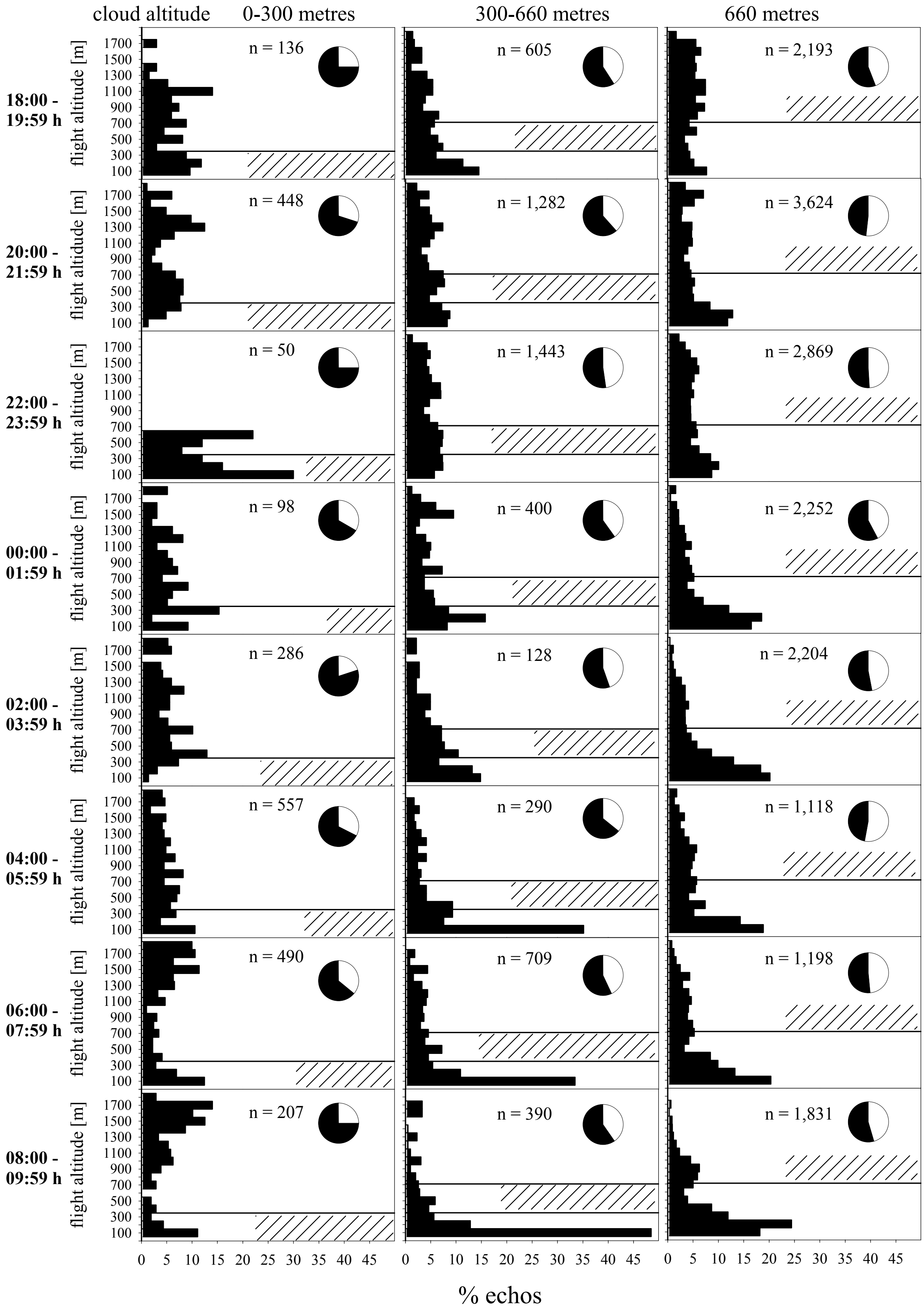

cloud altitude
0-300 metres
300-660 metres
660 metres
18:00 - 19:59 h
20:00 - 21:59 h
22:00 - 23:59 h
00:00 - 01:59 h
02:00 - 03:59 h
04:00 - 05:59 h
06:00 - 07:59 h
08:00 - 09:59 h
flight altitude [m]
1700
1500
1300
1100
900
700
500
300
100
n = 136
n = 605
n = 2,193
n = 448
n = 1,282
n = 3,624
n = 50
n = 1,443
n = 2,869
n = 98
n = 400
n = 2,252
n = 286
n = 128
n = 2,204
n = 557
n = 290
n = 1,118
n = 490
n = 709
n = 1,198
n = 207
n = 390
n = 1,831
0 5 10 15 20 25 30 35 40 45
% echos

Figure II-28: Changes in flight altitude (% echos) during the course of the night (summed for 2 hour-intervals) as a function of the altitude of the lowest cloud layer (only hours without rain). Figure left - clouds 0-300 m (45 days); middle - clouds 300-660 m (660 m = Median of cloud altitude distribution; 91 days); right - above 660 m (109 days). The cloud layer is shown hatched. The circle diagram shows the cloud cover. n = number of echos. The top boundary of 100 m altitude layers is indicated.

II-7.3 Discussion

The altitude measurements using ship radars were carried out from exposed island locations so that they are not directly comparable with measurements in the offshore areas. However, we were able to detect bird signals up to 2 km from the coast. The fact that bird migration over water generally occurs in lower levels than over land (North Sea: Eastwood & Rider 1965, Bruderer & Liechti 1998a) whereby terrestrial birds migrate at higher altitudes than waterbirds (Gruys-Casimir 1965) and waterbirds over land higher than terrestrial birds (Bergmann & Donner 1964, Berndt et al. 1993, Busche et al. 1993), does not mean that a change in altitude takes place when crossing from land to water: Bruderer & Liechti (1998a) did not find any relationship between change in altitude and distance from coast within a range of ± 2 km around the coastline. This project therefore allows the conclusion that the coastline does not have a large effect on the measured flight altitude. Furthermore, taking into account an average flight speed of 50 km/h means that the patches of water to be crossed before reaching the different measuring locations can be reached roughly within one hour. Thus birds are not expected to land and reduce altitude due to exhaustion immediately after crossing the water.

The results of this study correspond with other results to the extent that a large proportion of bird migration and foraging flights over the sea takes place at lower altitudes (e.g. Berndt & Busche 1993, Dirksen et al. 1996, 1998b, Koop 1997, Krüger & Garthe 2002a, b, chapter II-4 and II-5). Based on the lower 1800 m we registered over 25% of all bird activity below 200 m, in other words in altitudes where a direct danger by WEPs exists. Due to a restricted recording of the radar in the lower 50 m (see chapter II-6.1.5) the proportion of low flying birds is expected to be considerably higher (compare chapters II-4 and II-5). Helgoland showed the lowest proportion of low flying birds (19.6 %) whereas Fehmarn and Rügen had more low flying birds. This could, however, be related to the fact that the measurements were done at different times (each location was visited every 4 weeks) resulting in various factors such as species composition, weather conditions affecting the flight altitude during the different measuring periods. The fact that the two baltic locations had a larger proportion of low flying birds than in the North Sea could be related to a different species spectrum of migrating birds. It should be emphasized that the Baltic Sea is important for seaducks and dabbling ducks as well as for divers (Skov et al. 2000). Furthermore, the distance to be covered could also play a role: e.g. to cross the Fehmarn-Belt requires a much shorter distance than to fly over the North Sea. Large distances are often crossed at higher altitudes than short ones (Alerstam 1990). It is possible that the migration parallel to the coast takes place at lower altitudes.

Radar recordings of flight altitudes around Helgoland are available but they are either in very low layers and thus below our measurements (Clemens 1978: 94.5 % below 200 m, maximum 400 m) or above (Jellmann 1979, 1989: no migration below 150 m). However, in both cases there are major technical deficiencies with regard to accuracy of measurements, which make conclusions somewhat doubtful. In the region of the Fehmarn-Belt it is expected that 5 to 20 % of terrestrial birds cross the Belt at an altitude below 150 m (COWI 1999), whereas migrating seabirds (particularly Common Eider and Black Scoter on their way to moulting and wintering areas) to a large extent fly below 100 m (COWI 1999) or even 50 m (Berndt et al. 1993, Busche et al. 1993). On Fehmarn we registered a total of 28.3 % of all signals below 200 m with clear differences between spring (32.4 %) and autumn migration (17.0 %). It is particularly clear for Fehmarn that the altitude distribution is affected by the species composition. The highflying birds (peak at 1700 to 1800 m) are represented by raptors, which require the higher altitudes for soaring. Since we visited each locality at intervals of 4 weeks (2 weeks at each location) the results are also dependant on the migration phenology of the species engaged. For the region of the North Sea Eastwood & Rider (1965) and Jellmann (1989) found higher flying altitudes in spring than in autumn. This corresponds to our own measurements. On Helgoland the proportion of high flying birds (above 400 m) was 71.7 % and thus much higher than in autumn (62.0 %). The following reasons could be responsible for the seasonal effect (Eastwood & Rider 1965, Elkins 1988, Jellmann 1989): (1.) The prevailing wind direction of W to NW in Northern Europe means that there is often a headwind in autumn resulting in the preference of low altitudes (e.g. Bruderer & Liechti 1998b); (2.) Species specific altitude preferences are likely, although it is expected that roughly the same bird populations are involved during spring and autumn; (3.) Age differences: in spring there is a higher proportion of adult birds which may prefer higher altitudes because they have a better condition and thus possibly attain higher altitudes than younger birds; (4.) Since the migration to the breeding grounds is faster than that into the wintering quarters (Berthold 2000), the traversion of longer distances in spring could be performed at higher altitudes (without the necessity to land).

For the assessment of the seasonally dependant danger potential of offshore WEPs it is necessary to consider that during autumn considerably more birds cross the North and Baltic Seas than in spring, because there are large numbers of recently fledged birds, which are more endangered than adults because they lack experience and are often not well conditioned.

The observation that birds migrated at higher altitude at night than during the day corresponds well with results of other studies (e.g. Eastwood & Rider 1965, Able 1970, Jellmann 1979, Bruderer 1997b, Bruderer & Liechti 1998b, Zehnder et al. 2001). The temporal changes in flight altitude showing an rapid increase in flight altitude in the first half of the night and lower altitudes in the second half also compare well with other observations (Bruderer et al. 1995b, Bruderer 1997b, Bruderer & Liechti 1998b, Fortin et al. 1999, Zehnder et al. 2001). The rapid increase in altitude at the beginning of migration gives the birds an impression of the atmospheric conditions in different altitude levels and thus enables the birds to determine the appropriate altitude, whereby the wind plays a leading role (Bruderer et al. 1995b). The general differences between night and day migration are primarily attributed to species differences, since species specific preferences were observed in the diurnal timing of migration (e.g. Alerstam 1990, Berthold 1996, 2000). Almost all insect eating songbirds, waders and some ducks and geese are primarily or partial night migrants. Typical day migrants are short distance migrants such as larks, finches, buntings, wagtails and pipits. Some large birds also migrate during the day as they depend on thermals for soaring.

Since it is expected that the collision potential with WEPs is greater at night than during the day (due to the poor visibility) it becomes apparent that higher altitude migration during the night will reduce the potential hazard. However, one has to keep in mind that (1.) despite the relatively high medium flight altitudes (around 500 m) over 23% of all signals were still below 200 meters, (2.) migratory intensity and bird numbers are higher at night than during the day (chapter II-9.2.1.2), which means that at night, irrespective of the percentage distribution, there are more individuals in the dangerous hight of up to 200 meters than during the day, (3.) the nighttime migration may drop to lower altitude levels under particular weather conditions (e.g. rain, fog; see chapter II-7.3.2.3).

The effect of weather was observed in many studies, whereby wind played a major role (e.g. Bruderer 1971, Alerstam & Ulfstrand 1972, Alerstam 1979a, Hilgerloh 1981, Bruderer et al. 1995b, Liechti & Bruderer 1998, Krüger & Garthe 2002a). Bruderer et al. (1995b) demonstrated that birds select that flight altitude which provides the best wind support. By adjusting the flight altitude to the wind conditions birds can double there speed and thus halve the energy consumption (Liechti & Bruderer 1998, Liechti & Schaller 1999, Liechti et al. 2000). Since the wind speed generally increases with altitude, birds will tend to choose lower altitudes, particularly with headwinds (e.g. Bruderer 1971, 1997b, Kumari 1983, Alerstam 1990, Bruderer & Liechti 1998b). We also found a dependency of flight altitude on wind conditions. During headwinds (negative „tail-wind-component“) more birds flow below 100 m than during tailwinds. Since the ship radars only recorded a fraction of the birds below 50 m, the number of low flying birds with headwind is likely to be considerably higher than shown here. This means that corresponding to the main direction of migration, specific wind directions (spring: easterly wind; autumn: westerly wind) could result in a reduction of flight altitude and thus increase the risk of collision with WEPs.

Rain has a marked influence on the altitude of migration. Particularly the night altitudes were distinctly lower when it rained than under dry conditions. There was no difference during the day. This suggests that poor orientation in rainy nights causes the birds to select lower altitudes or even to rest. The direct influence of rain was demonstrated by the drastic change in altitude within a few hours as reaction to a rain shower. During bad weather large numbers of migrants may land on islands (e.g. Alerstam 1990). However, most of the landings on Helgoland actually occur during optimal migratory conditions, which allow a high migratory activity (e.g. Dierschke & Bindrich 2001).

The effect of rain has a significant relevance with regard to collision risk with WEPs. Bad weather causes poor visibility resulting in low flight altitudes, which in turn increases the risk of collision. Since activity increases at night, this fact is further enhanced.

The effect of clouds can probably be explained by the orientation capacity of the birds (Emlen 1975). Usually birds avoid to fly through dense clouds, but fly underneath or over them. Low-lying clouds are usually over flown (Lack 1960, Bellrose & Garber 1963, Bruderer 1971, Blokpoel & Burton 1975). In other words during a high cloud cover birds will fly higher and are more evenly distributed (without totally avoiding the clouds, Eastwood & Rider 1965). These observations correspond well with ours. During cloud altitudes below 300 m and a high cloud cover very few echos were detected in the lowest levels at night (very clear from 20 to 22 hours, and from 02 to 04 hours). Many echos were detected at greater altitudes, particularly in the early morning hours. When clouds occurred in the median heights, they were usually avoided by flying underneath these (Nisbet 1963, Blokpoel & Burton 1975). In our studies this was mainly the case in the early morning when up to 50 % of all signals occurred in the lowest 100 m. This suggests that the birds fly below the clouds enabling orientation using features on land. Although there was clear evidence that clouds were avoided, echos were also detected within clouds. The fact that birds also fly within clouds is also described by Bellrose & Garber 1963, Eastwood & Rider 1965 and Emlen 1975, however, as in our study these authors also do not provide any information on cloud density or upper limits of the clouds. This makes interpretation of the results difficult.

An increased risk of collision can therefore be expected, particularly in dense clouds of medium height, as birds will tend to fly underneath. Since birds also fly within clouds, low lying clouds will also be critical since the birds, albeit that fewer birds fly at low altitudes, will be severely endangered because of bad visibility.

Birds are capable of detecting slight differences in air pressure (e.g. Kreithen & Keeton 1974), whereby they obtain information on the current flight altitude and on weather changes (Schütz et al. 1971). Particularly during the first half of the night when birds fly high in order to select the advantageous flight altitude (Bruderer et al. 1995b), we found that birds tended to lower the altitude with decreasing air pressure. The air pressure probably is not as important as the actual associated change in weather conditions. Table II-16 clearly shows that low air pressure is associated with poor weather, i.e. dense and low cloud cover, high wind speed and high precipitation. The effect on flight altitude has already been discussed.

Table II-16: Weather parameters as a function of air pressure, divided into „low", "middle", "high" (defined in chapter II-6.3). Shown are means ± standard deviation as well as χ^2-values and significance of the Kruskal-Wallis-Test. The values are based on hourly measurements by the DWD for the period of investigation (exception: precipitation = last 6 h)

	air pressure					
	low	medium	high	χ^2	p	n
cloud cover (%)	66±30	47±35	31±34	241	0.000	408/987/596
cloud altitude (m)	972±1490	1773±2428	2419±2895	70	0.000	379/924/596
temperature (°C)	10.4±4.3	12.1±4.5	11.7±4.6	41	0.000	408/990/731
precipitation (mm/6h)	3.2±5.2	0.8±2.6	0.2±0.9	76	0.000	72/170/127
wind force (m s^{-1})	7.6±3.5	6.4±3.4	5.5±2.7	88	0.000	408/990/731

II-8 Flight direction, speed of migration

II-8.1 Introduction

The large-scale investigation on flight directions over the sea using the military radar, together with the information on migratory intensity, provides an indication of the preferred migratory routes. According to this information the migration over the North Sea occurs over a broad front i.e. there are no preferred routes. In the Baltic Sea, however, the coastline or islands seem to act as guiding lines. Conclusive information on the migratory patterns is scarce, however, so that the data obtained during this project for the first time allow a presentation of the large-scale patterns of distribution and direction of migrating birds in the offshore areas.

The migratory direction on Helgoland, Fehmarn and Rügen determined using ship radars provide additional information on direction at hot spots of migration in the North and Baltic Seas. Weather plays an important role in influencing the flight direction (particularly wind, e.g. wind drift) which can cause tremendous variability (e.g. Elkins 1988, Richardson 1978, 1990). Due to the low importance of local flight directions for the risk assessment of the offshore WEP we refrain from a detailed analysis of the wind effects on flight directions on Helgoland, Fehmarn and Rügen.

Since it is impossible to identify bird species on the radar, a calculation of the speed of migration provides some indication of the species groups involved (Bruderer & Boldt 2001). However, the ship radars do not provide systematic data on flight speeds (see chapter II-6.1.3.2), so that we are only able to supply relative speeds of migration. These enable a comparison within this project but not with other studies.

II-8.2 Results

II-8.2.1 Ship radars

II-8.2.1.1 Direction of migration

The distribution of flight directions for each location and season (spring and autumn migration) is shown in figure II-29.
For the calculation of the mean direction of migration (Table II-17) it was assumed that *migration* applied to birds which moved in the direction NE (45°) ± 90° during spring and SW (225°) ± 90° in autumn. Bird movements in the opposite direction were probably attributable to foraging flights.

Table II-17: Mean direction of migration (degrees ± standard deviation) during spring and autumn migration at the three investigated locations, comparing night and daytime migration (t-value; n Number of echos, t-test, p = probability)

		mean ± sd	t	n	p
Helgoland					
spring	day	50.28±46.23	1.042	131	0.298
	night	44.31±39.36		102	
autumn	day	207.57±34.66	-2.240	493	**0.025**
	night	213.35±38.41		328	
Fehmarn					
spring	day	56.00±47.99	-1.515	615	0.130
	night	60.97±47.70		323	
autumn	day	232.92±39.70	12.916	896	**0.000**
	night	212.76±39.38		2,235	
Rügen					
spring	day	45.99±28.10	-1.921	381	0.055
	night	49.78±27.92		426	
autumn	day	205.02±33.09	-1.583	570	0.114
	night	207.69±33.60		1,276	

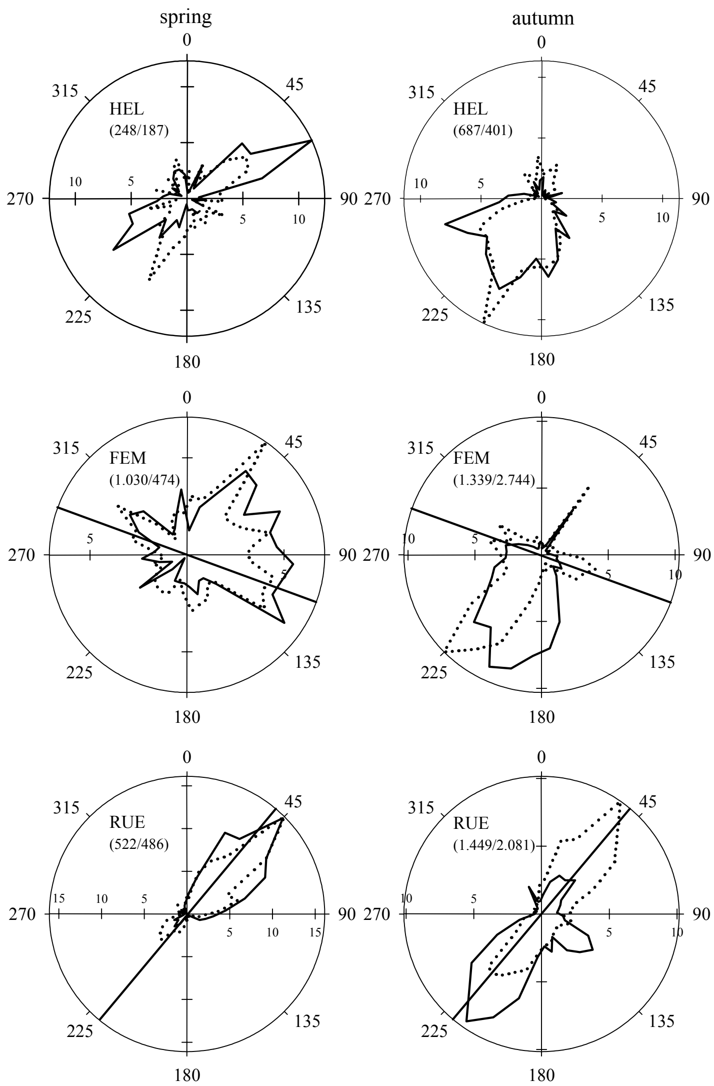


Figure II-29: Direction of migration at three locations: day/night comparison in spring (left) and autumn (right). Shown are the %-values of signals for every 10°-interval. Night: solid line, day: broken line. Abbreviations: HEL=Helgoland, FEM=Fehmarn, RUE=Rügen. The solid line for the locations Fehmarn und Rügen shows the coastline.

During spring, the main direction of migration was NE (around 45°), although a large proportion of migrants also flew in the opposite direction, particularly over Helgoland. The direction of migration on Fehmarn was not that focussed. The main direction varied between NNE and ESE (mean: 56 ± 47.9° during the day, 60.97 ± 47.9° at night, high standard deviations). On Rügen the direction was exclusively NE (45.99 ± 28.10° day; 49.78 ± 27.92° night, low standard deviations). The autumn migration at all locations was SW to SSW. Only at Rügen there was a clear migration in the opposite direction (NNE). Whereas the main direction of migration on Fehmarn was perpendicular to the coastline (birds crossed the Fehmarn-Belt), that on Rügen was almost exclusively parallel to the coast. Only a single peak in the pattern pointed to the fact that birds were flying in a SE direction at night to cross the sea.

During spring there were hardly any differences between the direction of migration during night and day (Figure II-29, Table II-17: all not significant). In autumn, however, significant differences were observed between day and night migration on Helgoland and Fehmarn: On Helgoland the directions varied more in the night than during the day and a larger proportion of birds flew over the island in a WSW direction during the night. On Fehmarn the nighttime migration had shifted clearly in a SSW direction, whereas during the day the major direction was SW. There were no differences between day and night on Rügen during autumn. A distinct migration opposite to the main direction was observed on Rügen during autumn. This took place mainly during the day. From observations it became apparent that these were primarily large gulls on foraging flights. The same was observed on Helgoland during spring. However, the sampling frequency was very low and the observed migration was only recorded on a few days (19.4. and 20.4.2001).

In general, the echos showing migrating in the main flight direction were found in higher altitudes (Figure II-30), particularly during autumn. This indicates that it was actual migration in the opposite direction rather than foraging flights. During autumn on the baltic locations, echos, which indicated migratory directions, were observed in large numbers below 100 m. This was especially true on Rügen where migration took place along the coastline (Figure II-30; migration parallel to coastline = no track, since birds cross the radar beam perpendicularly). Hence, over-sea migrants (with track) crossed the water at very low altitudes.

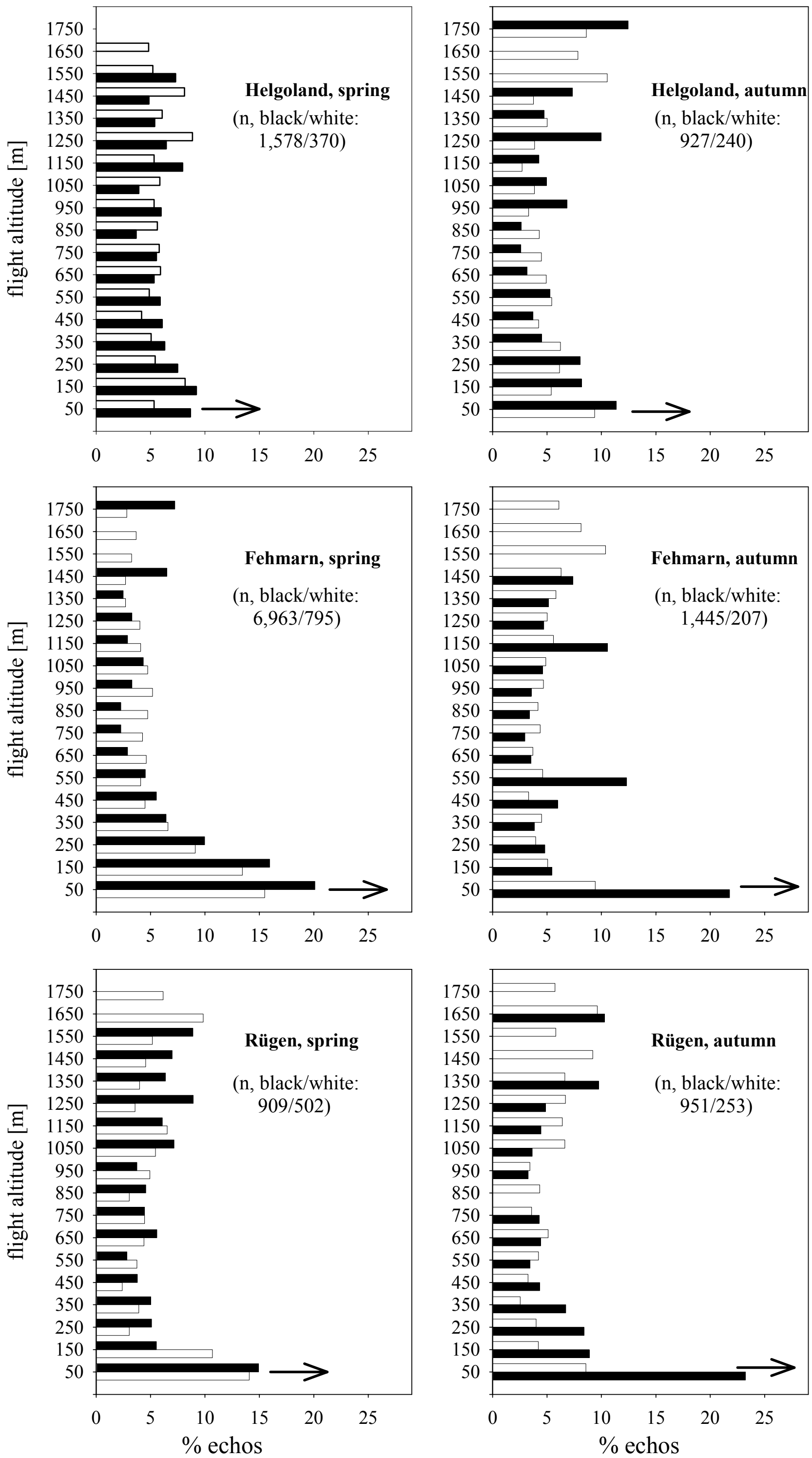


Figure II-30: **Flight altitude as a function of the „coarse direction of flight" determined with the vertical radar (differentiation: echo moves towards or away from radar).** ***Main direction: dark bars; reverse direction: grey bars.*** **Arrows indicate an underestimation of the lowest altitude class (see chapter II-6.1.5)**

II-8.2.1.2 Speed of migration

Since it was not possible to determine actual speeds of migration using the radar photographs, we report only on relative speeds determined from the length of the radar signals (tracks, see chapter II-6.1.3.2). A comparison between spring and autumn migration between locations clearly shows that there was a relatively large proportion of fast migrants over Helgoland and Fehmarn during spring (track lengths longer than 300 m). During autumn hardly any tracks of these lengths were registered (Figure II-31). The mean speeds at all locations varied significantly between the seasons. Distinctly higher speeds of migration were recorded during spring than during autumn (Table II-18). Clear differences between day and night speeds were observed on Rügen during autumn, where daytime migration was much faster than nighttime migration (Figure II-31). With the exception of Helgoland all day/night speeds were significantly different during spring (Table II-18). However, at the baltic locations, spring nights revealed greater speeds than days. In autumn the pattern was exactly opposite.

Table II-18: Relative speeds of migration at the three locations during spring and autumn (track length in m; mean ± standard deviation, t-test, p = probability

location	season	mean±sd	t	n	p
Helgoland	spring	257.51±98.97	13.873	435/1,088	**0.000**
	autumn	199.20±61.39			
Fehmarn	spring	224.49±76.48	43.444	1.504/4,083	**0.000**
	autumn	138.47±61.16			
Rügen	spring	241.09±86.79	4.908	147/3,530	**0.000**
	autumn	203.37±91.50			

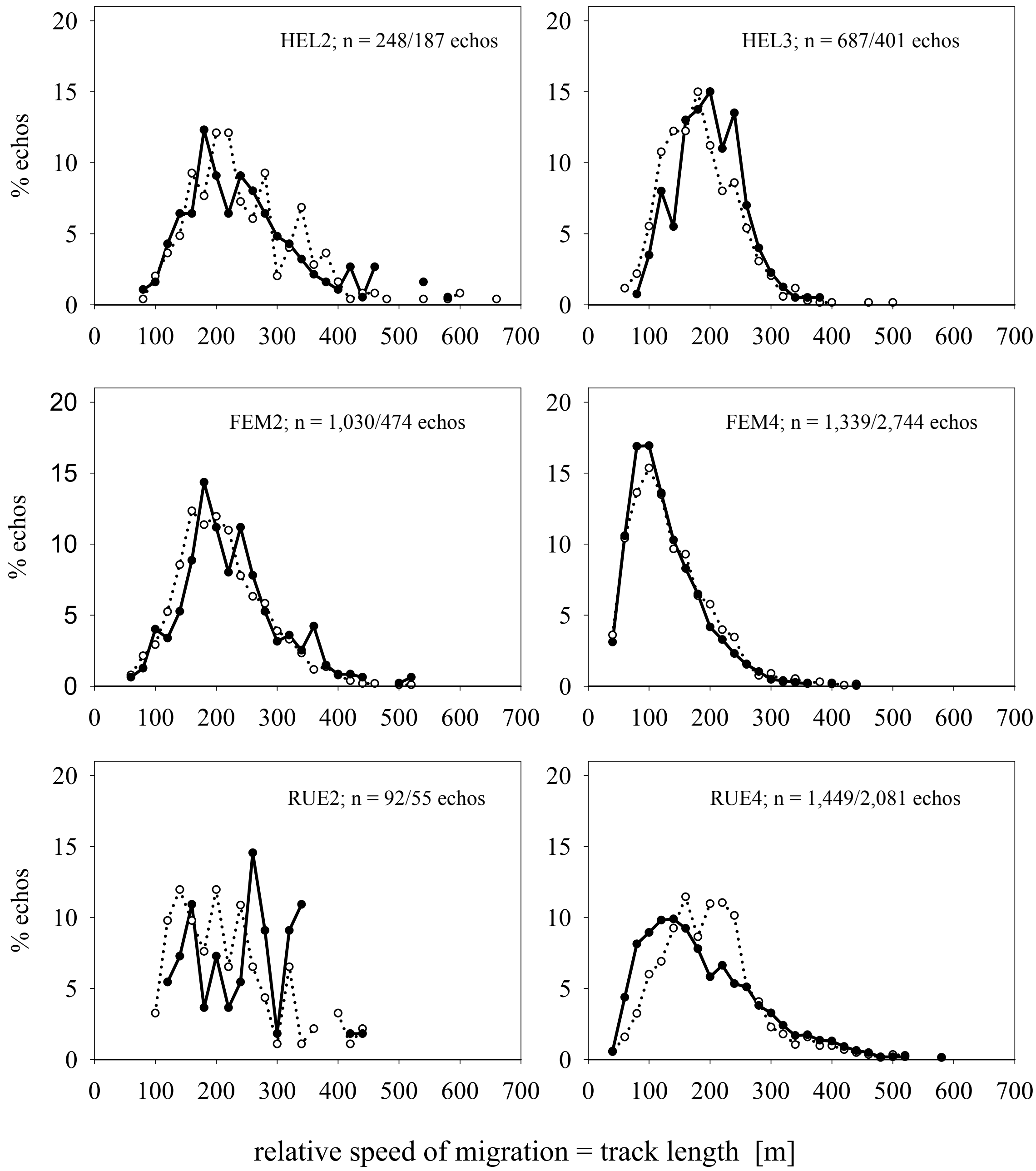


Figure II-31: Relative speeds of migration (track length in m; percentage distribution) in spring (left, Helgoland2, Fehmarn2, Rügen2) and autumn (right, Helgoland3, Fehmarn4, Rügen4) during the day (broken line; open symbols) and night (solid line; filled symbols)

Table II-19: Relative speeds of migration during the day and night at the three locations during spring and autumn migration (track length in m; mean ± standard deviation, t-test, p = probability)

location, season	day/ night	mean±sd	t	n	p
Helgoland, spring	day	256.92±93.92	-0.142	247/187	0.887
	night	258.28±105.55			
Helgoland, autumn	day	192.91±60.94	-4.466	687/401	**0.000**
	night	209.99±60.73			
Fehmarn, spring	day	219.34±73.08	-3.867	1,030/474	**0.000**
	night	235.68±82.39			
Fehmarn, autumn	day	143.24±65.08	3.482	1,339/2,744	**0.001**
	night	136.15±59.03			
Rügen, spring	day	226.28±83.87	-2.734	92/55	**0.007**
	night	265.85±86.68			
Rügen, autumn	day	210.20±81.68	3.712	1,449/2,079	**0.000**
	night	198.60±97.49			

Figure II-32 shows migration speeds in some species (after Bruderer & Boldt 2001). It is apparent that there is large overlap in the speeds of different species and groups. Most species lie within a range of 10 to 15 m s^{-1}. This range includes small birds such as larks, swallows and finches as well as larger birds such as raptors, herons and gulls. The faster flying birds are usually ducks, cormorants and pigeons.

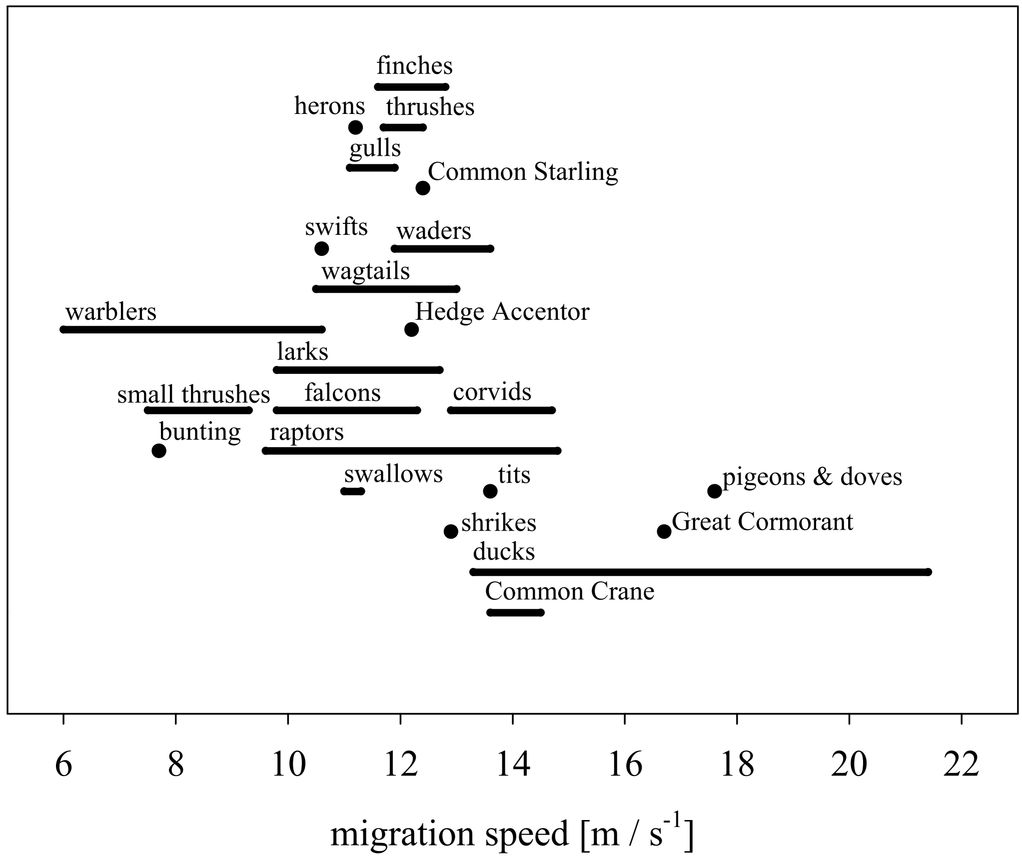


Figure II-32: Mean speeds of migration of various bird groups (inter specific ranges) after Bruderer & Boldt (2001)

II-8.2.2 Military radar

The unexpected difficulties in the analysis of the data from the military radar only permit a very limited subjective evaluation of direction of migration based on the animation of the data (compare chapter II-6.2.4). These data confirm the main direction of migration (northeast - southwest) as well as the migration parallel to the Baltic coastline (see example in figure II-33). Flight movements without unique directions during the daylight phase on Fehmarn (station Elmenhorst), north of Rügen (station Putgarten) and over Pomeranian Bight (stations Cölpin and Putgarten) are most likely attributable to foraging birds (gulls, ducks moving between feeding grounds). These types of movements are not recordable further away from the radar stations due to the low flight altitudes. Hence, it cannot be excluded that similar bird movements also occur over the North Sea and the western Baltic Sea.

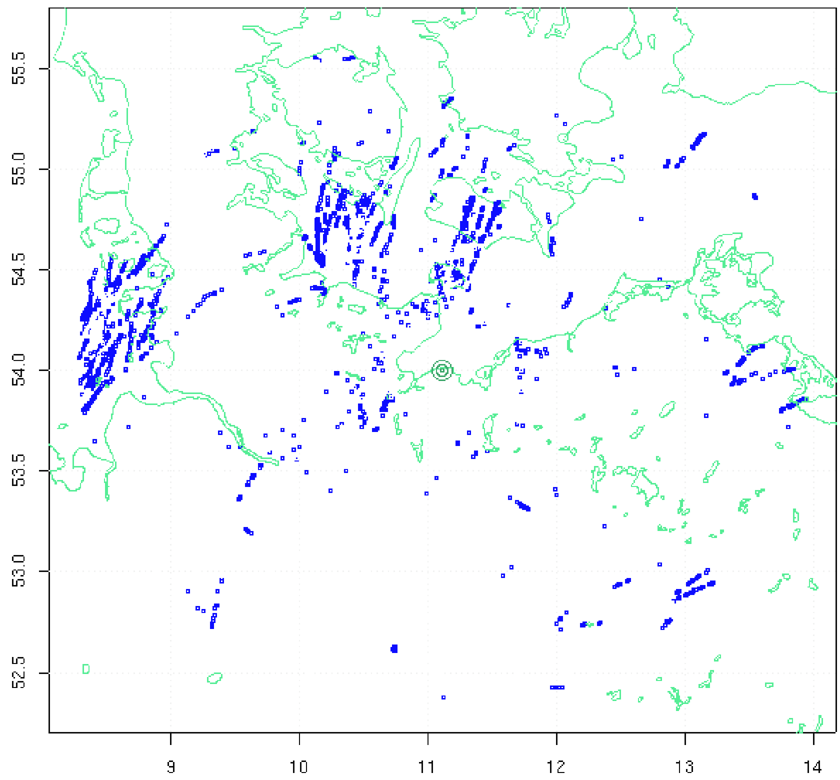


Figure II-33: **Strong migration over the North and Baltic Seas on 27. February 2001 (07:44 UTC) observed with military radar from the military base on Elmenhorst (circles in the centre, sunrise in Elmenhorst at 06:10). Migration routes from Fehmarn to Lolland are clearly visible („Vogelfluglinie"!) as well as from East Holstein to Fünen and Langeland and the eastern zone of the wide scale migration over the eastern North Sea. Also recognisable is the migration over the open Baltic north of Rügen and the deviating migration along the coast of eastern „Vorpommern".**

II-8.3 Discussion

The bird migration in autumn within the Paleoarctic African migratory system over Europe takes place in a SW direction (230°). However, long distance migrants appear to prefer more southerly routes and short distance migrants more westerly directions (Bruderer 1997b). The mean migration directions of 197° to 217° determined in this study lie within the SSW direction. This could be caused by a high proportion of night flying long distance migrants, which chose more southerly directions during autumn and at night compared to the daytime. Zehnder et al. (2001) found the mean migratory route for the south of Sweden (Falsterbo) to be 219° whereby the direction changed to more southerly routes with increasing altitude. The station on Falsterbo is on the same route as that over Fehmarn („Vogelfluglinie"), so that it is possible to compare them directly (Fehmarn: 217°). On Fehmarn in autumn, birds exclusively crossed the Fehmarn-Belt directly: The direction from which the birds were flying was 37° (which corresponds to the measured migratory direction of 217°) and reveals a good accordance with the direction over the open sea at our measuring station (20°). Next to a distinct peak into direction of the open sea, the data also show that the birds cross the Fehmarn Belt in a more easterly direction during spring. However, a part is probably also due to the migration parallel to the coastline over the ferry pier which reaches far into the sea. On the other hand these could also be foraging flights or flights to resting quarters (the nature reserve „Grüner Brink" lies 2km west of this area). The data reflect quite well the pattern of migration, particularly in autumn.

On Rügen, most migrants during autumn arrive from northerly or northeasterly directions and meet the island in the vicinity of Cape Arkona (Rautenberg 1956). One part continues in a southerly direction whereas the majority follow the coastline in the SW direction to change to Hiddensee and follow the coastline in the direction of Darß. Apart from this migration along the coastline there is also a migration over the sea between Hiddensee and Cape Arkona. In spring migration is in exactly the opposite direction. The radar was located between Cape Arkona and Hiddensee, exactly in the middle of the main migration along the coastline. The coastline at this point is directed 40° east. During spring and autumn the main flight direction corresponded to the coastline so that it can be assumed that migration was parallel to the coast. On Fehmarn the discrepancy between day and night migration was greatest in autumn. Besides to the different orientation mechanisms (visually during the day) the species specific night and day time migratory patterns is responsible for the deviation.

The migration in a NE-direction over the North Sea is considered to be the main migratory route, next to less significant routes in west-east direction and northerly direction (Jellmann 1977). According to Jellmann (1977) radar observations revealed that the migratory direction ranged from 20° to 55°. Clemens (1988) established the median route over Helgoland to lie between 59.7° and 52.4° during two spring seasons. The main direction in this study was 48.9° and thus lies within the established routes albeit a little more northerly. The median-value of 57° for the directions in spring corresponds to that of Clemens (1988). The relatively high deviation of the median from the average is probably due to the migration of some birds in a NNW direction, which was therefore not included in our calculations (definition 45° = NE ± 90°). The relatively high proportion of bird movements in the opposite direction in spring is probably due to foraging flights of seabirds from the „Guillemot“ cliffs on Helgoland. Reverse migration due to bad weather conditions (e.g. Berthold 2000) can probably be excluded. The main migratory direction in autumn is not exactly the opposite of that in spring. It is slightly more southerly (20° relative to the mean, 30° relative to the median value). This could be related to the fact that in autumn and spring, the migrants (particularly those coming from the north) leave the coastline early to cross the German Bight and thus pass Helgoland at different angles.

Since the migrating speeds of different species show a strong overlap (e.g. Bruderer & Boldt 2001), it is almost impossible to allocate species to the radar signals. Only fast flying birds such as ducks, cormorants and pigeons or extremely slow flyers such as finches and warblers allow an estimate of the species groups involved. The dominant bird groups for which migratory speeds are available on Helgoland were gulls and terns (during spring Little Gull in particular, during autumn Common and Arctic Terns), which were usually detected at some distance and were thus quite likely not responsible for the echos found on the photos. The fact that all the birds flew faster during spring than in autumn confirms the observation that the spring migration is generally more rapid than in autumn (and at greater altitude, see chapter II-7.2.1) probably because of predominant tailwinds in spring (Bruderer & Liechti 1998b). The apparent slower migratory speeds in autumn on Fehmarn are the result of a high proportion of small birds (finches, pipits and linnets), which often crossed the Fehmarn-Belt against headwinds during the period of our data collection (aee chapter II-4; Annex). The most distinct difference between day and night migration was seen on Rügen in autumn. High speeds during the day were caused by Common Eider, Black Scoter and Long-tailed Duck (see chapter II-4; Annex). Clearly slower echos were registered at night, caused by small birds e.g. insect eating long-distance flyers (Berthold 2000). The influence of wind on these large differences can be excluded.

In view of potential collisions with offshore WEPs, the high migratory speeds increase the collision probability as time for evasive movements is limited. It is not senseful to compare localities because measurements were carried out at different times at the various sites. The spring migration must be considered be more critical due to the higher migratory speeds, although the birds tend to fly at higher altitudes and the number of birds is less than in autumn (larger proportion of young birds; chapter II-7.2.1). Birds migrating at night are particularly threatened because of poor visibility. These include waders, some duck and geese as well as thrushes and small birds, particular long distance migrants such as warblers (Berthold 2000). Due to the lack of data it cannot be assessed whether these species are also endangered because of their speed of migration.

II-9 Intensity of migration

II-9.1 Introduction

The seasonal migratory intensity is correlated to the species or population specific migration phenology (e.g. Berthold 2000). Apart from the endogenous effects on the annual rhythm in the pattern of migration, exogenous factors also govern the migration, whereby weather plays a key role. Although the actual cause/effect relationship is not yet clear, there are some fundamental factors (overview in Elkins 1988, Richardson 1990): (1.) Migratory activity is low in poor weather (precipitation, strong cloud cover, poor visibility), (2.) Special climatic conditions can promote migration, (3.) Local weather conditions determine the local migration pattern. Especially two factors favour migration activity: (1.) tailwind, (2.) avoidance of precipitation (Alerstam & Ulfstrand 1972, Alerstam 1990). Lateral winds may cause birds to drift from their route and corresponding compensation requires the orientation along bottom topographic features, which are missing at sea. Strong winds while crossing over water may cause a drifting off onto the open sea (Alerstam 1979b, 1990).

Even during the main period of migration the intensity may vary from day to day or night to night. Birds will wait for better conditions when the weather is bad, and then start in large numbers. Thus a large part of the migration may take place within a few days (e.g. Gauthreaux 1971, Alerstam 1990). In general, the variation in the intensity of migration can be regarded as an adaptation to „good flight conditions“ that may be related to short-term changes in the environment (e.g. birds leave breeding sites during cold spell, Alerstam 1990).

Knowledge of the migratory control is crucial for potential adjustments of the operation of offshore wind energy parks to bird migration activity. It could be considered to shut down a plant during periods of intense migration.

II-9.2 Results

II-9.2.1 Ship radar

II-9.2.1.1 Seasonal progression

The seasonal course of the migration intensity showed strong variation and was characterized by a fewer days of very high migratory intensity in spring (Figure II-34) e.g. on the first day of observation on Helgoland and during the last days of the first visit to Fehmarn (FEM1). On Fehmarn and Rügen several days in autumn were characterized by strong migration (FEM4 und RUE4).

Summing up the hours of highest migratory intensity yields the following result: In spring half of the total number of echos was recorded in the first 5% of the period of observation (Table II-20). Based on the number of days of observation, this means that this limit is reached after 3 out of 59 days (5.1 %). These values are slightly higher for autumn: (8.5 % of the hours and 10.6 % of the days). This clearly shows that a large proportion of migration takes place within a few days.

Table II-20: Total of the hours (resp. days from 12 h to 12 h) with the highest intensity of migration during which 50 % of all echos were recorded in spring and autumn as well as the total period.

	spring	autumn	total
∑ hours (total-hours)	44 (874)	78 (918)	110 (1,792)
%	**5.0**	**8.5**	**6.1**
∑ days (total-days)	3 (59)	7 (66)	10 (125)
%	**5.1**	**10.6**	**8.0**

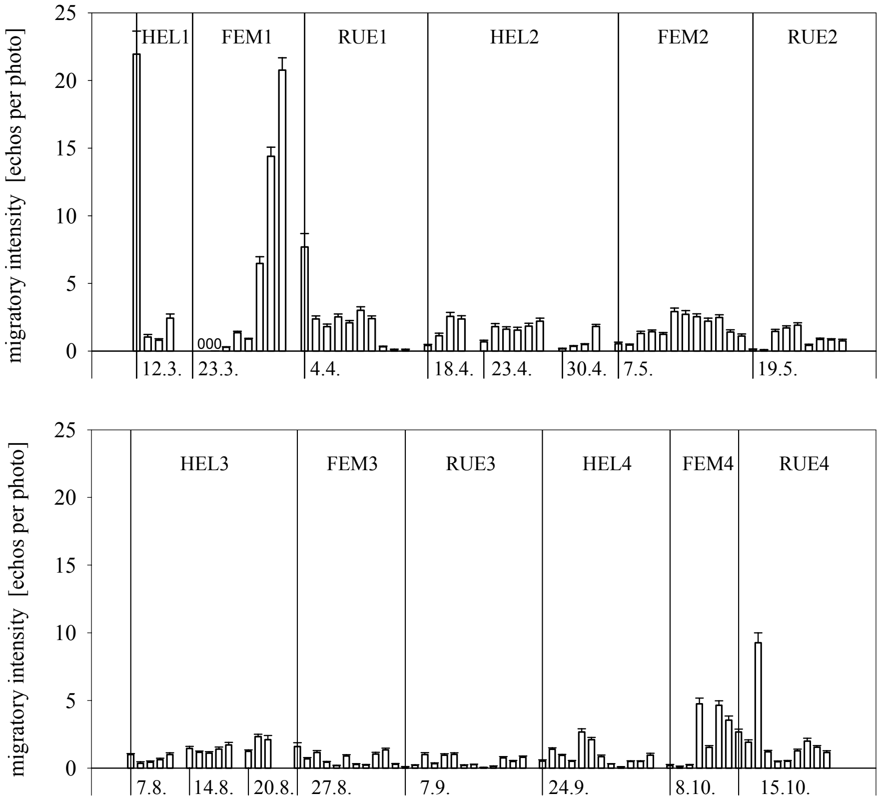


Figure II-34: Migratory intensity (number of echos per photo, standard error, n from photos in Figure II-15) of individual recording days in spring (top) and autumn (bottom). The abbreviations are: HEL=Helgoland, FEM=Fehmarn, RUE=Rügen; the number denotes the consecutive numbering of the measuring campaigns. The date represents the first day of each campaign or pauses between campaigns. No migration activity (0) was only observed during the first 3 days on FEM1

In order to confirm that the migratory intensity observed with the radar provides a representative picture of migration at low altitudes, the intensity is compared with synchronous observations of migration (identical 1-hourly-intervals; data from chapter II-4). Different species categories are build according to morphological similarities („divers“ = Red-throated Diver, Slavonian Grebe, tubenoses, Northern Gannet, auks, mergansers; „gulls / waders“ = gulls, terns, skuas, waders; „ducks / geese“ = seaducks, dabbling ducks, diving ducks, geese, swans, herons, cormorants; „small songbirds“ = finches/sparrows, larks, swallows, pipits/wagtails, accentors, buntings; „large songbirds / pigeons“ = thrushes, corvids, Common Starling, pigeons). The presentation is further subdivided according to data from the „seawatching“, „passerine observations“ and „raptor observations“ (compare chapter II-4).

There were significant correlations in migration intensity determined by different methods in three categories: „divers“, „seaducks“, „finches“ and „thrushes“ (Figure II-35). On the other hand there was no correspondence between „gulls“ and „raptors“.

Although it is apparent from the figures that there are deviations in the migratory intensity, the correlations between visual and radar recordings show that the radar data provide a representative picture of the actual migration of seabirds and coastal birds as well as for songbirds.

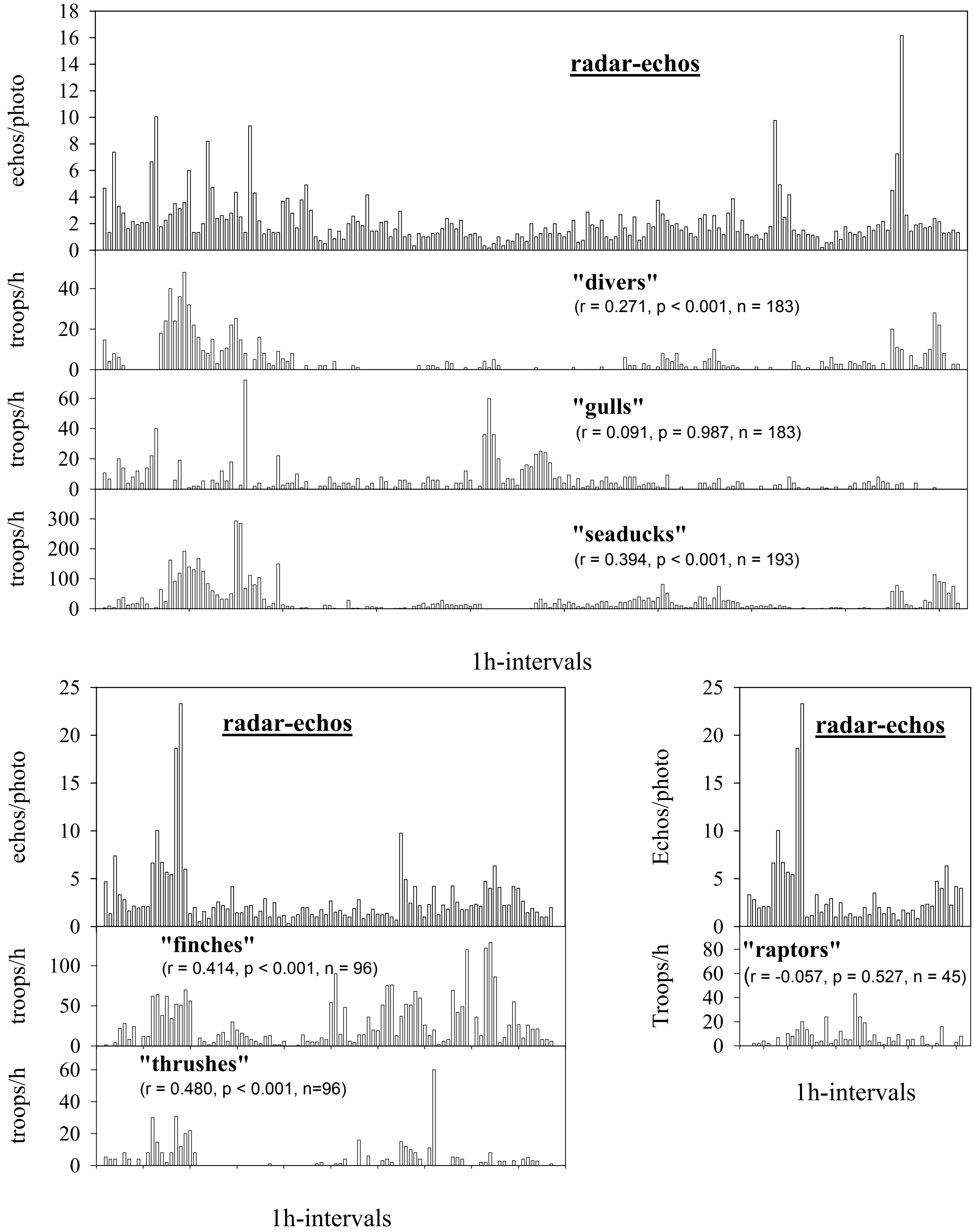


Figure II-35: Comparison of migration intensities determined by radar (top graphs, „Radar-echos“) as well as sightings (below the radar graphs). Shown are the intensity per hourly interval during synchronous radar and visual observations (in brackets: Spearman-correlation coefficient, p, n). Species groups were selected according to morphological features (see text).

II-9.2.1.2 Diurnal pattern of intensity

Migratory intensity showed strong diurnal fluctuations (Figure II-36). A general pattern was observed independently of location or season: The least activity occurred in the afternoon, whereas after one hour after sunset activity increased markedly. During the course of the night until sunrise, the intensity decreased again. On Fehmarn the spring migration had another clear activity peak from 00:00 to 01:00. This was not observed in autumn, however. Other seasonal differences in the diurnal activity were observed on Helgoland and Rügen: On Helgoland the autumn increase in activity after sunset was very weak, whereas it was very strong in spring. On Rügen the autumn intensity after sunset increased very slowly, whereas during spring (also at the other locations) it increased very steeply. A slight intensity peak was noticeable on Rügen in autumn, 2 to 3 hours after sunrise.

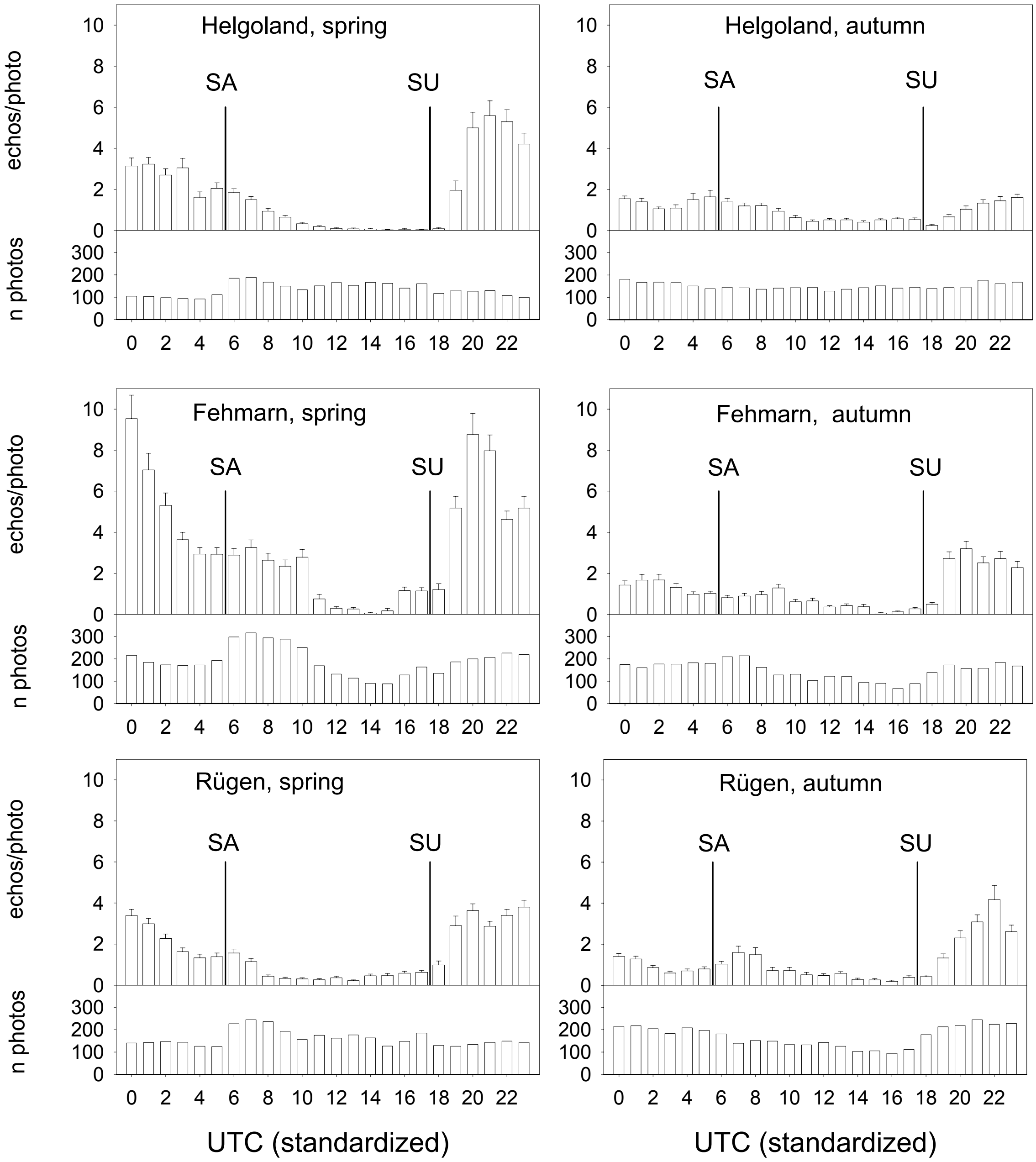


Figure II-36: **Migratory intensity (number of echos per photo; mean, SE) as a function of daytime (UTC, standardized) during spring (left) and autumn (right) separated according to the three locations. The number of photos per hourly interval is shown in the bottom graphs. The time represents the following periods: Example 8:00 = 08:00 to 08:59, 9:00 = 09:00 to 09:59. SA=sunrise; SU=sunset.**

II-9.2.1.3 Influence of weather

As mentioned previously, the migration activity is extremely dependant on the large scale weather situation. Thus, *local* migration patterns need not necessarily be correlated with local weather conditions. Due to the complexity of the weather influences on migration, it was not possible to carry out a comprehensive and conclusive analysis in this project, which entailed the general weather conditions as well as single interacting weather parameters. Therefore, we provide exemplary and descriptive aspects on the local influence of weather on migration.

Figure II-37 shows the seasonal intensity of migration in relation to temperature and wind speed. A relationship between temperature as well as wind speed is only seen during phases of intense migration. On Fehmarn, in spring (FEM1) there was a noticeably increase in migratory intensity coinciding with an increase in temperature and decreasing wind speeds. At the beginning of this measurement period when temperatures were near zero and strong winds prevailed, no migration was observed (no signals on three consecutive days). Within the second Fehmarn campaign (FEM2) there was an increased intensity coinciding with increasing temperatures and decreasing wind speeds up to the 12th May. This was followed by a decrease in intensity with increasing wind speeds and a drop in temperature.

During the northeasterly migration in spring, southwesterly winds are advantageous, whereas easterly winds mean headwinds for the birds. In some cases there was an increase in intensity coinciding with a change in wind direction from S to SW (Figure II-38): from 26th to 30th March, from 23rd to 24th April, from 11th to 12th May. Winds turniung east coincided with both decrease and increases in intensity. During autumn, easterly winds are favourable (tailwinds) for migration. Although there is no clear correlation, the highest intensity in autumn was related to the turning of winds from SW to E on the 15th and 16th October.

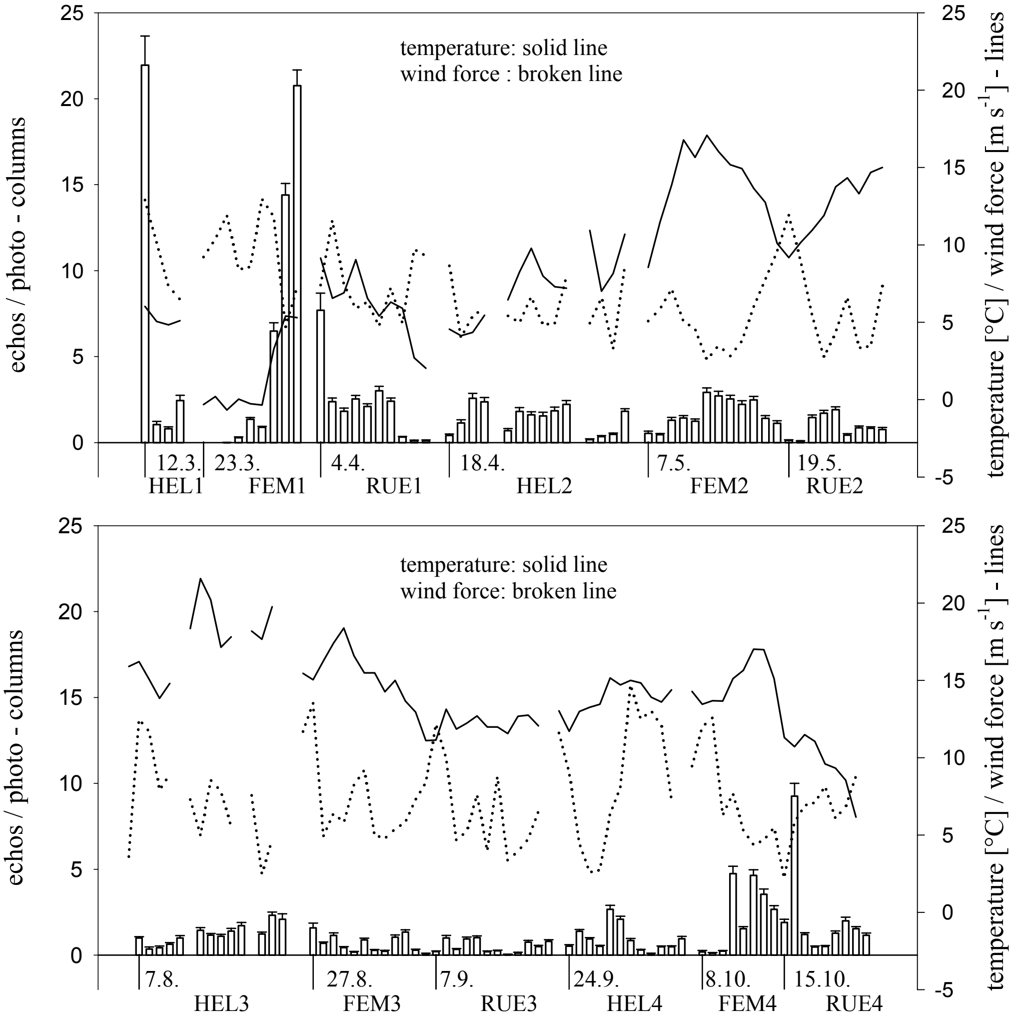


Figure II-37: **Average daily temperatures and wind speeds on days with migration observations in relation to the registered migration activity (for the labelling of the observation campaigns see Figure II-34)**

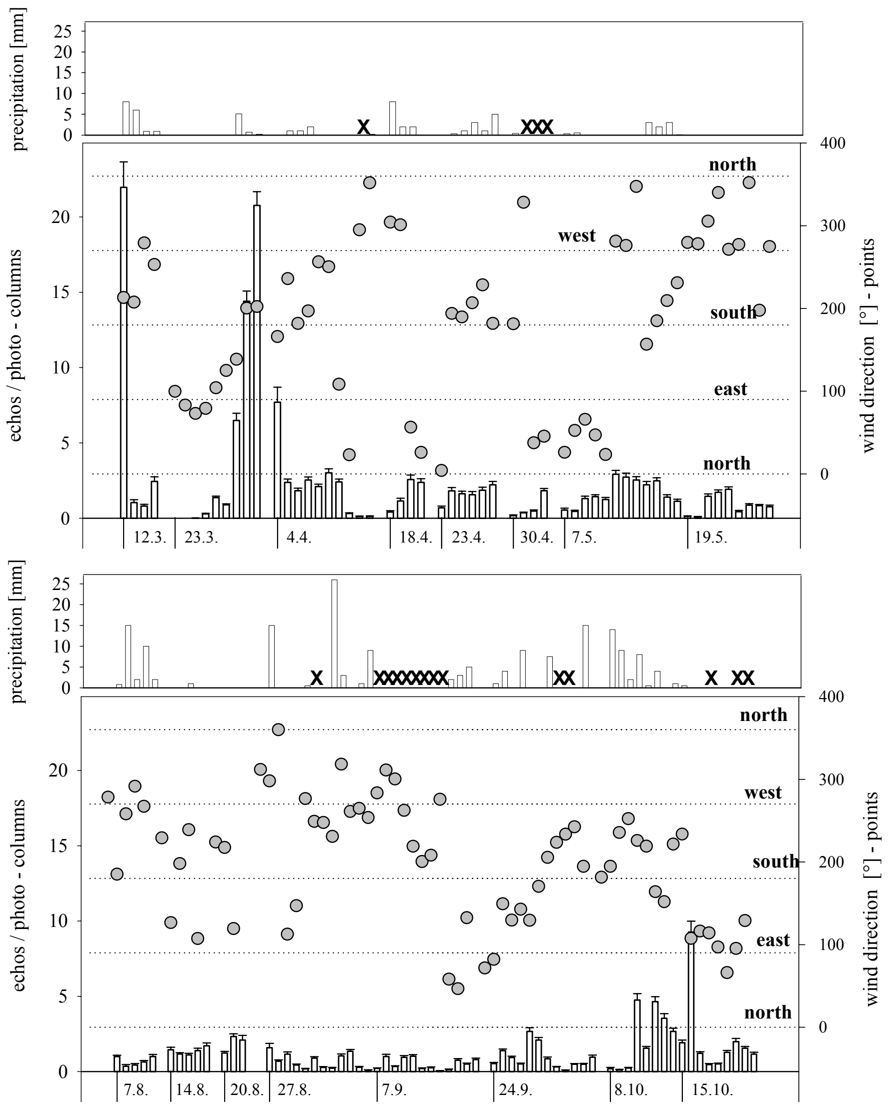


Figure II-38 **Average wind direction and daily precipitation (x = no values) on days with migration observations in relation to registered migration activity (for the labelling of observation campaigns see figure II-34)**

The Tail-Wind-Component (TWC) is more important than the individual factors wind direction and wind speed. This parameter integrates the wind direction in relation to direction of migration of the bird as well as the wind speed. Negative values denote headwinds and positive tailwinds. Wind speed and direction were used as mean values for the hourly intervals. The strongest migration activity was observed during the strongest tail winds (TWC > +5; Figure II-39); however, there was no general increase in activity with increasing tail winds. An intense migration was also observed during calm periods and light headwinds and the high number of hourly intervals of TWC from -2 to +1 indicate that this wind situation occurred very often.

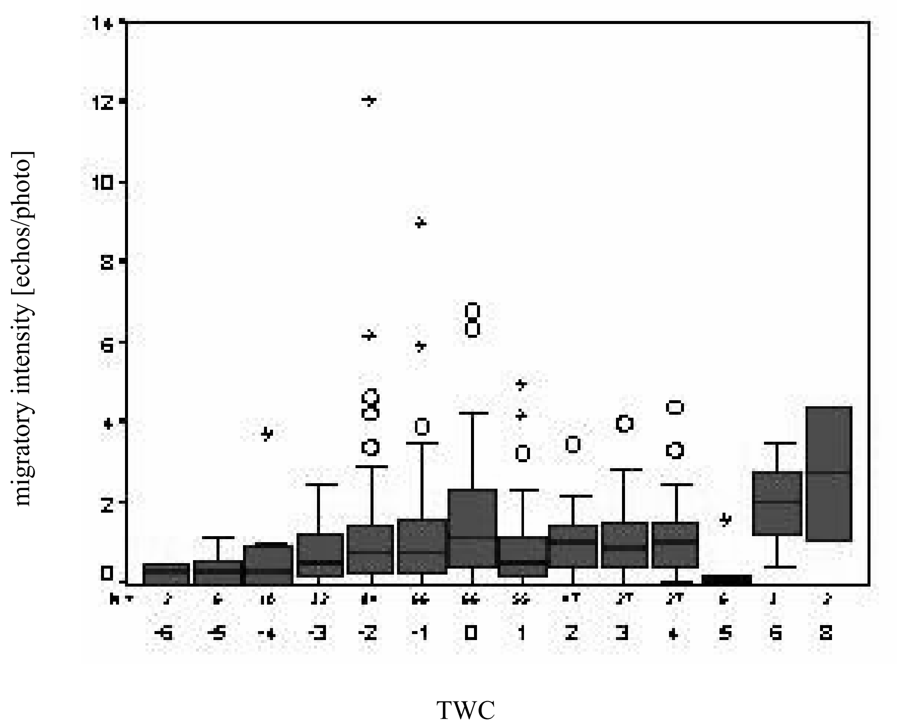


Figure II-39: **Migratory intensity in the lowest 500 m per TWC-group (Tail Wind Component: negative = headwind, positive = tailwind). Box plots show: bar=median, box=25/75 % percentile, circle=outliers (1.5 to 3 times distance from top box end), stars=extreme values (over 3 times the distance from top box end), whiskers = maximum values (without extreme values and outliers). n = number of hours per TWC-group**

When it rained the migration activity did not increase as strongly after sunset as during dry weather (Figure II-40), but the activity peak was shifted to a later time in the night. Thus, when it rains migration activity is retarded and generally low.

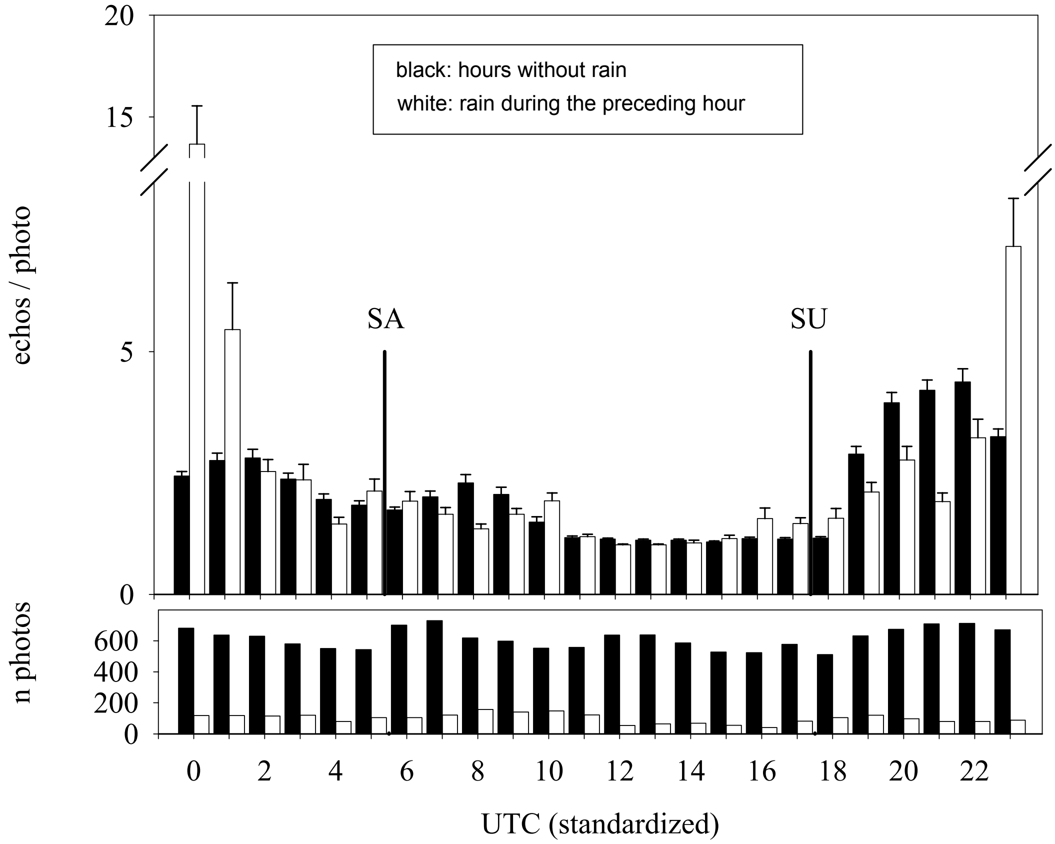
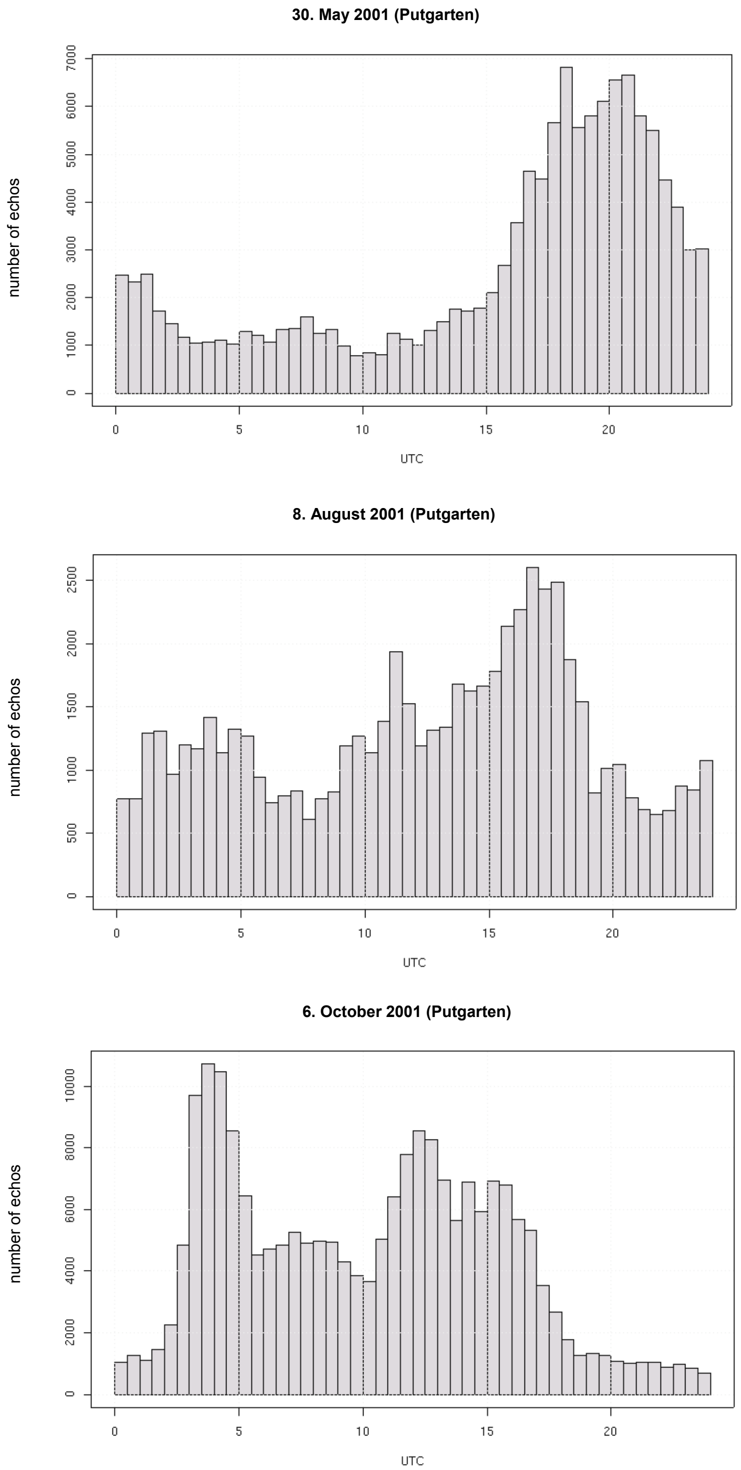


Figure II-40: **Diurnal course of migratory intensity (standardized UTC; means with SE) as a function of weather: black bars - dry; open bars - rain during the preceding hour. The number of photos for each category is shown in the bottom graph. SA=sunrise; SU=sunset.**

II-9.2.2 Military radar

As discussed in chapter II-6.2 the number of recorded echos is strongly dependent on the filter and amplifier settings of the radar. These are changed daily but since they fall under military secrecy they are not disclosed. Thus the daily distribution of migratory intensity needs to be treated with caution (examples in figure II-41). The increase in number of echo numbers by midday or early afternoon are very apparent and clear before sunset (example 8th August and 6th October 2001). It appears that sometimes there is an intensity peak near sunrise (example 6th October). These results do not coincide with those of our own recordings with ship radars (chapter II-9.2.1.2), which is indicative of strong artefacts.

The visualization of the tracks, however, does provide a subjective impression of the migratory intensity using the military data (chapter II-6.2): Accordingly, intensive migration starts when the sun sets. It decreases during the second half of the night but continues well into the morning. At sunrise there is noticeable small-scale flight activity without preferred directions, particularly over the Baltic and the coastal North Sea as well as the mainland coastline. This decreases again during the afternoon hours. It should be emphasized, however, that this is a subjective observation, which can only be used to support our own observations. A quantification of the military data with regard to the daily and seasonal activity is only possible with an enormous effort (mainly manual data treatment), if at all.



FigureII-41: Three examples of the daily distribution of echos from the military radar station at Putgarten (Rügen): 30.05.2001 (sunrise: 02:43 UTC, sunset: 19:25), 08.08.2001 (sunrise: 03:32, sunset: 18:48), 06.10.2001 (sunrise: 05:17, sunset: 16:31)

II-9.3 Discussion

Due to the complexity of weather influences on migration activity, it was not possible to adress this aspect in a comprehensive and conclusive manner. We would have had to consider the local interaction of various factors as well as the changes in large scale weather conditions. More precise measurements of the wind conditions would have been essential (e.g. wind profiles, speeds and direction at different altitudes). We therefore resort to the treatment of single factors, which could be responsible for the observed variation in migratory intensity.

The migration intensities observed during this study are characterized by a number of periods of very intense activity. This means that on average half of the entire migration took place within 6.6 % of the total number of recording hours or 8.2 % of the total number of days of investigation (3 days during spring and 7 in autumn). Dierschke (1989) who used acoustic detection of migratory calls on Helgoland, found that half of the migration, detectable with this method, occurred within 5 nights between the middle of July to the beginning of October 1987. This corresponds well with the daily capture data from the trapping garden of the Institute of Avian Research „Vogelwarte Helgoland" on Helgoland. The institute regularly rings migrating birds: during the spring 2001 half of the total of 2840 birds was caught within 13 days (= 7.2 % all trapping days). During the autumn migration half of a total of 8797 birds was caught within 14 days (= 7.6 %; Hüppop unpubl.). Strong daily variations are often the result of local weather phenomena, which may lead to migratory waves (e.g. Bruderer & Liechti 1998b, Hilgerloh 1981). These may be followed by days of low migratory activity (e.g. Zehnder et al. 2001). During spring, the period of maximum migration (i.e. with the strongest fluctuation in activity) was correlated to drastic changes in the weather. During the first measuring campaign on Fehmarn (23.3. to 31.3.2001) there was no migration in the presence of a strong easterly storm and low temperatures (no echos). Subsequently the wind changed to south-southwest and decreased while temperatures increased (see II-37 and II-38). This change was followed by an intense migration. Unfortunately, it was not possible to run the horizontal radar during this period due to technical difficulties, with the result, that there are no data on the tail wind component for this period. However, the primary direction of migration being NE with the winds coming from S to SW indicates that the birds did have tail winds during this period of migration. Tailwinds lower flight costs and are one of the most important factors favouring migration (e.g. Richardson 1978, Bruderer et al. 1995b, Bruderer 1997b). However, a general correlation between an increasing tail wind component and increasing migration activity could not be established. Apart from the high intensities observed during strong tail winds (TWC 6 and 8), high intensities were also observed during calm days and during slight head winds (TWC -1 to -3). Very low activity was observed when head winds were strong (TWC -4 to -6). During light tailwinds, values were similar to those during slight head winds. It should be remembered, however, that calm days and slight head winds (TWC 0 to -3) occurred during 57 % of the hours of measurement and thus constitute a large proportion of the total weather situation. When slight headwinds prevail for longer periods, the birds probably do not wait for optimal tail winds, but will tend to start under suboptimal but acceptable conditions in order not to waste time.

The effect of rain on migration activity became apparent in a markedly decreased activity after rain (after sunset). The shift of the activity peak by several hours until midnight became very apparent and was very intensive. The reason for this could be that the birds postponed the start of migration because of the rainy weather and to leave in great numbers after rain stopped. The shift in the activity peak is mostly attributed to the activity on the 29th and 30th March on Fehmarn, where despite several rain showers there was strong activity due to the described change in weather (mainly wind). The diurnal activity curve for Fehmarn shows that during spring a peak occurred 2 to 3 hours after sunset (similar to the other locations). The assumption therefore is, that most birds begin their migration within a radius of 100 to 150 km (estimated flight speed 50 km h^{-1}).

The migration activity was strongly related to the time of day, which corresponds with other observations. The activity peaked before midnight and subsequently decreased during the second half of the night (Able 1970, Bruderer 1997b, Bruderer & Liechti 1998b, Fortin et al. 1999, Liechti et al. 1997, Zehnder et al. 2001). The lowest activity was recorded during midday. Particularly long distance migrating insectivores (and also waders, ducks and geese) are typical nocturnal migrants, whereas small seedeaters (short distance migrants; finches, buntings, larks) and large birds (which require thermals to soar) are exclusively or mainly daytime migrants (Berthold 1996, 2000).

The analysis of the military data yielded disappointing results on the migration intensity. According to the current state of knowledge, the own measurements are the only data, which can be used for the quantification of migration both diurnally and seasonally (see also chapter II-13).

II-10 Spatial distribution of migration over the North and Baltic Seas

II-10.1 Introduction

The current understanding is, that migrants cross the North and Baltic Seas in a broad front (e.g. Jellmann 1977, Buurma 1987, 1995, Alerstam 1990), whereby the direction and intensity are species specific and dependant on the weather (e.g. Jellmann 1977, Alerstam 1990). In the area of the highly differentiated coastline of the Baltic Sea, the coast often acts as a guiding line for low flying migrants. This applies to both terrestrial birds which prefer to fly short distances over water or are not „brave“ enough, as well as to sea and coastal birds (particularly ducks) which avoid flying over land (for examples see e.g. Figure 87 in Alerstam 1990). Guiding lines are less apparent along the North Sea coast (see Jellmann 1988).

Former radar investigations were, without doubt, useful for the understanding of migration. But they mainly deal with single species, particular weather situations or are locally too restricted for an spatial assessment. In this project we attempted for the first time an spatial quantification of migration over the eastern North Sea and the western Baltic Sea during the main periods of migration. This covers a large proportion of the migratory routes of Norwegian and Swedish breeding birds.

II-10.2 Results

In the North Sea area it is clear that there is a reduction in migratory intensity towards the sea (Figures II-42 and II-43). This was particularly obvious in March 2001. However, during all months there is a broad band of intensive migration along the entire coast of the Netherlands up to Denmark. A constant and distinct peak occurs off the Netherlands coast. This peak is continued along the main direction of migration off the coast of Schleswig Holstein (compare north-south-profile). The broad band of migration activity off the Schleswig Holstein coast varies in width but stretches up to 80 to 100 km out to sea.

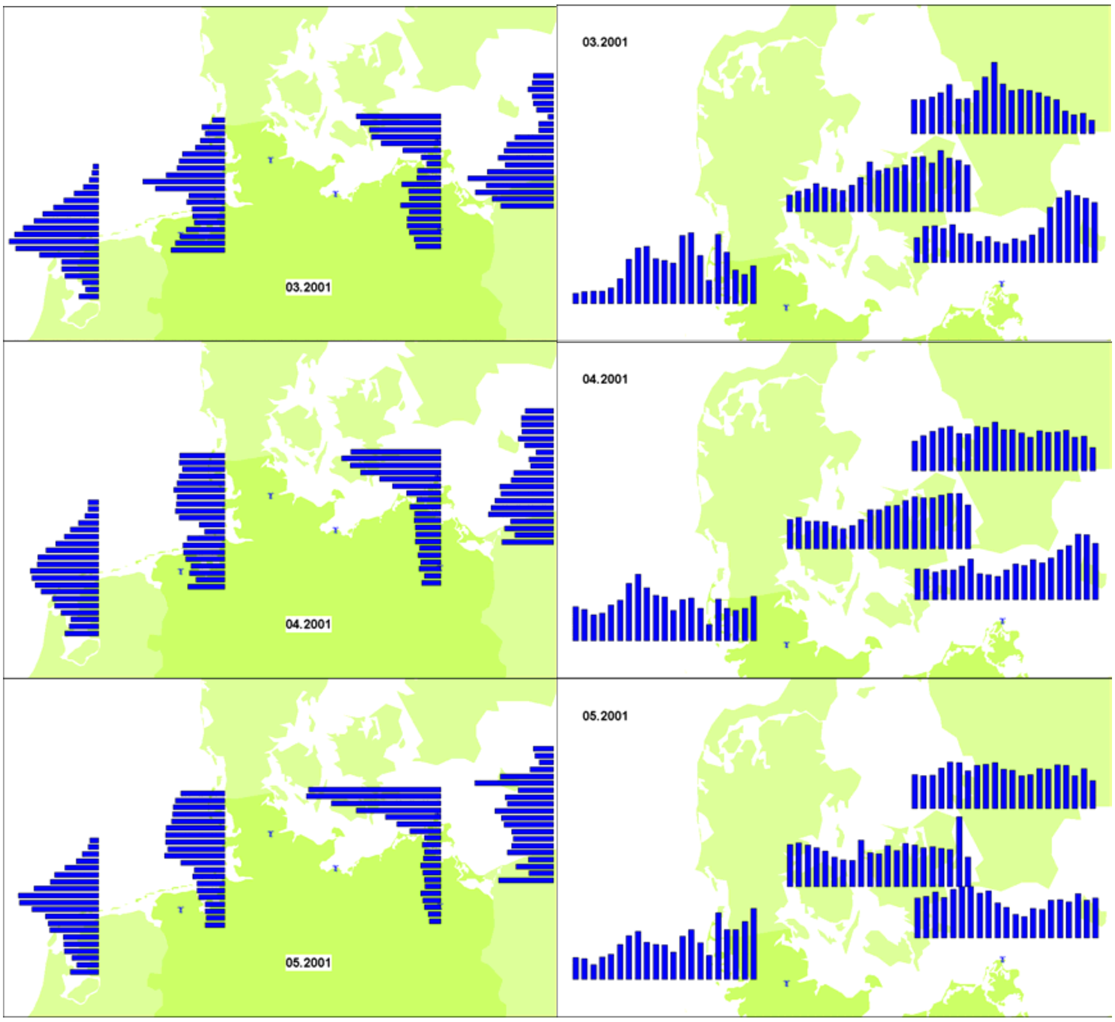


Figure II-42: **Relative (!) migratory intensity derived from military radar data along north-south- (left) and west-east- (right) transects during spring migration (March to May 2001). The basic lengths of the transects are scaled to the map.**

As the west-east transects show, there is also a broad front migration over the Baltic Sea of a similar intensity from Schleswig-Holstein and Mecklenburg-Vorpommern to Denmark and Sweden (local concentrations such as the „Vogelfluglinie“ cannot be plotted using this method, see. chapters II-8.2.2 and II-12.1.2!). It is only over Jütland and Lolland that the migration is slightly less intensive at times. The north-south profiles show clear spatial differences in intensity during all months. This is attributed mainly to the extraordinary flight activity of seaducks or perhaps gulls in the area north of Rügen and the Bay of Pomerania, as already seen in the radar visualization (chapter II-8.2.2). During September 2001, and less obvious in March and August 2001, there are smaller peaks over the mainland south of Rügen.

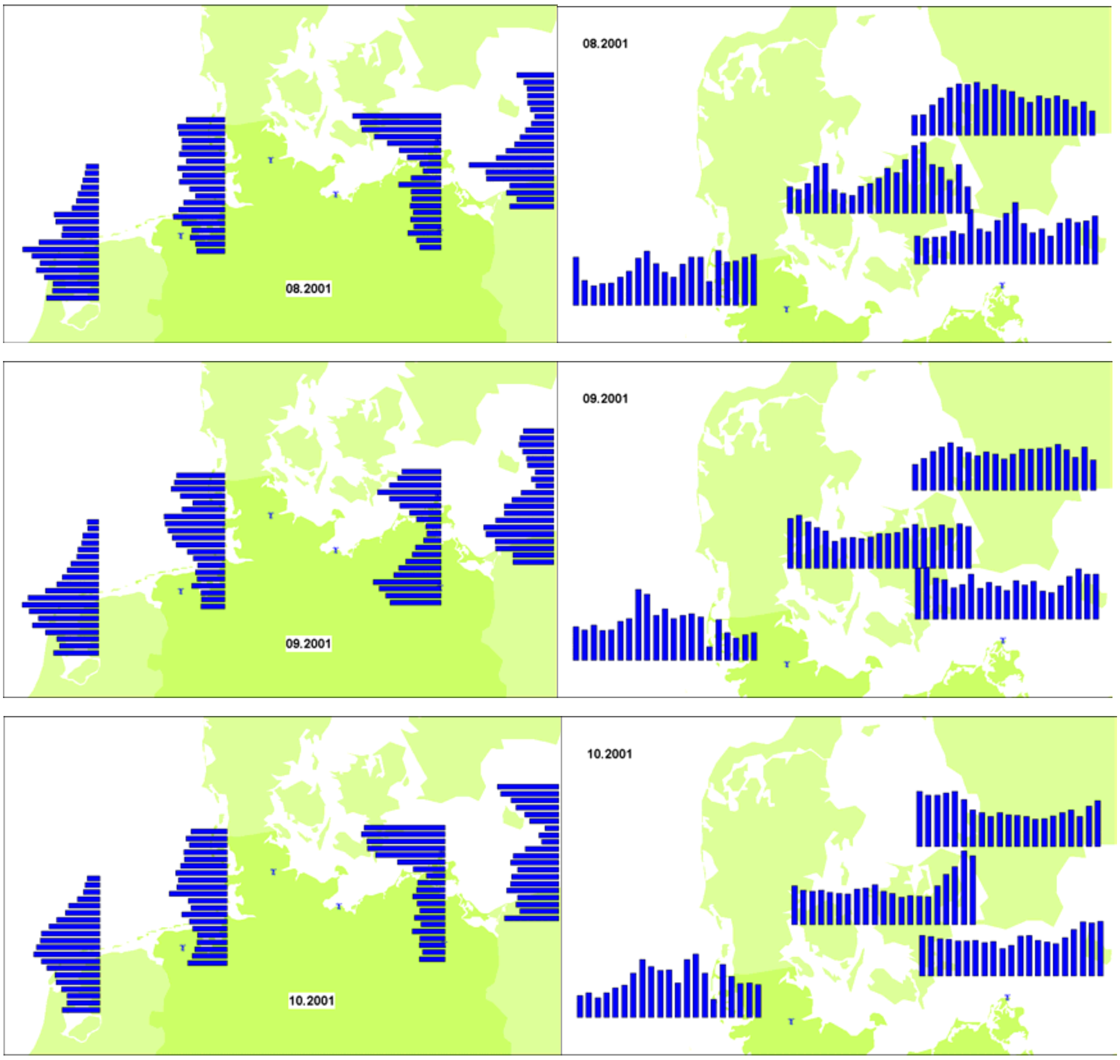


Figure II-43: Relative (!) migratory intensity derived from military radar data along north-south- (left) and west-east- (right) transects during autumn migration (Months: August to October 2001). The basic lengths of the transects are scaled to the map.

II-10.3 Discussion

The data collected with the large military surveillance radar allow a good spatial quantification of migration, despite the methodological shortcomings. The main uncertainty is the question as to what extent the echos obtained with the radar are representative for the lower airspace. Our own data which were obtained with the vertical radar (chapter II-6.1) show a high correlation of the bird echos between 0 and 200 m with the daily sums of bird echos between 1500 and 2000 m ($r = 0.523$, $n = 124$ days, $p < 0.001$). This permits the conclusion, that the average military data are also representative for the lower airspace, despite the fact that these zones are out of reach for the radar due to the curvature of the earth. The relationship is probably more precise when the factors wind force and direction are included. However, it remains unclear, understandably so, how representative the monthly means are relative to the long-term comparisons (see research needs, chapter II-15).

The recent visual observations by Dierschke (2001b) who found that the migration intensity becomes less from the coast towards the central North Sea were confirmed by the radar, although the data did not reveal such clear differences. This may be due to the large proportion of birds migrating at night. Our data also correspond well with those of Jellmann (1977) who found that the migration over the inner German Bight was denser than elsewhere.

For the Baltic, the picture was more complex. The summary of examples selected by Alerstam (1990) can be used to extrapolate for the entire migration in this region. There is an overlap of many species which fly over the area in a broad front (e.g. Common Wood Pigeon in Alerstam 1990), which overlaps with the Common Eider during the high intensity migration parallel to the coastline of the southern Swedish coast (compare chapter II-4). The activity peaks north of Rügen should also include terrestrial birds which, like the Common Crane (Alerstam 1990), cross the sea at its narrowest point after leaving Mecklenburg-Vorpommern.

II-11 Distribution of selected sea and coastal birds in the North and Baltic Seas (by Stefan Garthe)

II-11.1 Introduction

The predominantly coastal regions of the German North and Baltic Seas up to a water depth of 30 m are internationally extremely important feeding, resting and moulting sites as well as wintering zones for a large number of sea and coastal birds. Areas of particular importance in the North Sea are the eastern German Bight off the coast of Schleswig-Holstein and a relatively narrow strip off the East Frisian Islands (Skov et al. 1995, Mitschke et al. 2001). In the Baltic, the significant areas are the Bodden waters around Darss up to the mouth of the Oder river, the Pomeranian Bight including the Oder Bank, and the Kiel Bight (Skov et al. 2000, chapter II-3). Many of the species occurring there fall under the international convention for the protection of birds, particularly the EU guideline on the preservation of wild bird species (79/409/EWG) and the African Eurasian Waterfowl Agreement (AEWA, Haupt et al. 2000). The aim of this chapter is to describe the distribution of species worthy of protection in the German offshore regions of the North and Baltic Seas as well as to provide a comprehensive assessment. Due to the variability in the data, particular emphasis will be placed on the German North Sea areas.

II-11.2 Material and Methods

The occurrence of sea and coastal birds has been investigated from ships following to standardized methods within the "Seabirds-at-Sea"-Programme since 1979. Initially investigations were only carried out in the North Sea. However they have now been extended to bordering seas. The data are archived in various international databases and regularly transferred to the "European Seabirds at Sea Database" which currently holds more than 1 Million observations and is updated twice annually. The database is coordinated by the "European Seabirds at Sea Co-ordinating Group" (see recent overview on German participation in Garthe & Hüppop 2000).

Observations of birds take place from ships top decks (= “roof”) or nock (= “balcony” on side of the bridge) (Tasker et al. 1984, Webb & Durinck 1992, Garthe et al. 2002). One to three observers count all flying and swimming birds within a 300 m wide transect parallel to the ship on one or both sides of the ship. At the same time the position of the ship as well as the environmental conditions are recorded for every counting interval (standard: 10 min; special cruises: 1 min) so that all observations have a corresponding position. Birds are generally observed with the naked eye. Binoculars are used to determine or check species, age and sex etc. The recording of sea ducks and divers which often fly at high altitudes (often > 1 km) has to be done by systematic survey from the front of the ship. To calculate densities (e.g. individuals per km²) it is essential to distinguish between birds within and outside the transect. Within the transect, means all swimming birds between 0 and 300 m from the ship, as well as all flying birds which are within this area on the full minute (per convention). All swimming birds outside the 300 m line as well as flying birds which are not observed on the full minute are regarded as being outside the transect. This correction for flying birds prevents the overestimate or repeated counting of birds, which occur in large numbers or fast flying birds.

The density of swimming birds was corrected by applying the factors of Stone et al. (1995) since birds that were somewhat distant from the ship could not be seen that well (depended on species and conditions of observation).

The ESAS data bank Version 3.0 (Date July 2000) as well as the German "Seabirds at Sea" data bank (date April 2002) which is maintained at the FTZ Büsum (Kiel University) are the backbone of this study. The latter comprises data from the FTZ, the IfV, of the IfM Kiel and the ZIM of the University of Hamburg. This constitutes a large data set which is much more comprehensive than that used for the project: "Erfassung der Verbreitung, Häufigkeiten und Wanderungen von See- und Wasservögeln in der deutschen Nordsee und Entwicklung eines Konzeptes zur Umsetzung internationaler Naturschutzziele (BOFFWATT)" (Mitschke et al. 2001). Two special cruises with the research vessel "Heincke" were carried out, particularly for this project in areas of the North Sea which have not been covered extensively before. The studies were carried out from the 16th to 20th January 2001 and from the 29th November to the 5th December 2001. Since the Baltic has only recently been included in the ESAS coverage, there are fewer systematic observations, mainly from the German data bank. The first German survey was carried out here in February 2000. It was not possible to carry out further studies due to a lack of funding. In addition the updated observations of international waterbird surveys including ship surveys by Danish colleagues, whose data have not yet been included in the ESAS data bank are summarized in this study

A combined database for the North Sea was formed from the data banks mentioned above which constitutes the base of all charts. The temporal coverage comprises the last 10 years i.e. from 1992 to 2001. All the maps for the North and Baltic Seas are based on a matrix, which has grid sides of 6' (width) and 10' (length) and an area of 120 km². Each grid represents the bird density, which is derived from the total of all identified individuals divided by the sum of the charted area.

For the North Sea six species which according to the "Important Bird Areas for seabirds in the North Sea including the Channel and the Kattegat" (Skov et al. 1995) fulfil the criterion of constituting at least 1% of the resting biogeographical population in the German Bight were plotted on individual maps. The distribution and frequency of these species is described and briefly analysed, corresponding to the appropriate period of observation. Winter maps for five Baltic species which are at least listed in one of the "Important Bird Areas" (Skov et al. 2000) and for which the data base seemed appropriate for a short description, are presented: Slavonian Grebe, Black Scoter, Common Eider, Long-tailed Duck und Velvet Scoter.

Furthermore, a Windenergy-Sensitivity-Index (= WSI; Garthe & Hüppop in press) prepared for the German North Sea waters could be used to depict a chart of the resting bird populations which are sensitive to the utilization of offshore wind energy This presentation is based on the four seasons: winter = December to February, spring = March to May, summer = June to August, autumn = September to November.

The index comprises the following factors by which each species is classified according to: 1 (least impact by offshore Wind energy plants) to 5 (greatest impact) based on data and expert estimates (compare for example Furness & Tasker 2000).

1) Manoeuvrability during flight
2) Flight altitude
3) Frequency of flying versus swimming
4) Nocturnal activity
5) Dependency on special feeding grounds
6) Variability in the choice of habitat
7) Sensitivity to disturbance by shipping
8) Biogeographical population size
9) Species specific mortality of adults
10) Protection-/endangered status in Europe

The WSI value is derived from the mean of the classification into factors 1 to 3, multiplied by the mean of the classification factors 4 to 7, multiplied by the mean of the classification factors 8 to 10.

The product gives a species specific WSI value (Garthe & Hüppop in press. The peer reviewing brought some minor changes from the preliminary values and maps presented here. However, we did not correct these to avoid deviations from the already published German final report):

Red-throated Diver (*Gavia stellata*)	45.0
Black-throated Diver (*Gavia arctica*)	45.0
Sandwich Tern (*Sterna sandvicensis*)	33.0
Great Skua (*Catharacta skua*)	26.3
Red-necked Grebe (*Podiceps grisegena*)	24.5
Great Crested Grebe (*Podiceps cristatus*)	24.4
Velvet Scoter (*Melanitta fusca*)	21.0
Northern Gannet (*Morus bassanus*)	21.0
Lesser Black-backed Gull (*Larus fuscus*)	15.8
Little Gull (*Larus minutus*)	5.0
Atlantic Puffin (*Fratercula arctica*)	14.0
Common Tern (*Sterna hirundo*)	13.3
Black Scoter (*Melanitta nigra*)	11.3
Arctic Skua (*Stercorarius parasiticus*)	11.3
Black Tern (*Chlidonias niger*)	10.5
Great Black-backed Gull (*Larus marinus*)	10.5
Razorbill (*Alca torda*)	10.0
Great Cormorant (*Phalacrocorax carbo*)	10.0
Common Eider (*Somateria mollissima*)	9.8
Mew Gull (*Larus canus*)	9.0
Northern Fulmar (*Fulmarus glacialis*)	7.5
Arctic Tern (*Sterna paradisaea*)	7.0
Herring Gull (*Larus argentatus*)	6.0
Black-headed Gull (*Larus ridibundus*)	4.1
Black-legged Kittiwake (*Rissa tridactyla*)	4.0
Common Guillemot (*Uria aalge*)	4.0

Subsequently for each grid and every season the WSI value is multiplied by the natural logarithm (ln) and the density (+1, to avoid undefined values) of each species and is then summed for all species. The result is a WSI value for each grid and season.

II-11.3 Results and discussion

II-11.3.1 Distribution and frequency of the most important species

German Bight

Divers (Red-throated Diver *Gavia stellata* and Black-throated Diver *Gavia arctica*):
The main distribution area of both diver species in the North Sea is the eastern German Bight (Skov et al. 1995). While only low densities are observed in autumn (Figure II-44), values in winter (Figure II-45) and spring (Figure II-46) are much higher. Key area is the 20 meter depth zone off the coast of Schleswig-Holstein, which correspondingly is off great international importance. High densities are also attained in the region off the East Frisian Islands and in the Weser-Jade-estuary. The spatial distribution of the main occurrence in the eastern German Bight varies with the shift in salinity fronts, which is determined by the freshwater inflow of the Elbe River as well as wind direction and force (Skov & Prins 2001).

Red-necked Grebe (*Podiceps grisegena*):
This species was only observed in isolated cases and low densities in the eastern German Bight (Figure II-47).

Black Scoter (*Melanitta nigra*):
Due to the extreme difficulties in recording this species occurring in locally high concentrations in shallow waters (Hennig & Hälterlein 2000), the distribution maps are only conditionally meaningful (Figures II-48 to II-50). Currently the most important areas in the German Bight are the area west of the peninsula Eiderstedt, south of Amrum as well as north of the Island of Sylt (Mitschke et al. 2001, Hennig 2001). The occurrence off Eiderstedt is particularly interesting since the birds occur there throughout the year even during the moulting season (Figure II-48). The occurrence is probably correlated with appropriate mussel beds, whereby interference by ships also plays an important role (Hennig 2001).

Little Gull (*Larus minutus*):
The Little Gull occurs in the German Bight throughout the year. It attains large densities particularly during the temporally highly concentrated migration from mid April to the beginning of May (Figure II-50/51; compare Garthe 1993) as well as during their autumn migration (Figure II-53). During summer (Figure II-52) and winter (Figure II-54) its distribution is more diffuse with key areas being the Elbe-Weser-estuary and further north.

Mew Gull (*Larus canus*):
During the breeding season, the Mew Gull is concentrated near the breeding colonies along the coast where it occurs in larger densities. Further away from the coast it occurs only sporadically and at lower densities (Figure II-55). When they leave to migrate in autumn, the species moves further out to sea (Figure II-56). During winter, the Mew Gull is the most frequent and widely distributed species in the German Bight (Figure II-57). This is particularly true for the zone between the coast and the 30 m depth isoline. Its occurrence is of international importance (Skov et al. 1995). The pattern of distribution at sea is strongly correlated to the wind. These gulls move further out to sea during east wind situations where they congregate in larger densities than during westerly wind conditions. There the distribution appears to be concentrated on a rather narrow strip off the coast (Garthe & Hüppop 1997, Garthe unpubl. data). The pattern during spring migration (Figure II-58) resembles that during autumn migration.

Sandwich Tern (*Sterna sandvicensis*):
During the breeding season the Sandwich Tern occurs mainly in the offshore area of the Wadden Sea (Figure II-59). There it has its main feeding areas, which may be up to 45 km away from their breeding grounds (Garthe et al. in prep.). After the breeding season the basic distribution pattern remains the same although in some areas Sandwich Terns may congregate in larger numbers (Figure II-60).
Germany has the international responsibility of conserving the breeding areas. Since the species only has a few breeding colonies, their food supply beyond the Wadden Sea national Park has to be guaranteed (see Mitschke et al. 2001).

German Baltic Sea

In their recent compilation, Skov et al. (2000) list a total of 19 "Important Bird Areas", which in their main distributions lie within the German Baltic waters or the coast. These include the Kiel Bight, the western Mecklenburg Bight, and the area north of Darss as well as the Pomeranian Bight. At least 20 sea and coastal bird species reach internationally important numbers in these offshore wintering or resting grounds. However these data could not be used for this project at this stage (see Material and Methods). However, the utilizable ESAS and FTZ/IfV data allow the following conclusions:

Slavonian Grebe (*Podiceps auritus*):
The Slavonian Grebe was almost exclusively found in the Pomeranian Bight within the German Baltic regions (Figure II-61). Despite the low density of the species, it has a wide distribution. This finding has important international importance since a large proportion of the biogeographical population (25% of the German and Polish populations combined) winters there (Skov et al. 2000).

Common Eider (*Somateria mollissima*):
The Common Eider is concentrated in the western region of the German Baltic during winter (Figure

II-62). Key area is the Kiel Bight, although the distribution of this duck species has not yet been completely determined.

Long-tailed Duck (*Clangula hyemalis)*:
Despite an incomplete data set it is clear that the Long-tailed Duck has two key areas of distribution in the German Baltic waters during winter: the Pomeranian Bight and the area north of the Darss (Figure II-63). It is not clearly discernable that the Kiel Bight and parts of the Mecklenburg Bight may also have an important role in the winter occurrence of the species (see Durinck et al. 1994).

Black Scoter (*Melanitta nigra*):
The distribution of the Black Scoter resembles that of the Long-tailed Duck, however it has a clearly more restricted distribution area (Figure II-64).

Velvet Scoter (*Melanitta fusca*):
In the German parts of the Baltic Sea, the Velvet Scoter has only been observed in the Pomeranian Bight where it occurs in high densities and almost throughout the Oder bank (Figure II-65).

II-11.3.2 Sensitivity grid of the occurrence of resting birds in the German Bight in relation to offshore wind energy utilization

The sensitivity grid, which is based on the wind energy sensitivity index, clearly shows the regions in the German North Sea, which are particularly sensitive to wind energy utilization (Figure II-66 to II-69). Of particular importance during all seasons is a 20 to 40 km wide zone off the East and North Frisian Islands as well as the complete outer Elbe-Weser-estuary. The significance of these areas, also in absolute values, is particularly great during winter (Figure II-69) whereby it remains unclear, due to a lack of data, how far this zone reaches out to sea. During summer, the area around the island of Helgoland is of greater importance, especially the area nearer to the coast (Figure II-67). The sensitivity values for the German Bight are relatively low during autumn (Figure II-68), whereby the outer regions of the German EEZ become sightly more important due to the active migration of sea and coastal birds at this time of year.

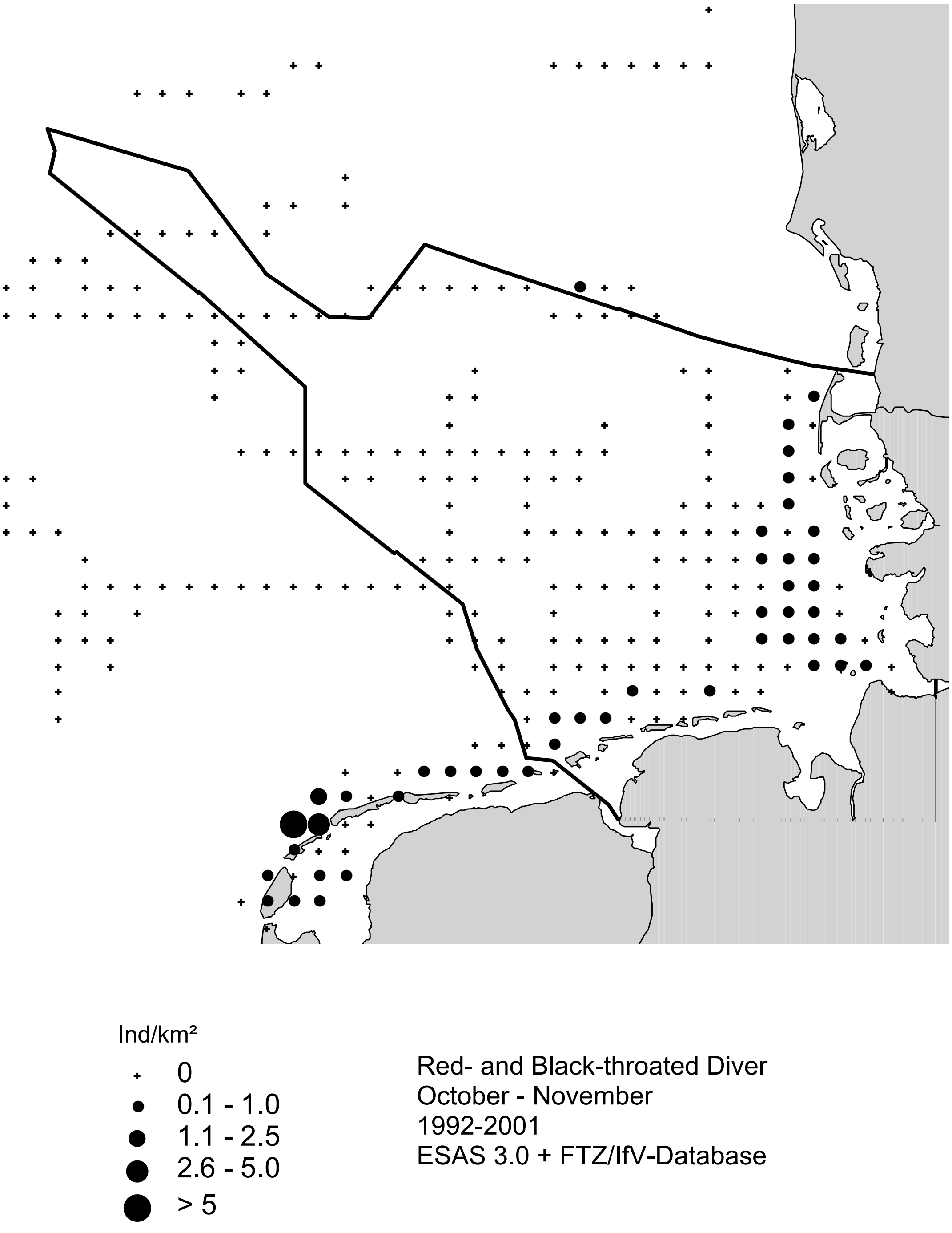


Figure II-44: Distribution of Red-throated and Black-throated Divers in the German North Sea regions from October to November 1992-2001.

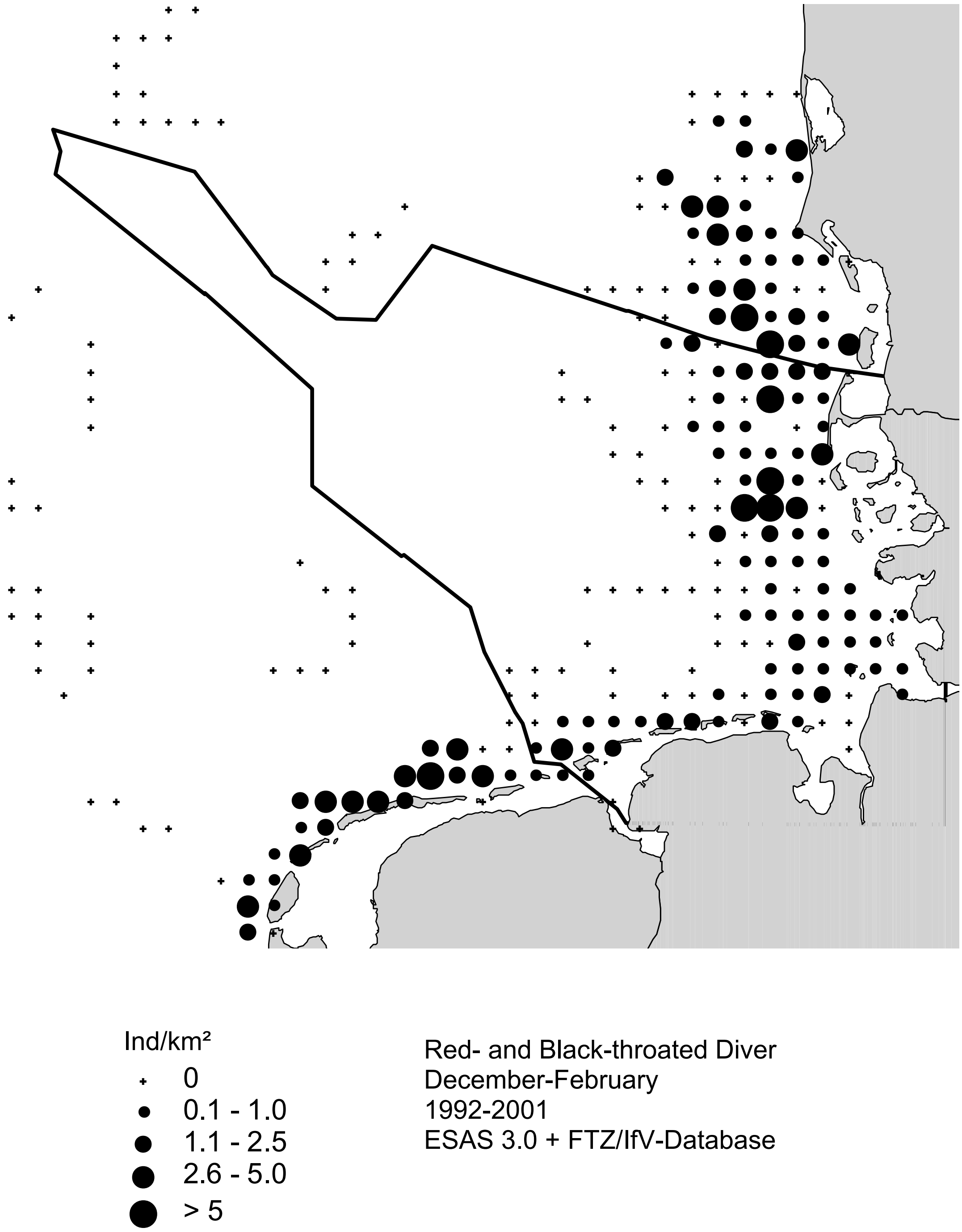


Figure II-45: Distribution of Red-throated and Black-throated Divers in the German North Sea regions from December to February 1992-2001.

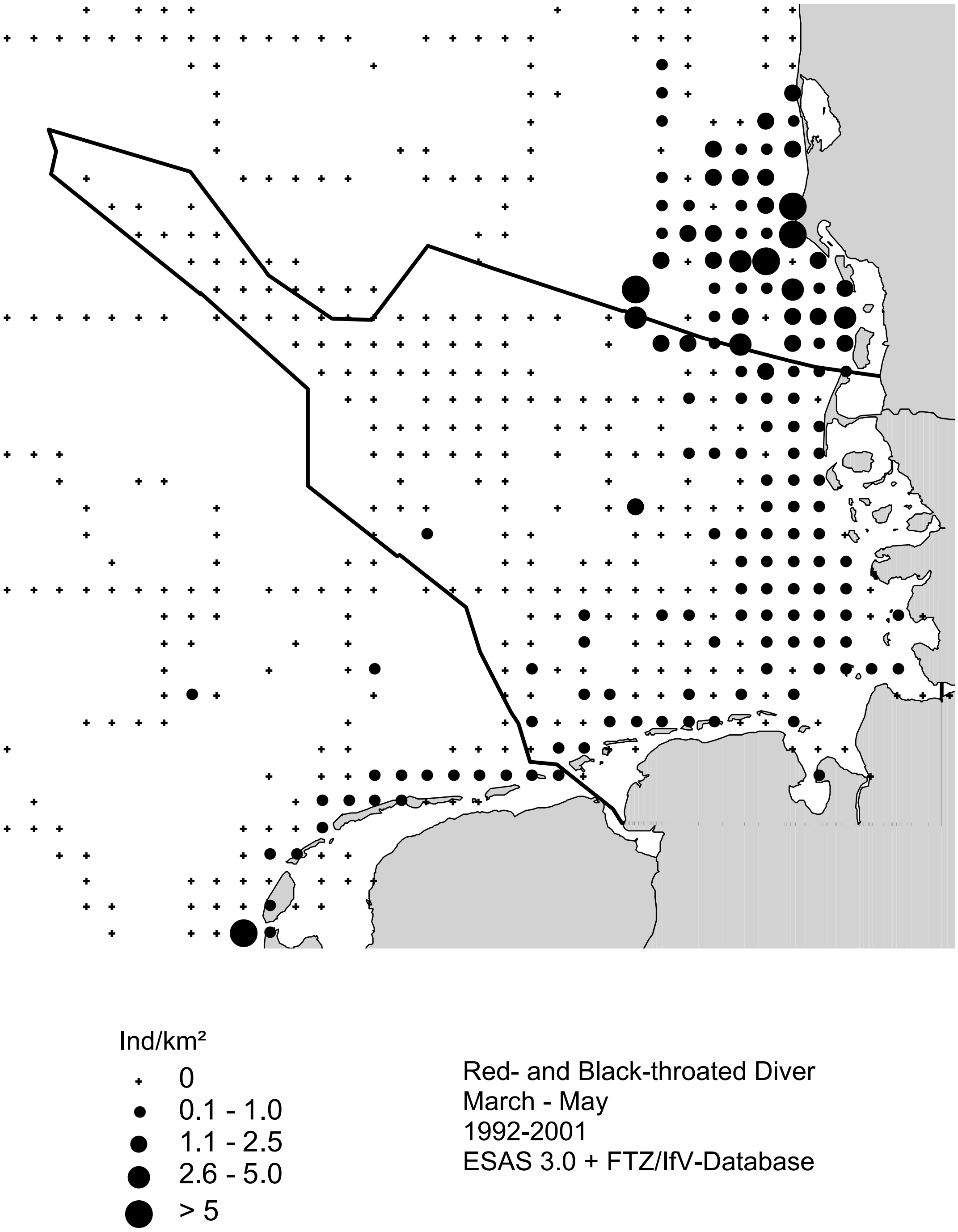


Figure II-46: Distribution of Red-throated and Black-throated Divers in the German North Sea regions from March to May 1992-2001.

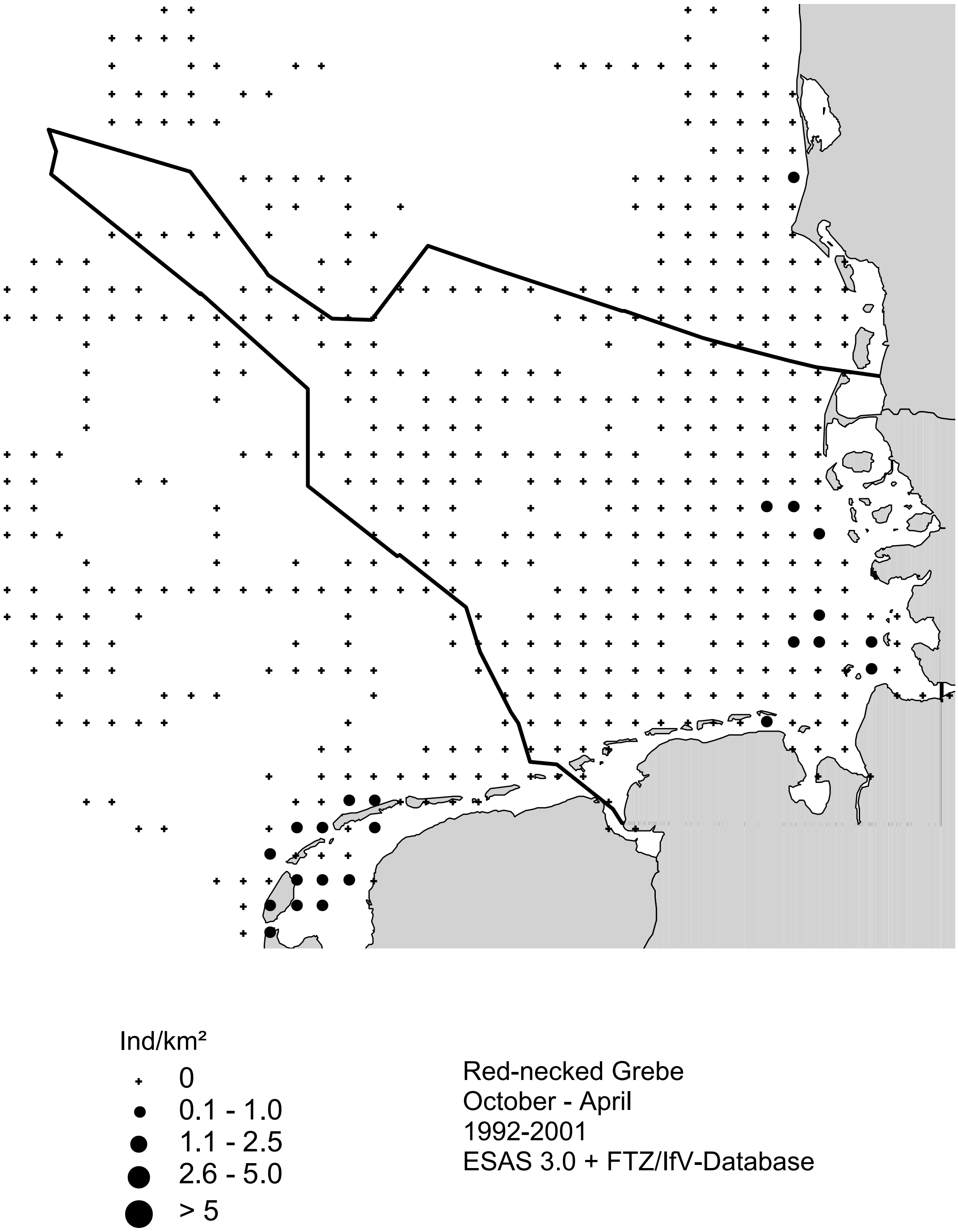


Figure II-47: **Distribution of the Red-necked Grebe in the German North Sea regions from October to April 1992-2001.**

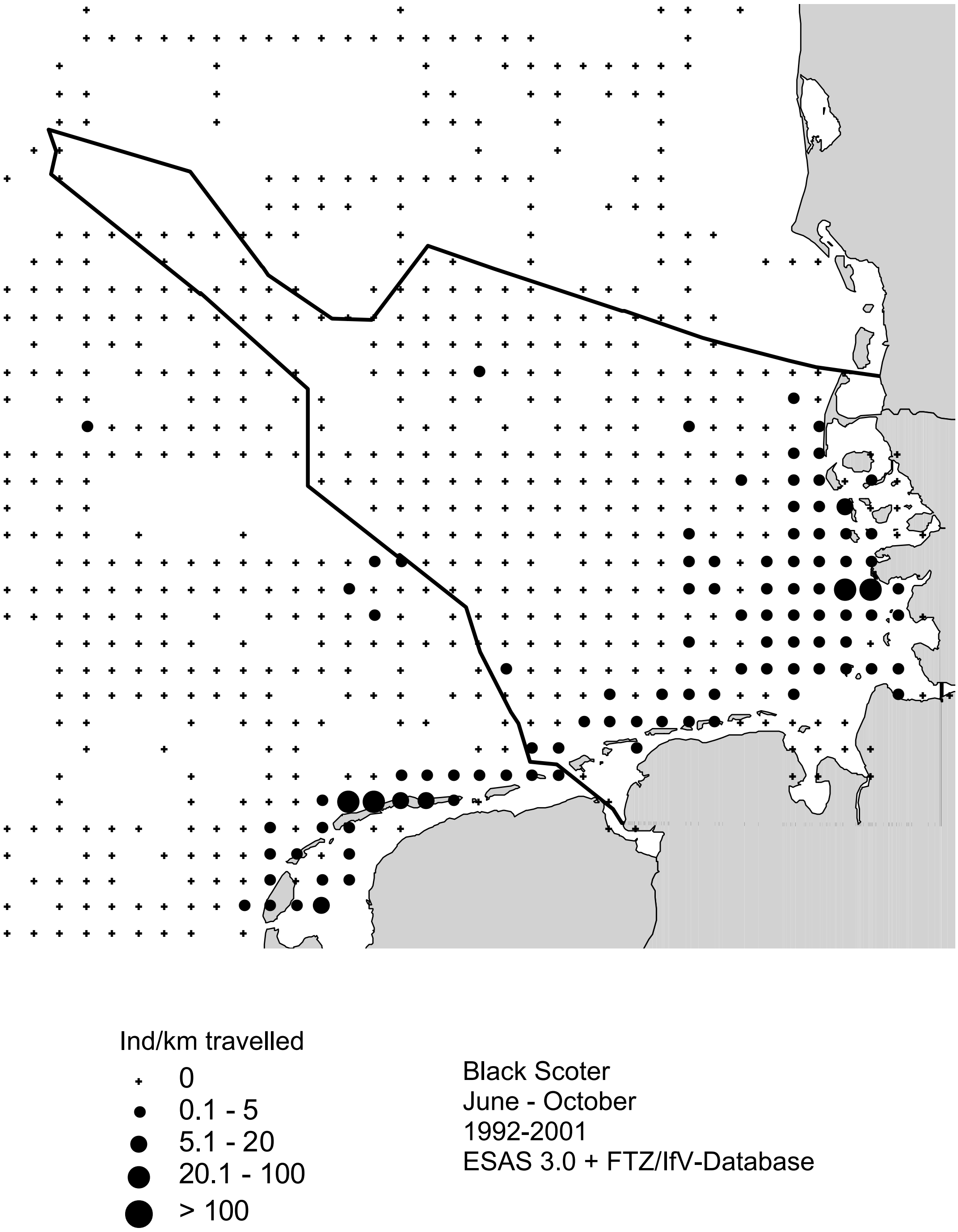


Figure II-48: Distribution of the Black Scoter in the German North Sea regions from June to October 1992-2001.

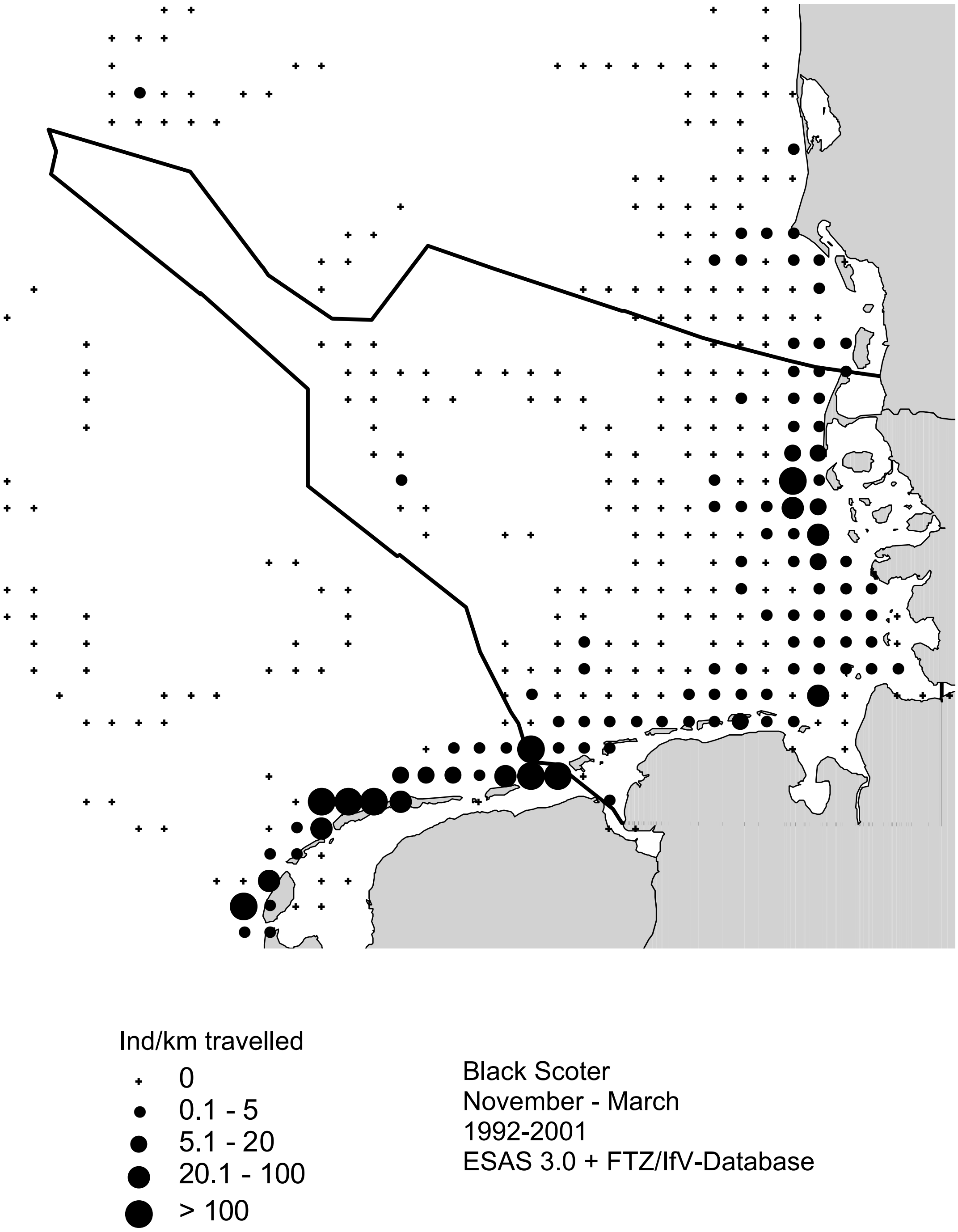


Figure II-49: Distribution of the Black Scoter in the German North Sea regions from November to March 1992-2001.

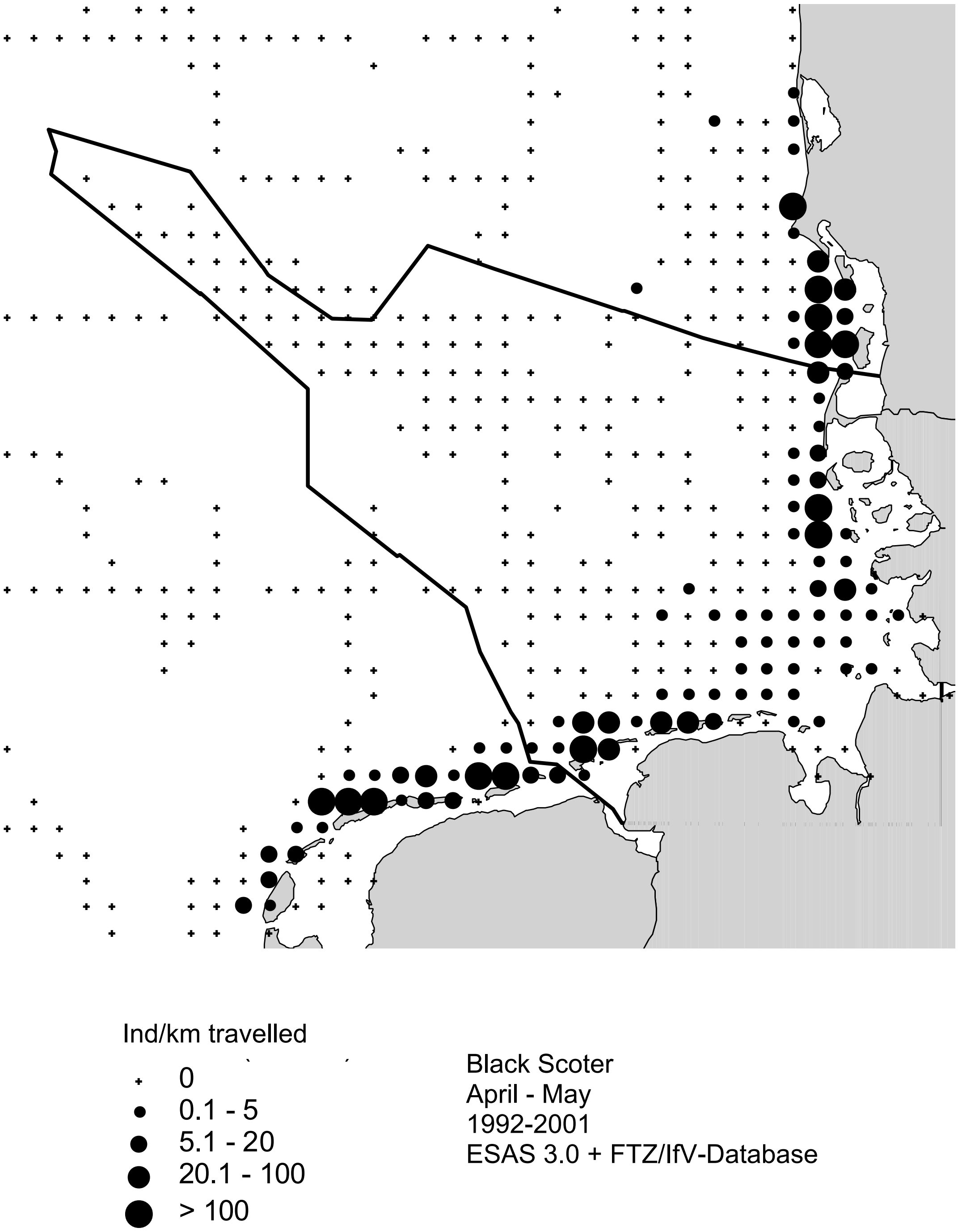


Figure II-50: Distribution of the Black Scoter in the German North Sea regions from April to May 1992-2001.

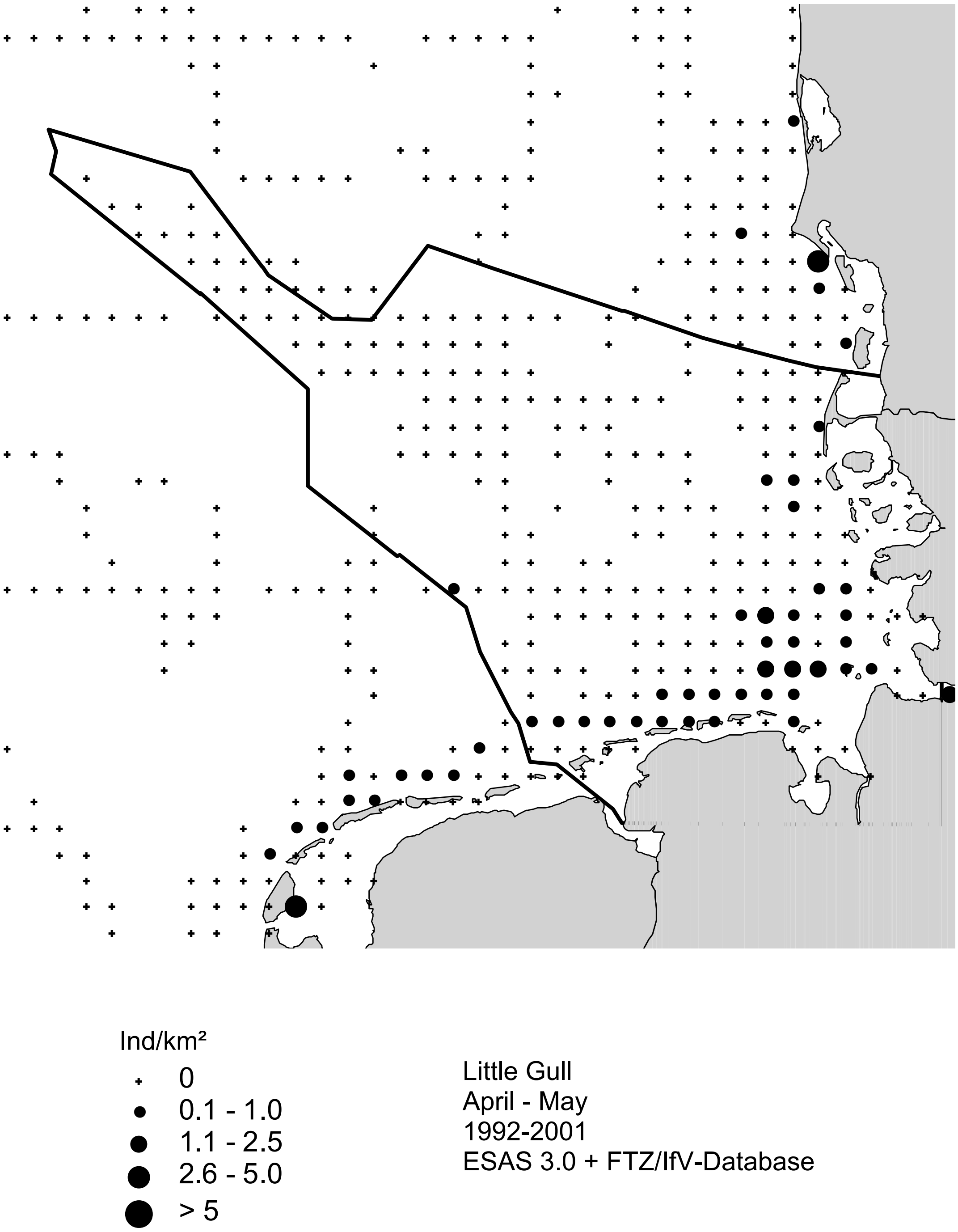


Figure II-51: Distribution of the Little Gull in the German North Sea regions from April to May 1992-2001.

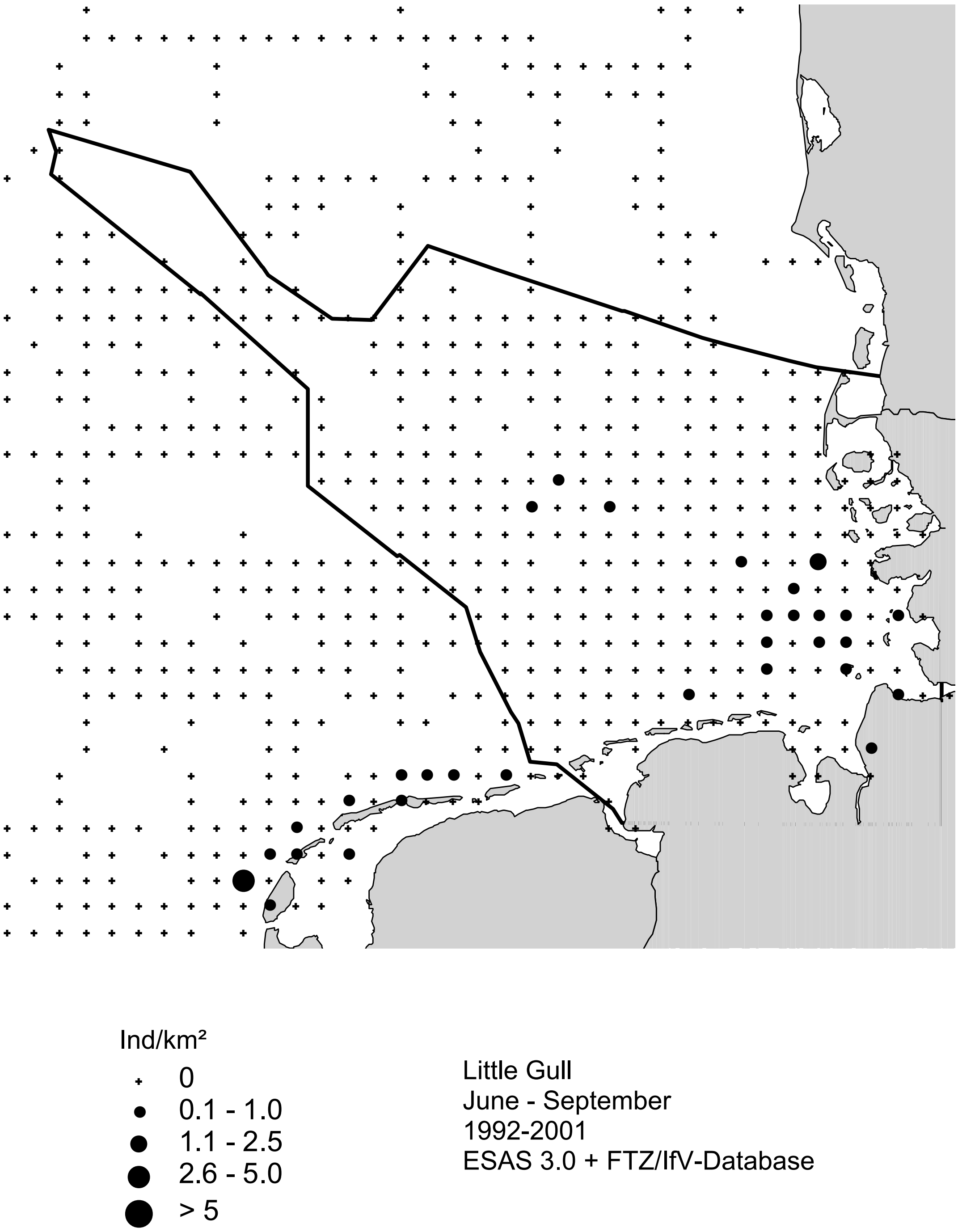


Figure II-52: Distribution of the Little Gull in the German North Sea regions from June to September 1992-2001.

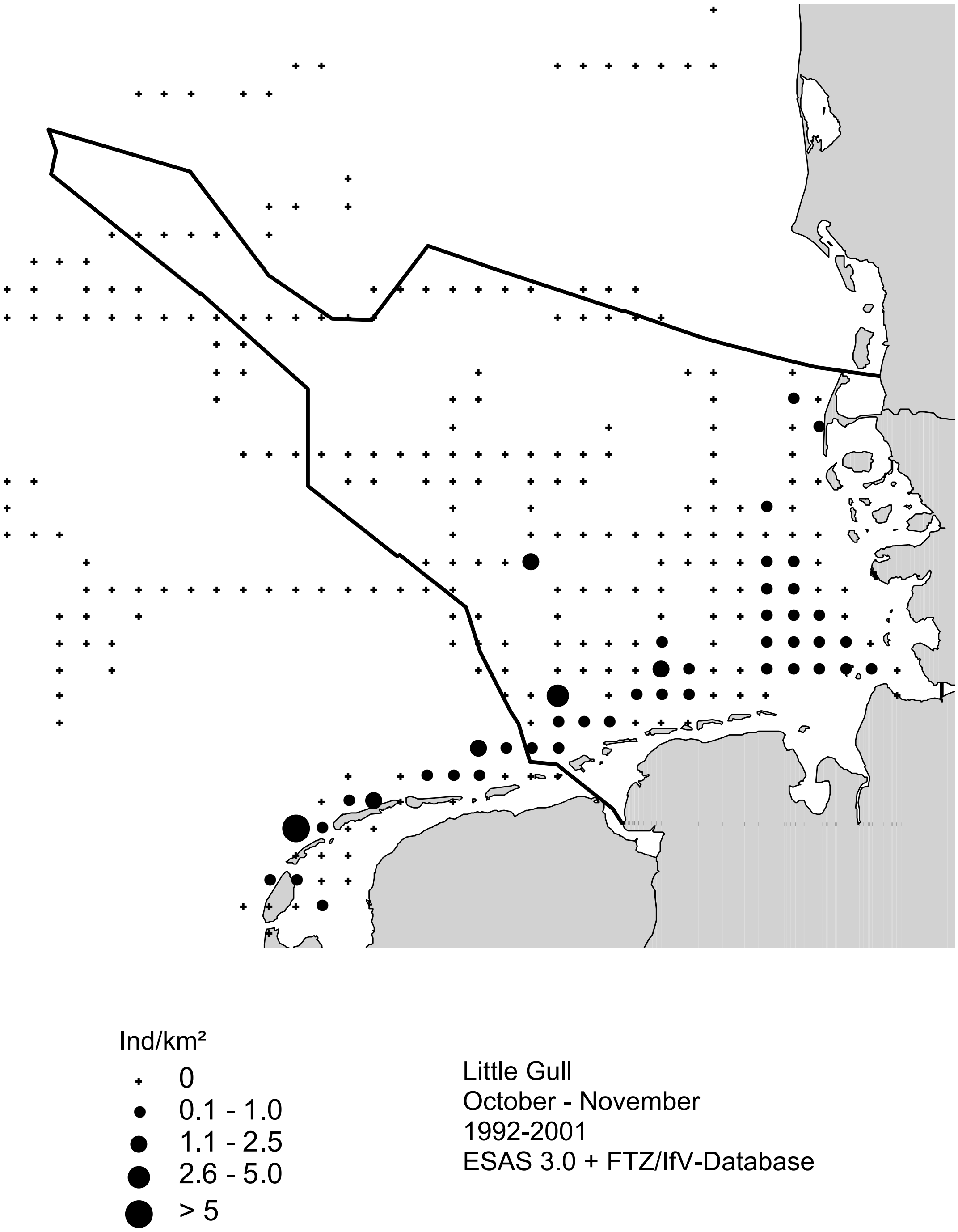


Figure II-53: Distribution of the Little Gull in the German North Sea regions from October to November 1992-2001.

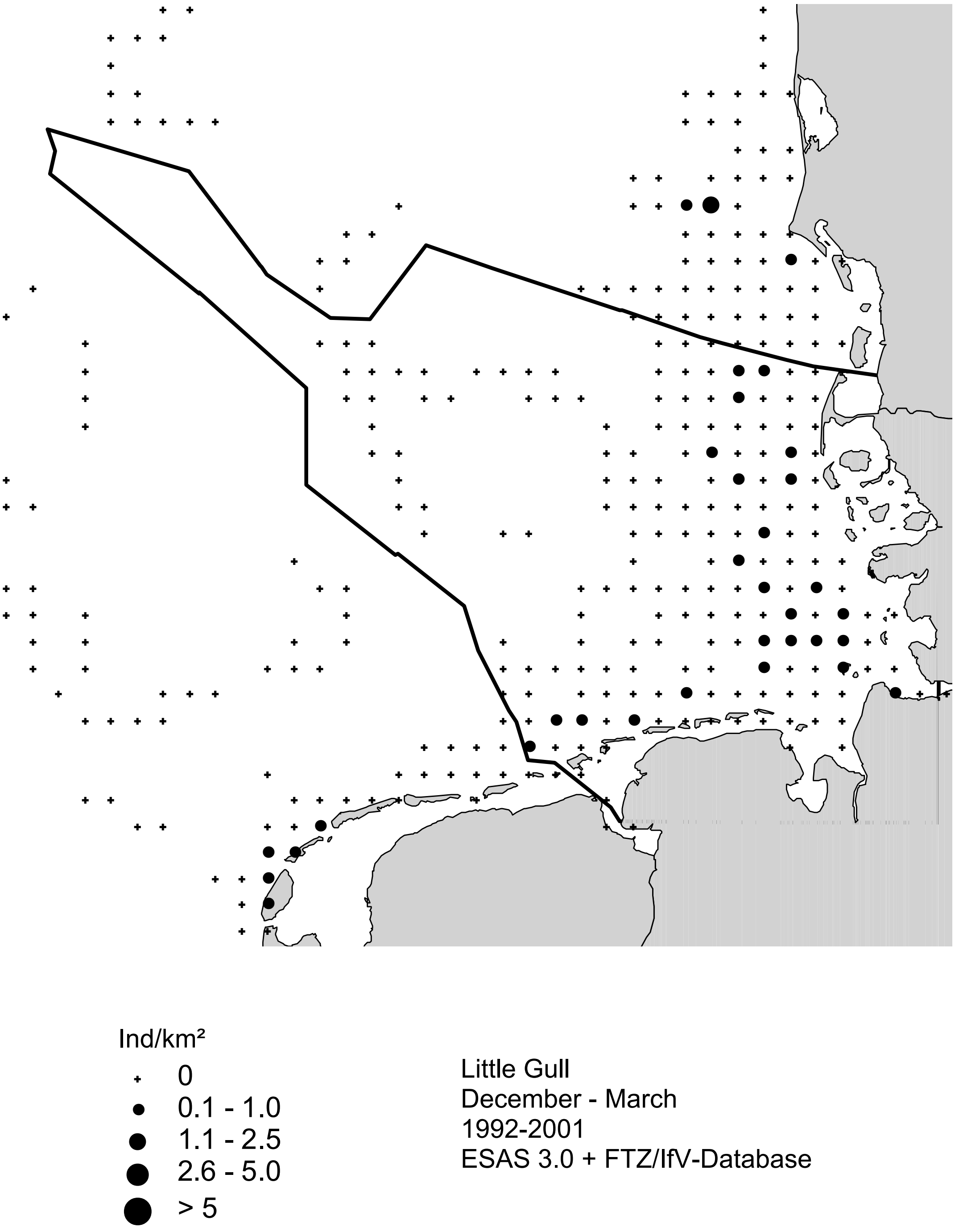


Figure II-54: Distribution of the Little Gull in the German North Sea regions from December to March 1992-2001.

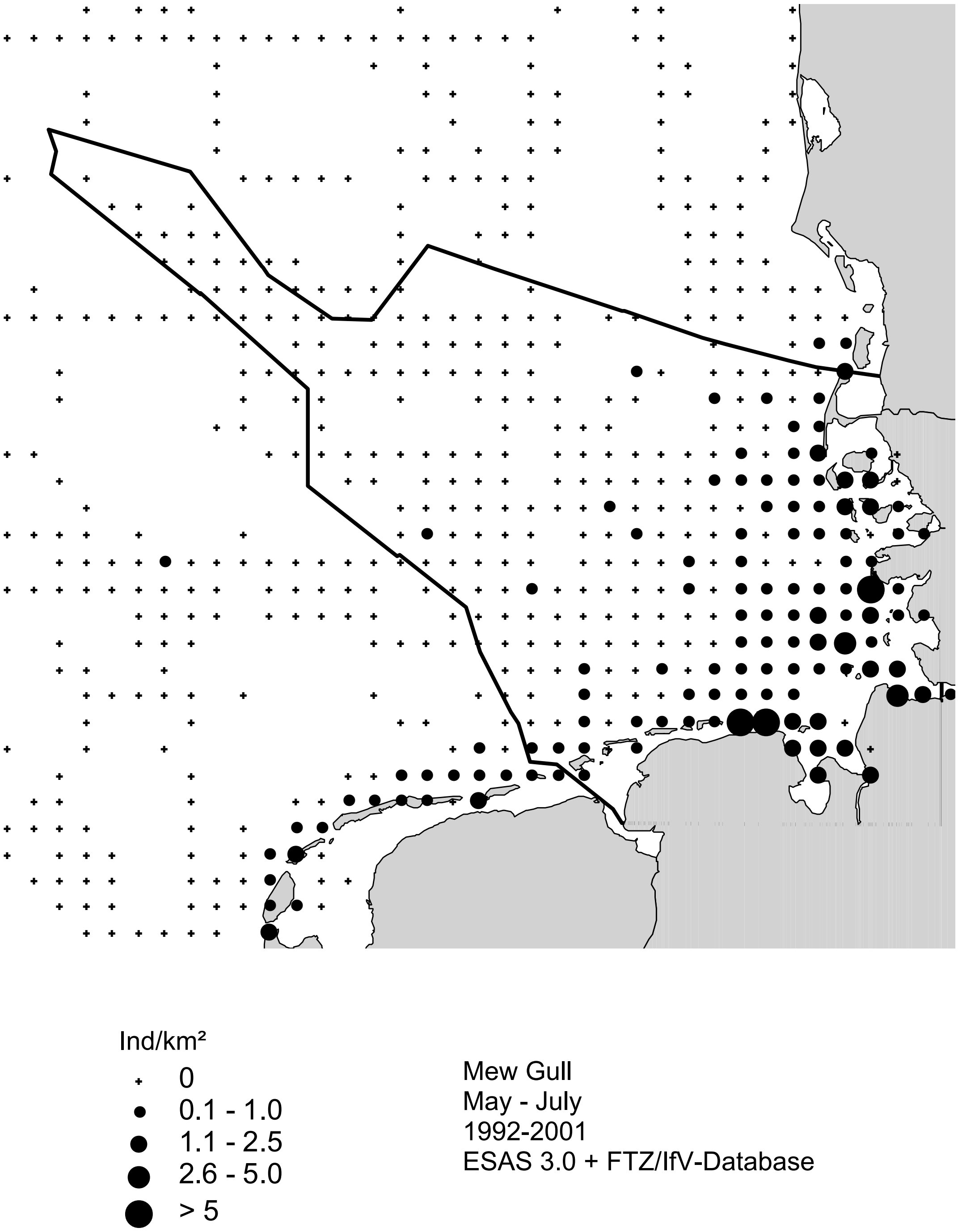


Figure II-55: Distribution of the Mew Gull in the German North Sea regions from May to July 1992-2001.

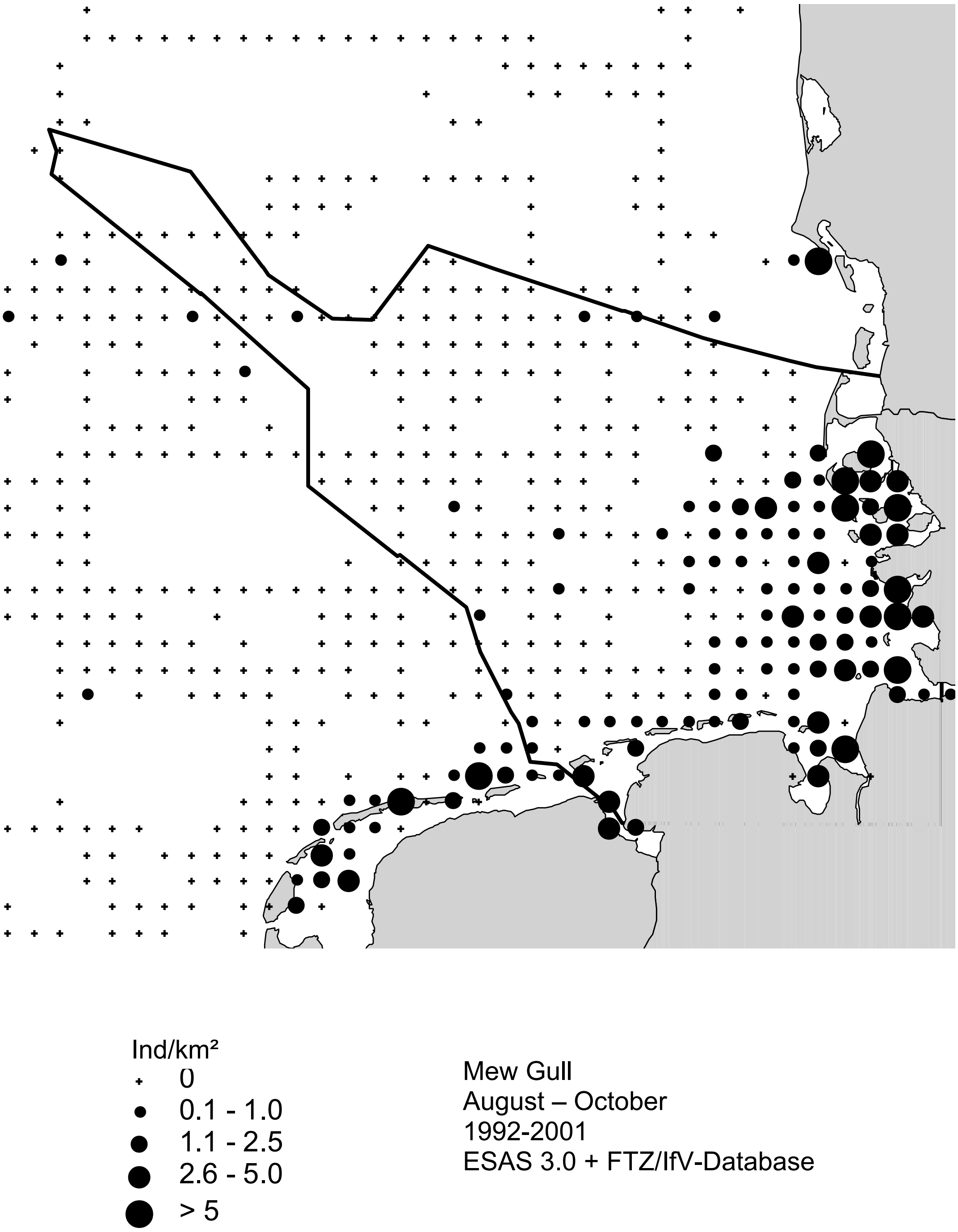


Figure II-56: Distribution of the Mew Gull in the German North Sea regions from May to August to October 1992-2001.

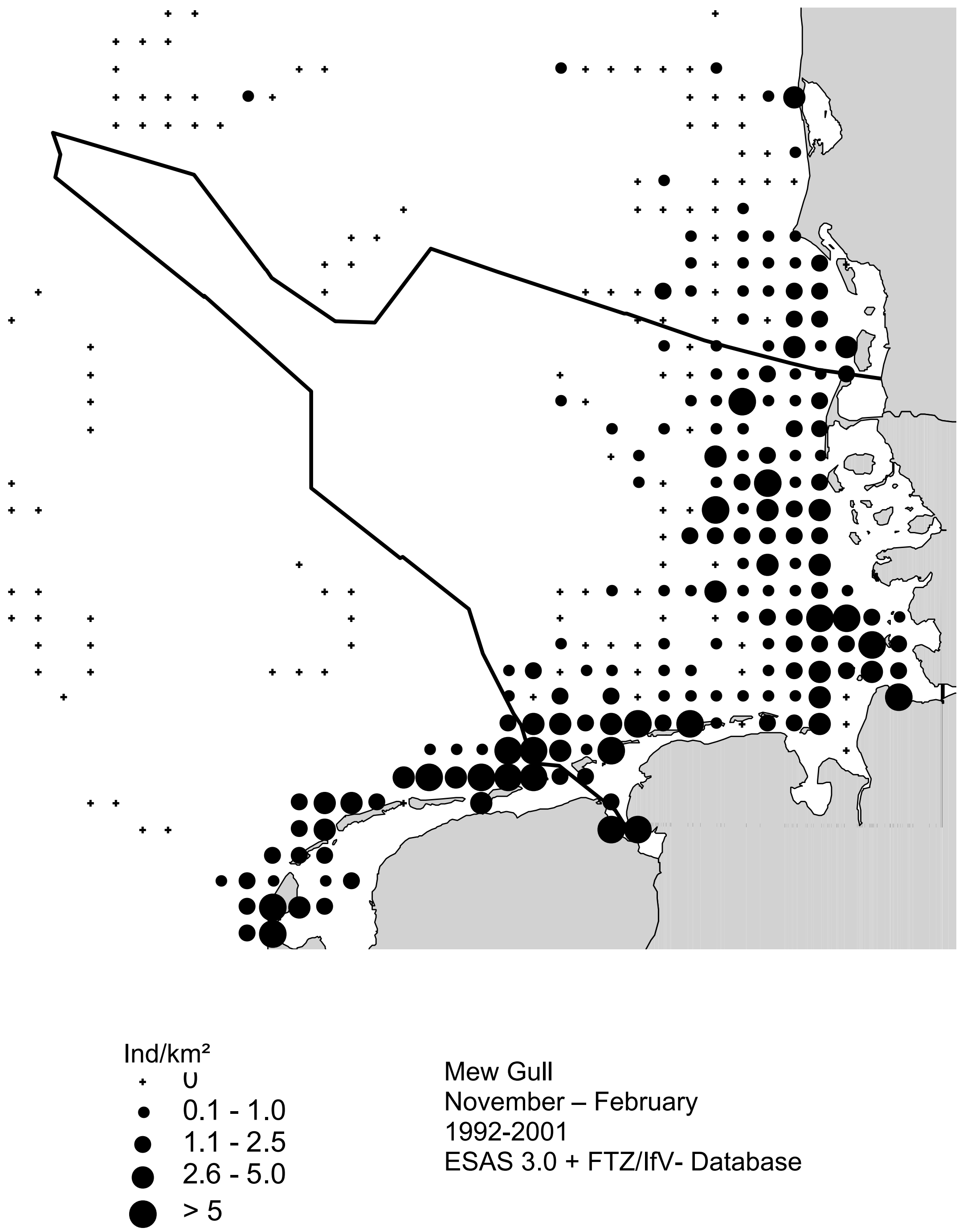


Figure II-57: Distribution of the Mew Gull in the German North Sea regions from November to February 1992-2001.

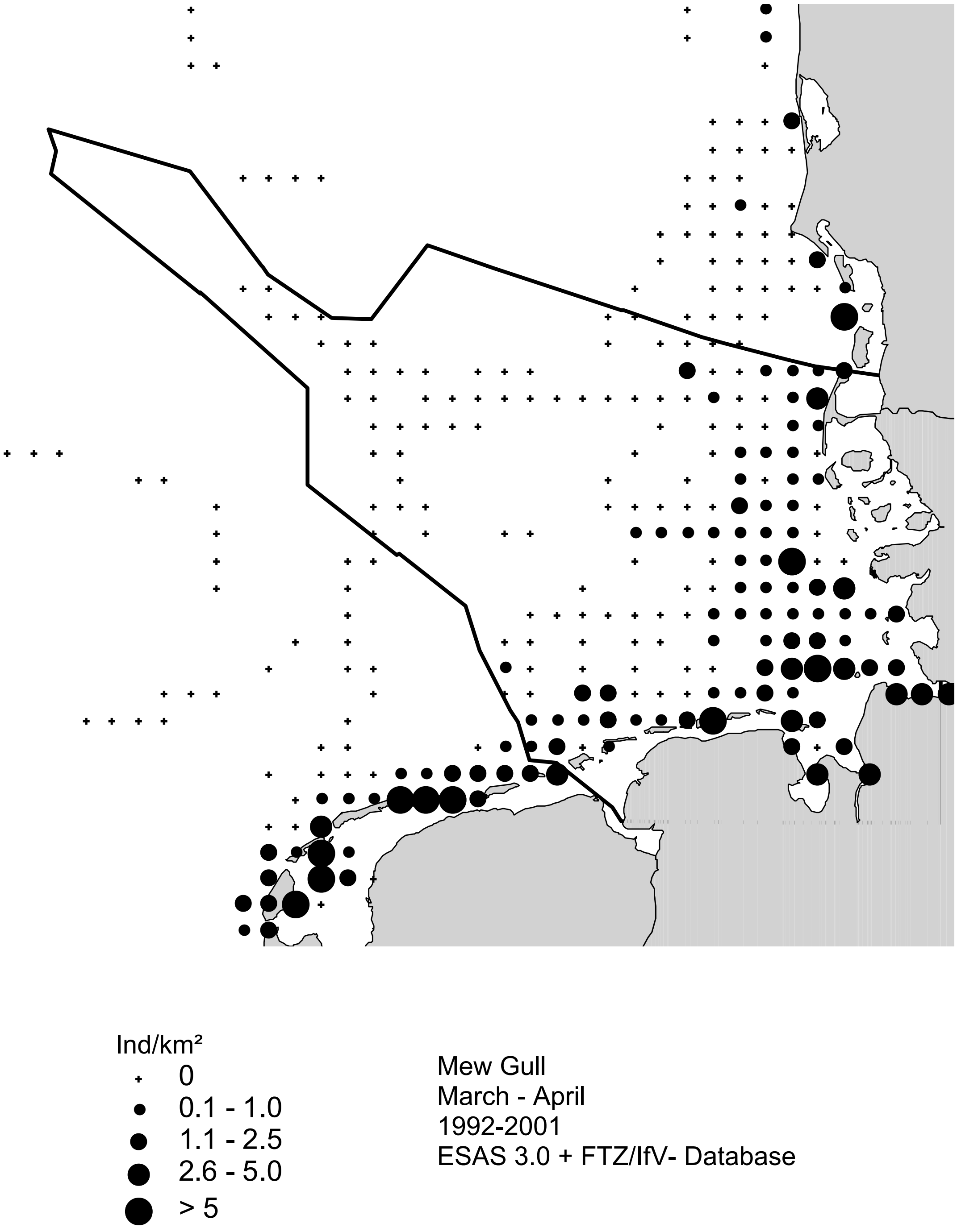


Figure II-58: Distribution of the Mew Gull in the German North Sea regions from March to April 1992-2001.

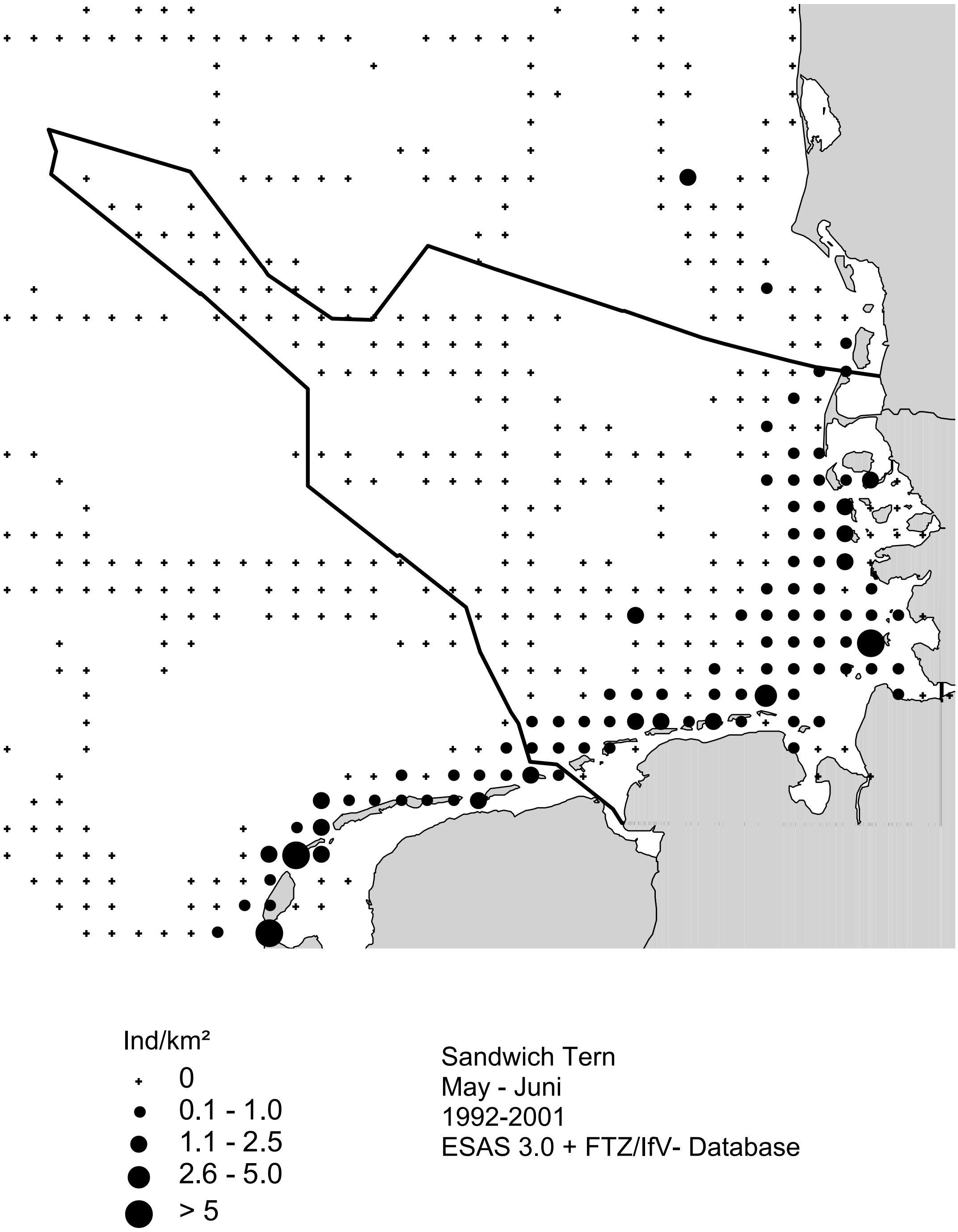


Figure II-59: Distribution of the Sandwich Tern in the German North Sea regions from May to June 1992-2001.

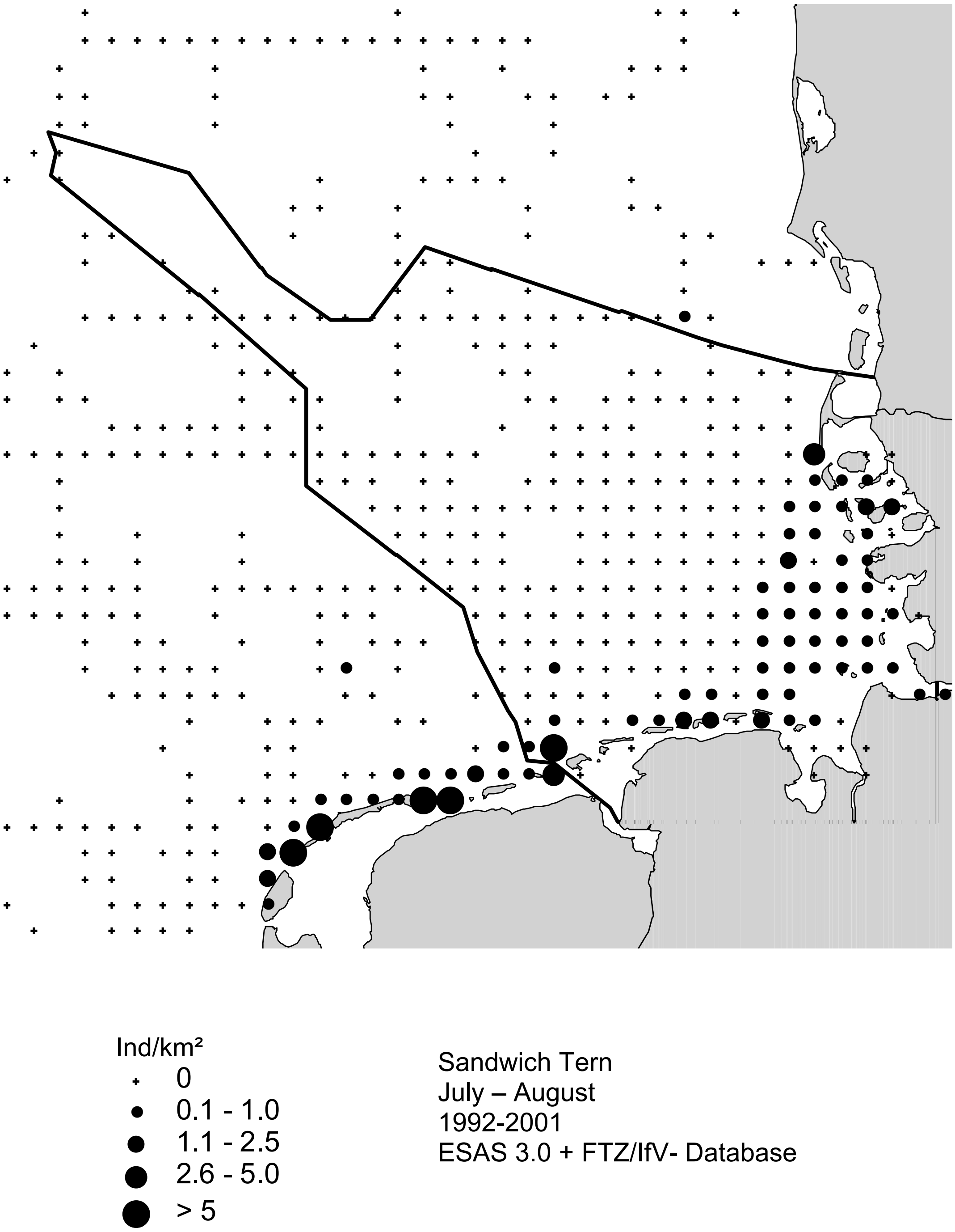


Figure II-60: Distribution of the Sandwich Tern in the German North Sea regions from July to August 1992-2001

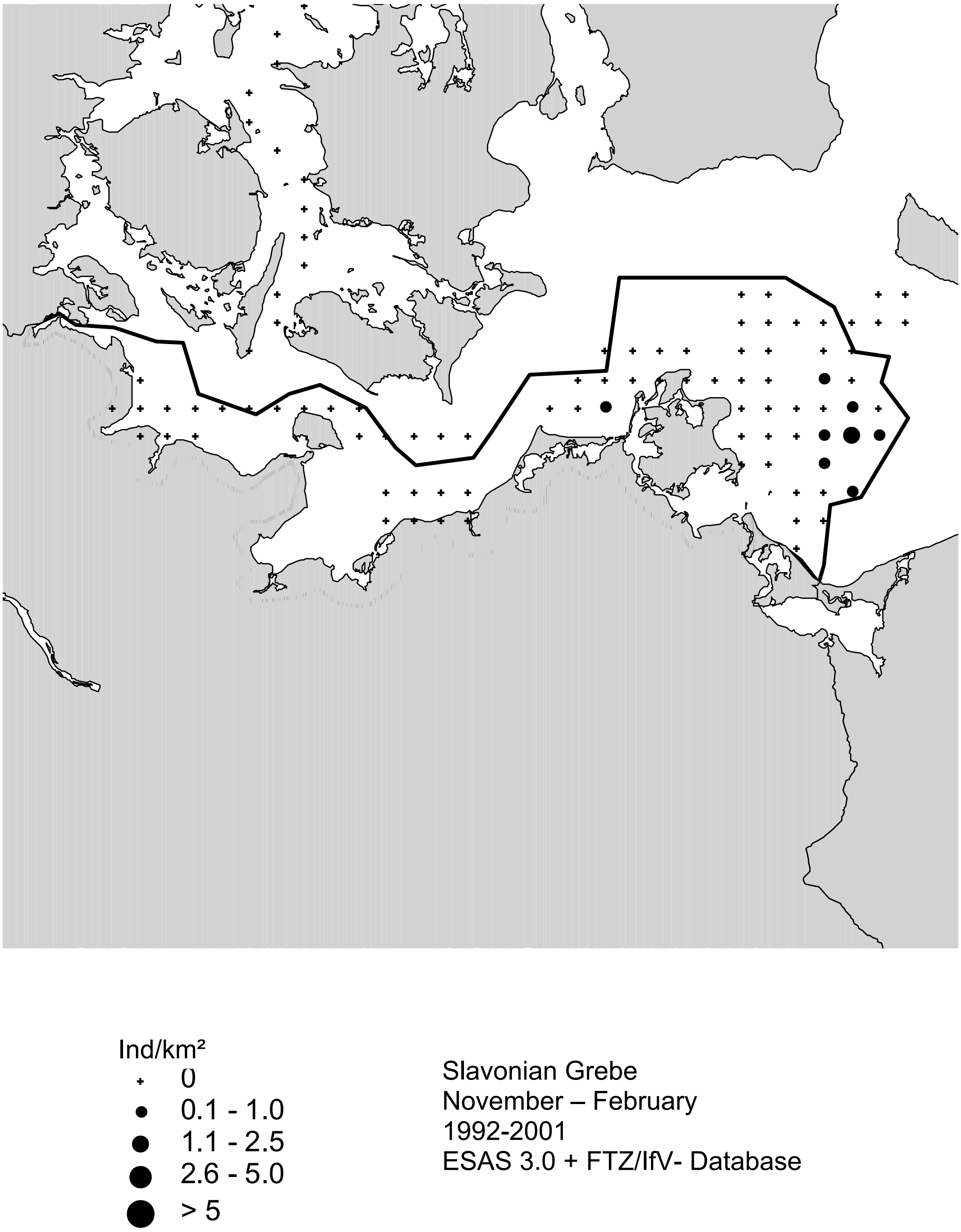


Figure II-61: Distribution of the Slavonian Grebe in the Baltic Sea regions from November to February 1992-2001.

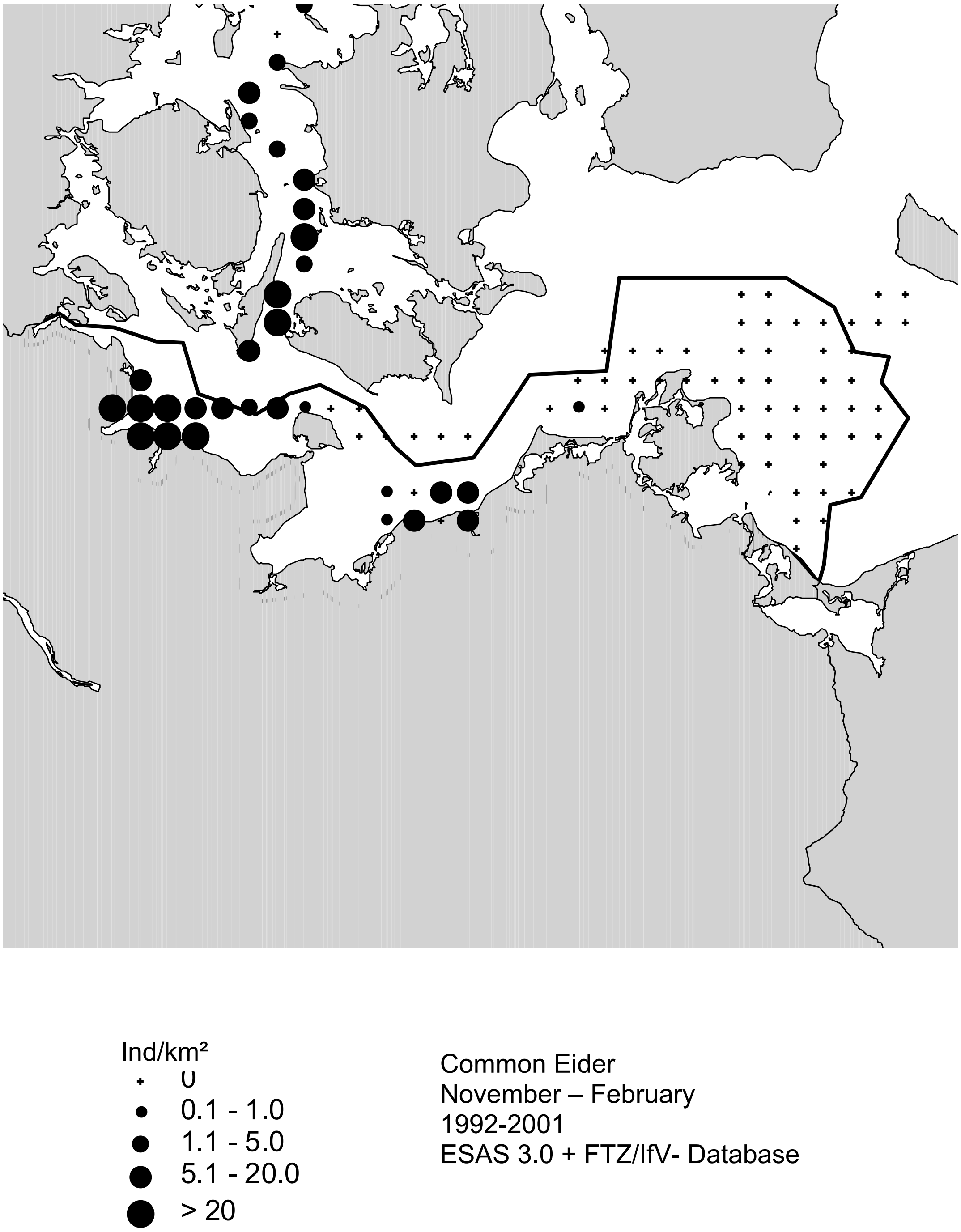


Figure II-62: Distribution of the Common Eider in the Baltic Sea regions from November to February 1992-2001.

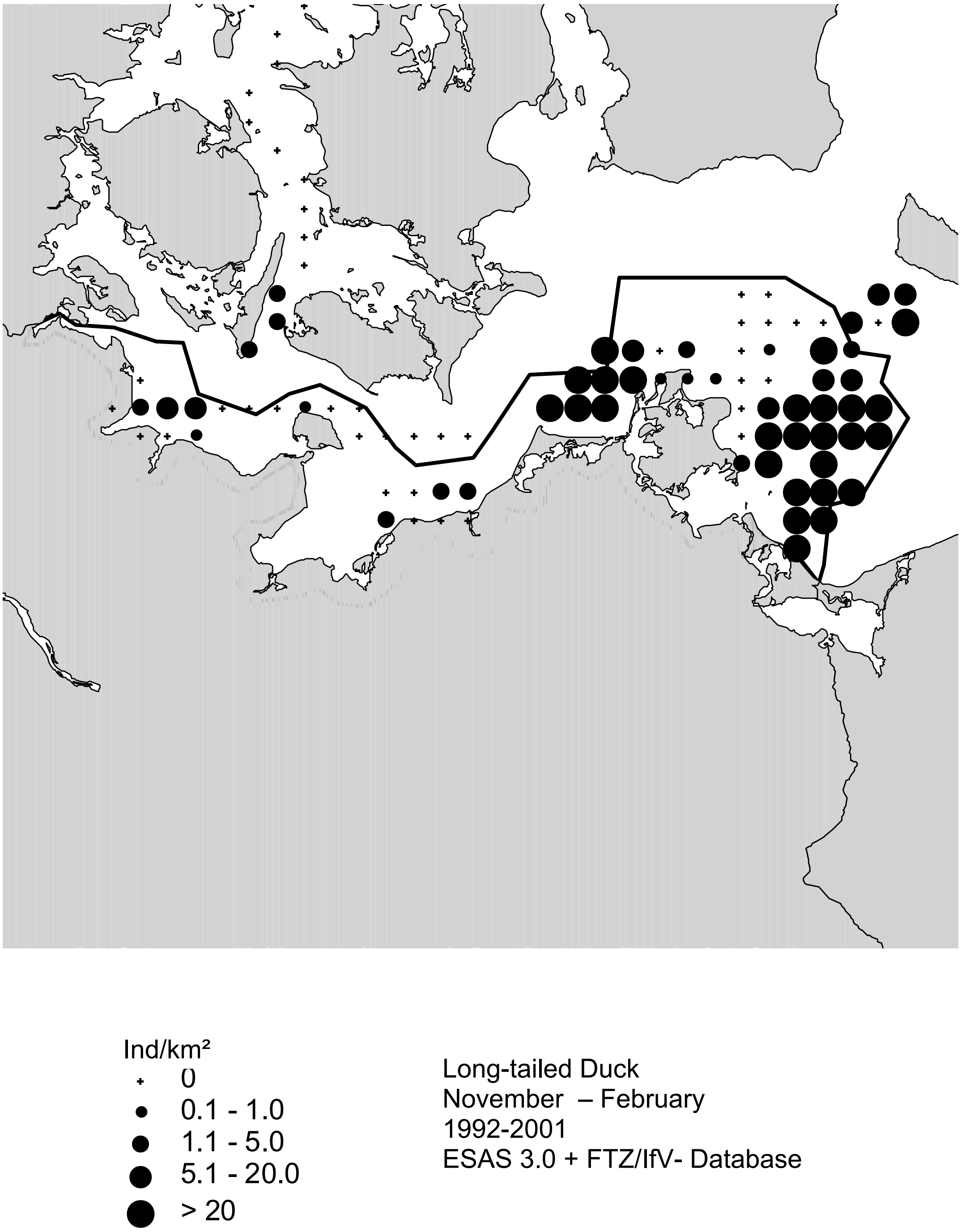


Figure II-63: Distribution of the Long-tailed Duck in the German Baltic regions from November to February 1992-2001.

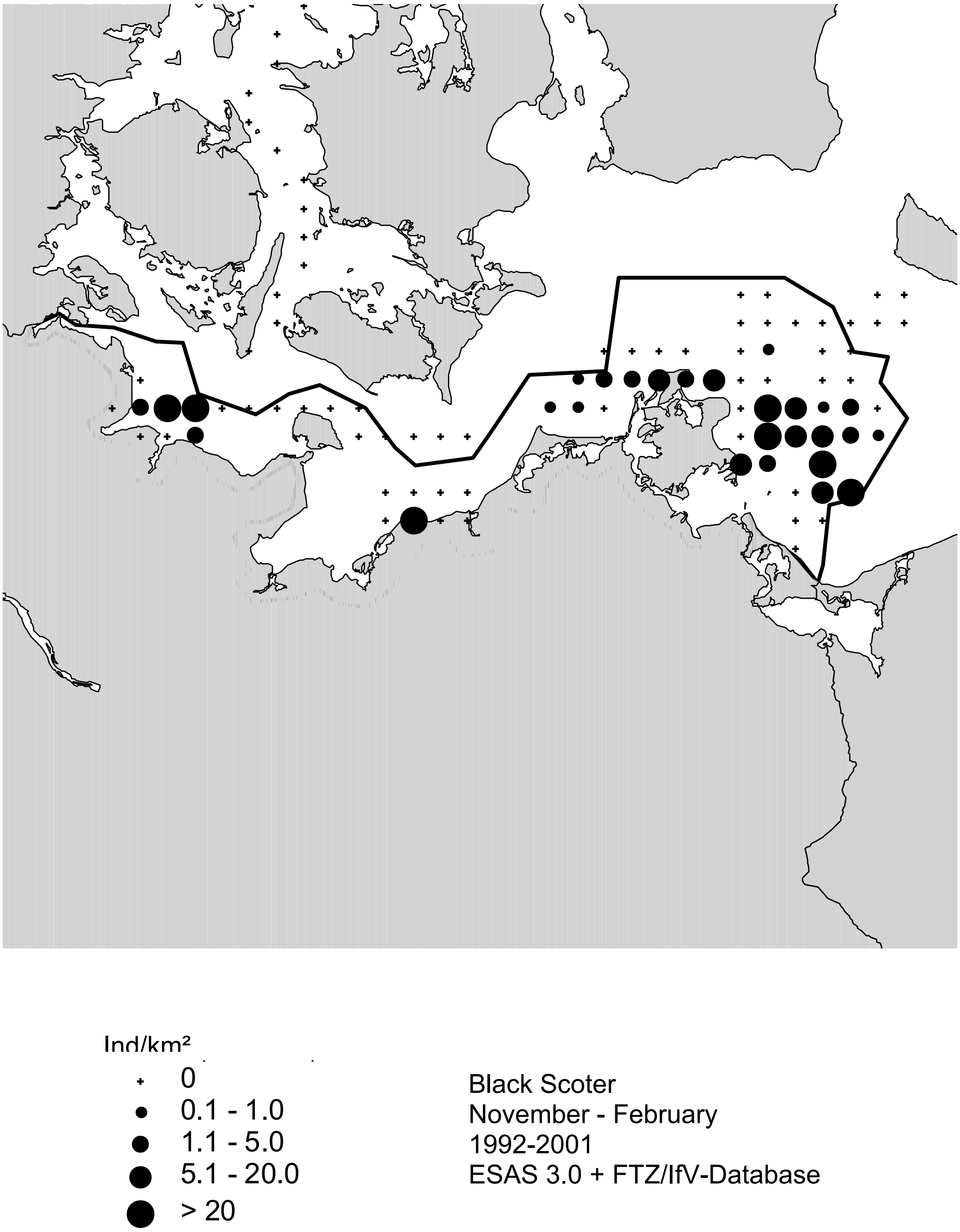


Figure II-64: Distribution of the Black Scoter in the German Baltic regions from November to February 1992- 2001.

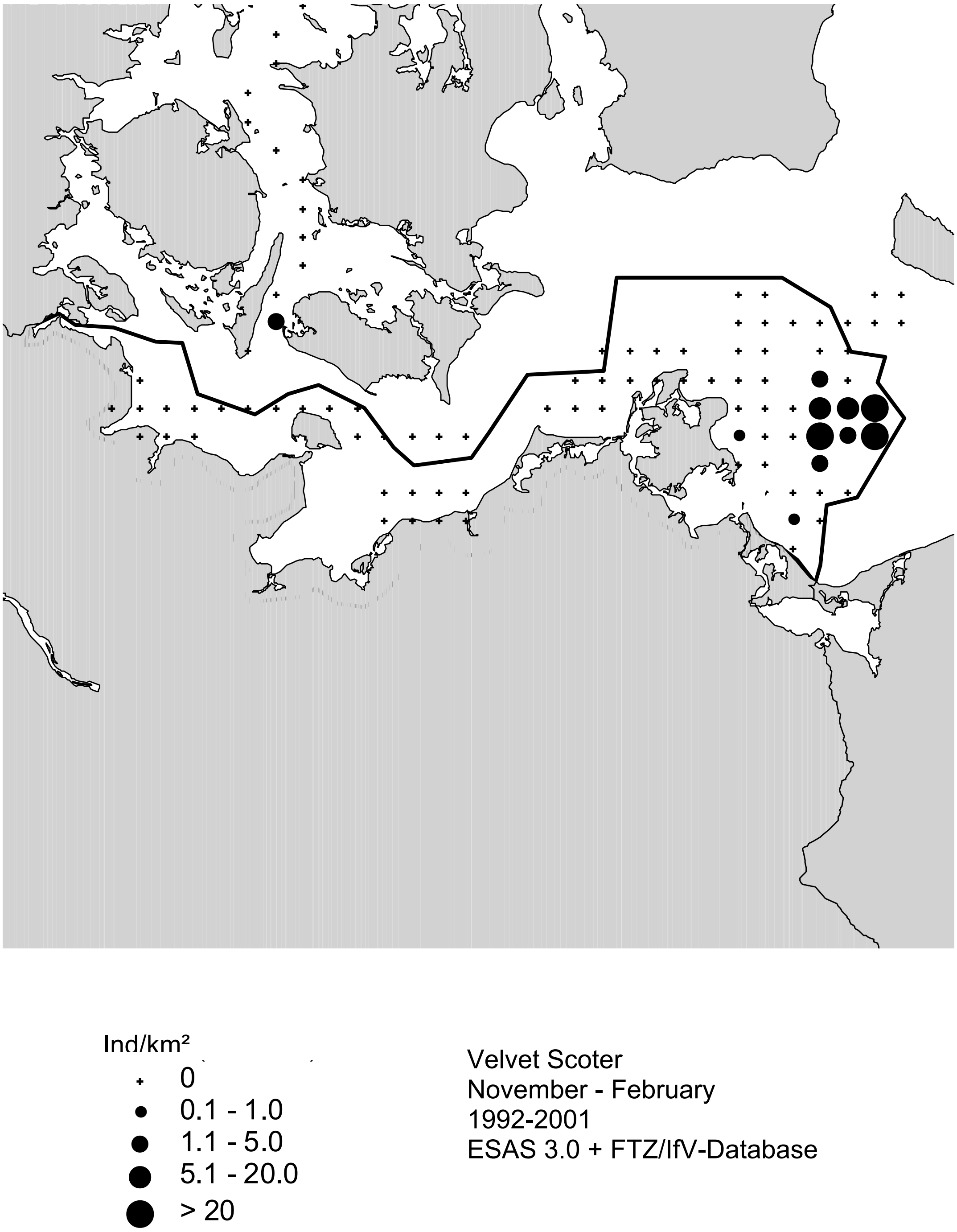


Figure II-65: Distribution of the Velvet Scoter in the German Baltic regions from November to February 1992-2001.

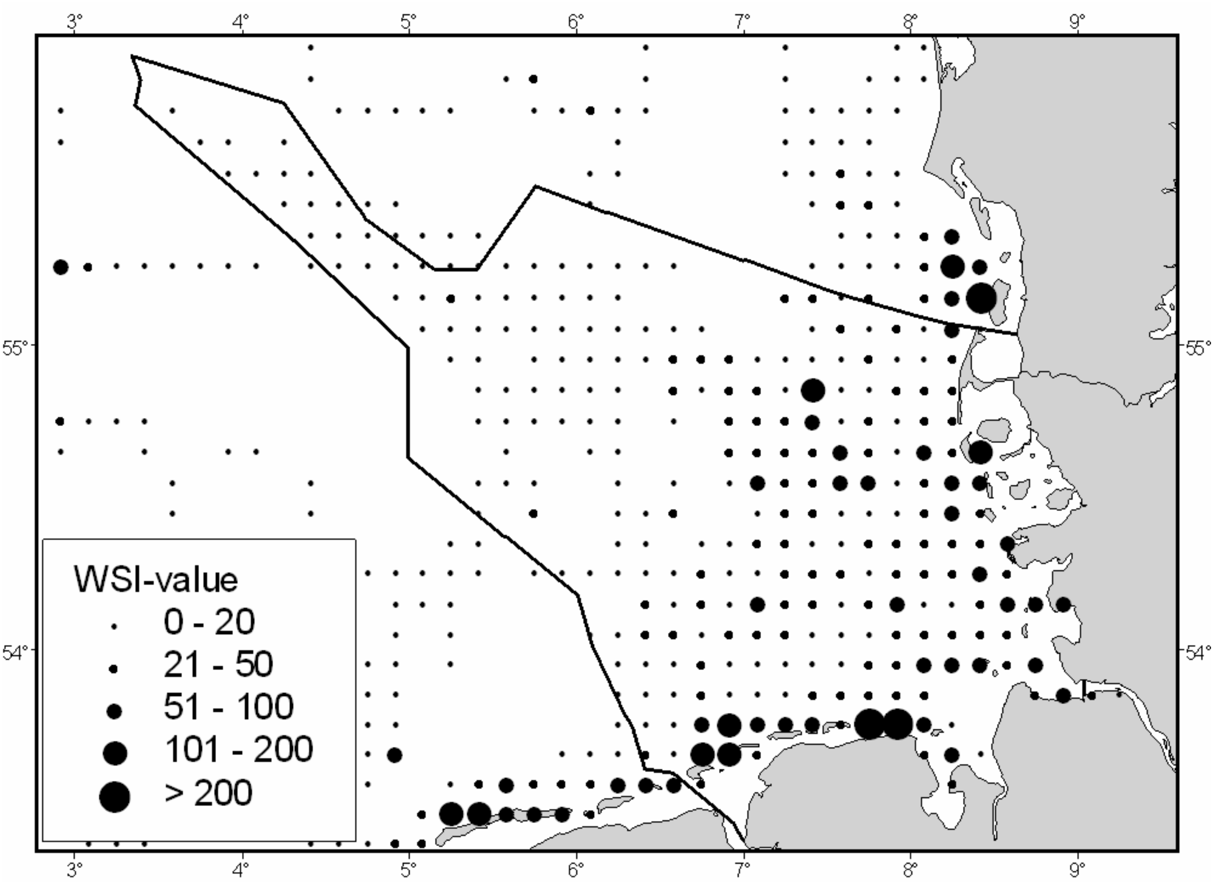


Figure II-66: **Geographical assessment of seabird concentrations sensitive to offshore wind energy plants in the German North Sea regions during spring (March to May). After Garthe & Hüppop (in press).**

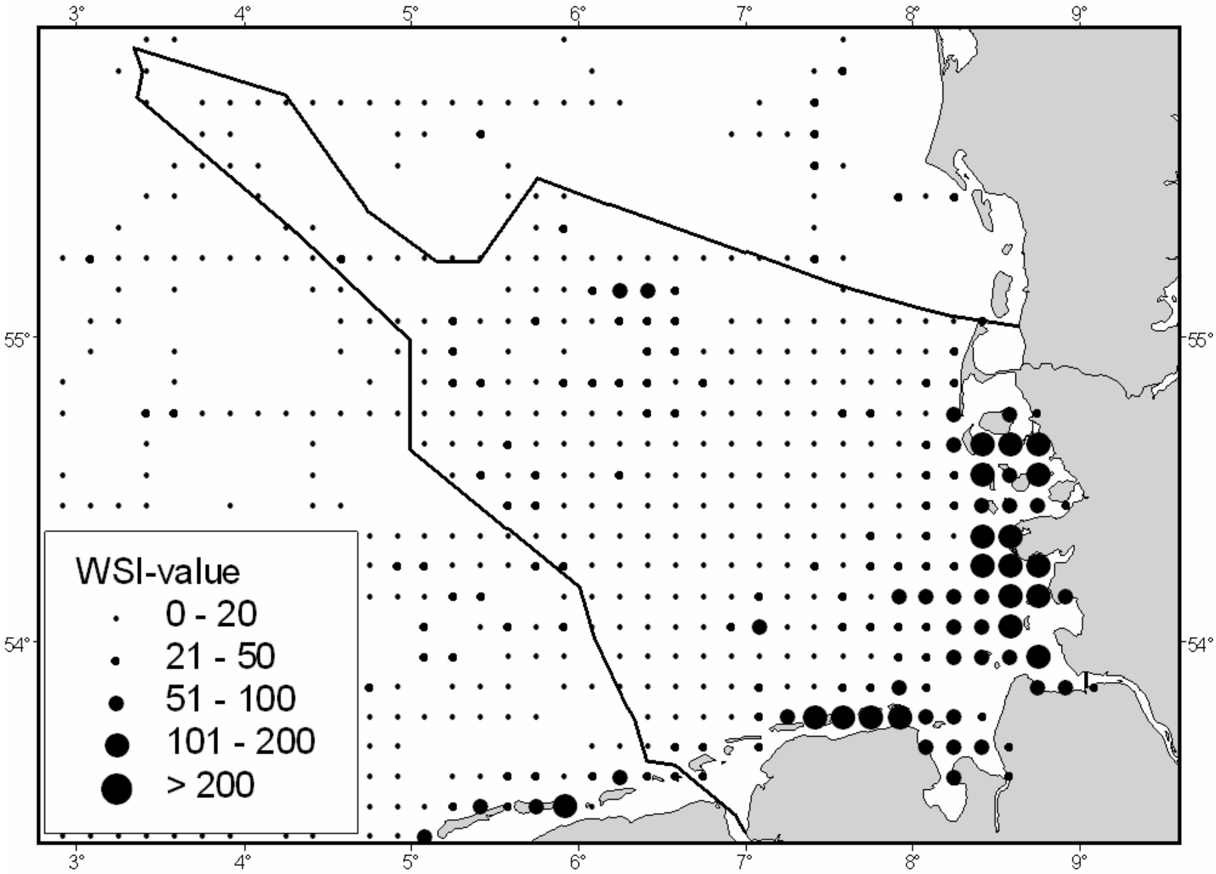


Figure II-67: Geographical assessment of seabird concentrations sensitive to offshore wind energy plants in the German North Sea regions during summer (June to August). After Garthe & Hüppop (in press).

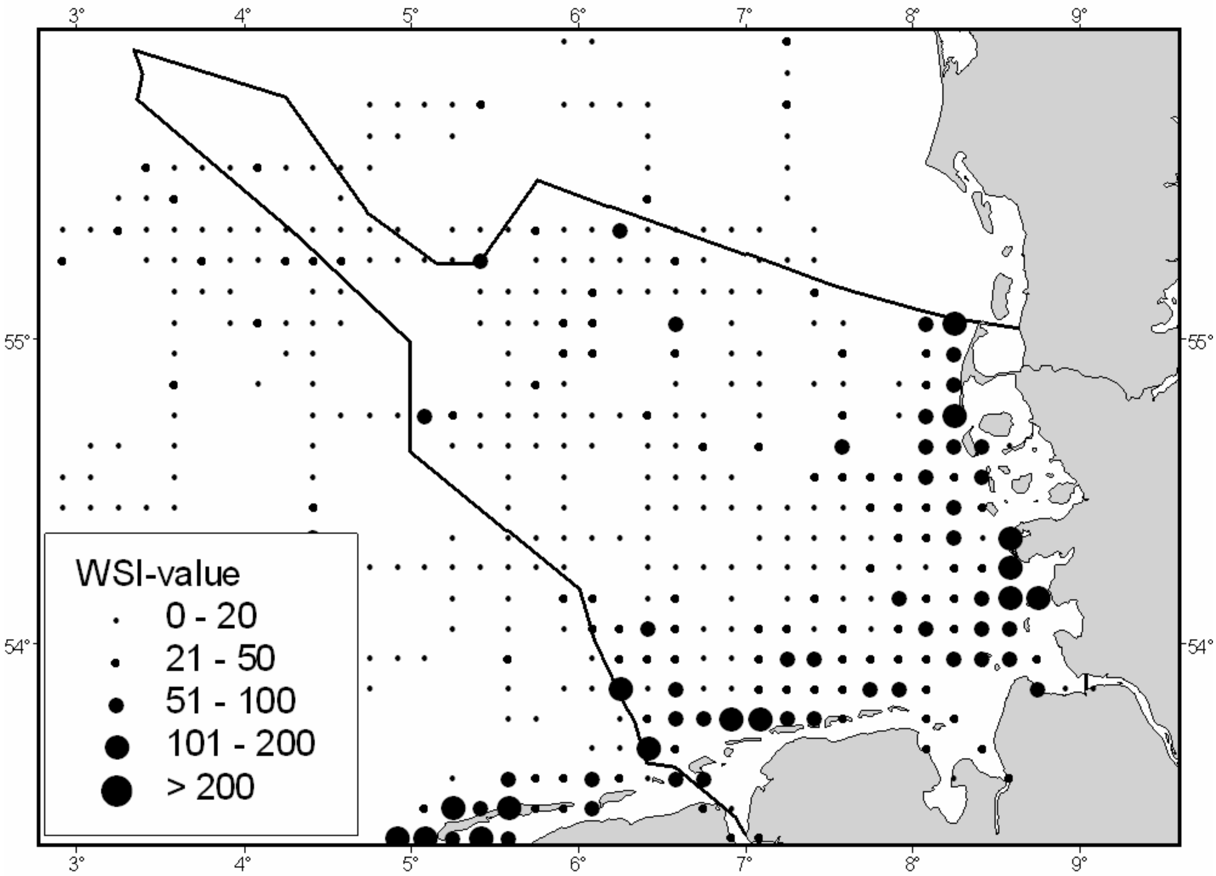


Figure II-68: Geographical assessment of seabird concentrations sensitive to offshore wind energy plants in the

German North Sea regions during autumn (September to November). After Garthe & Hüppop (in press).

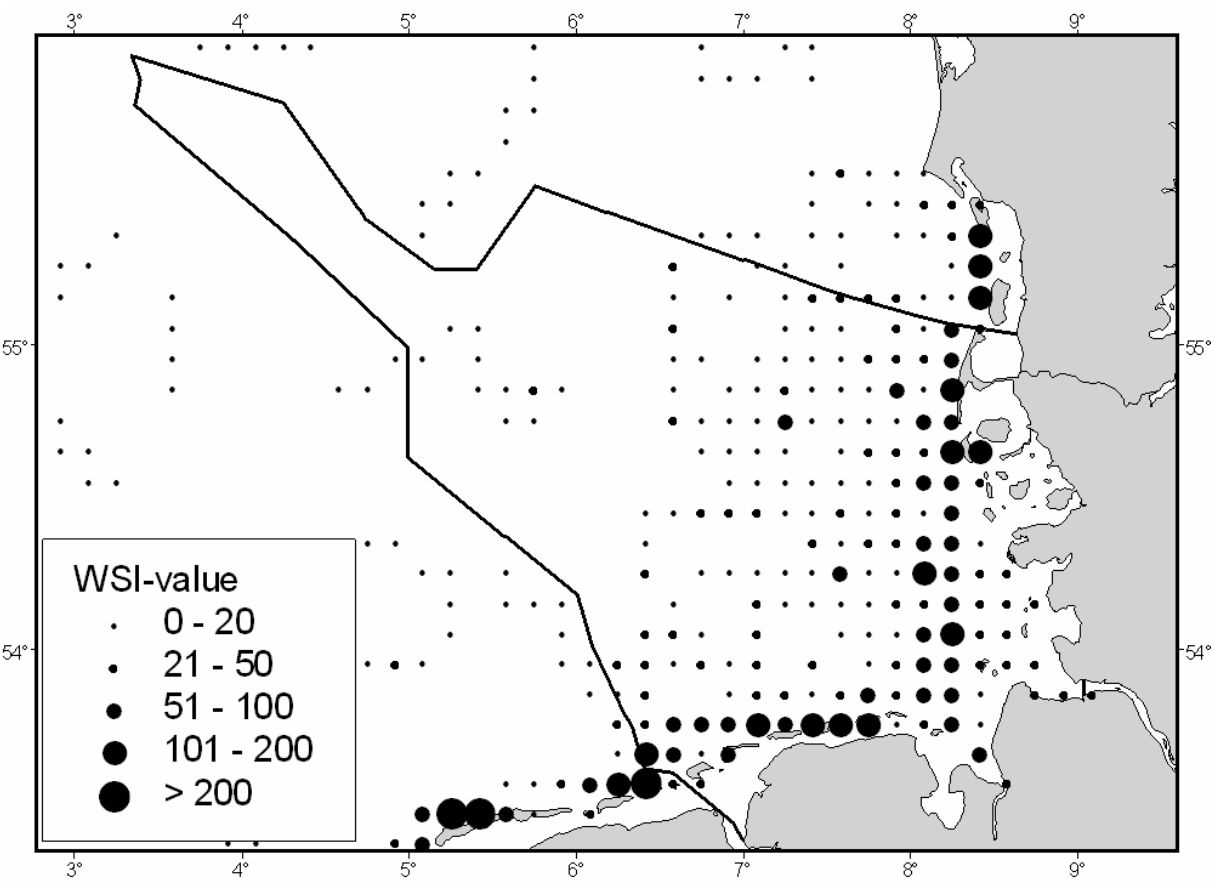


Figure II-69: Geographical assessment of seabird concentrations sensitive to offshore wind energy plants in the German North Sea regions during winter (December to February). After Garthe & Hüppop (in press).

II-12 Integrated assessment of available methods of investigation and of potential zones for the construction of wind energy plants

II-12.1 Methods to observe bird movement in relation to offshore wind energy plants (WEP)

Several methods were applied during this project. Their feasibility and significance are compared, and the results summarized below. In addition we have incorporated an evaluation of methods not yet tested by us.

II-12.1.1 Visual observations and acoustic recording

Visual observations and acoustic recording are the technically least complicated methods which have been in use successfully for several decades and have been used as standard methods (chapters II-4 und II-5). Prerequisites are a good knowledge of species and, for visual recordings, good visibility. During the day it is possible to determine species spectrum, migratory intensity, altitude and direction. However, only altitudes from the water surface to a few hundred meters can be covered. It is also often possible to distinguish between migrating and foraging birds based on their behaviour. The acoustic recording of birds along the coast and over the sea is often severely hampered by strong wind noise. However, this method can be automised taking into account a few limitations (Dierschke 1989, Evans & Mellinger 1999). But it is not possible to classify the type of migration or the local proportions of the entire migration with these methods.

Modified methods for nighttime visual observations include the counting against the moon (e.g. Liechti et al. 1996) or using a ceilometer (Gauthreaux 1969). These methods can be appropriate for particular situations and in the case of moon watching easily carried out by field observers. However, they were not appropriate for the problems of this study since they can only be used during „good" weather. In some cases, nevertheless, they provide good additional information (species groups, flock sizes).

II-12.1.2 Large surveillance radar

The first studies on bird migration using radar were done with civilian or military radar to observe airtraffic activity. This enabled a tremendous improvement in understanding of bird migration (e.g. Eastwood 1967, Bruderer 1997a, b). However, these instruments just like weather radars are not solely used for bird studies due to the high purchasing costs. This means that only data obtained as a by-product by such instruments are available. Thus the Amt für Wehrgeophysik uses data obtained by large aircraft surveillance radar of the German Airforce for bird-strike warnings (Friebe 1998). As long as the primary as well as the filter and amplifier data fall under the military secrecy (in contrast to the Netherlands, Buurma 1995), the available data can only be used with restrictions to quantify bird migration. Accuracy of altitude and time of migrating birds are limited by the angle precision and spatial resolution (e.g. Bruderer et al. 1995a). Nevertheless, under certain assumptions spatial comparisons of migratory intensity and direction can be made, which could not be determined otherwise (chapter II-11). Because of the enormous quantity of data and the military restrictions regarding several details, it is only possible to have the data evaluated centrally by governmental institutions. Currently a lot of „hand" work is required concerning screening and analysis despite the fact that the data are provided in digitalized form by the Amt für Wehrgeophysik. As with all radar observations, (with the exception of target radar, see below) it is not possible to make conclusive statements regarding species spectrum and flock size.

II-12.1.3 Ship radar

Ship radars are a relatively cheap and mobile alternative to investigate local bird migration. Depending on the requirements, the instruments can be used in the normal horizontal position of the turning antenna bar or as an altitude radar by tilting the antenna by 90° or fitted with a parabolic antenna (chapter II-12.1.4, Cooper et al. 1991, Harmata et al. 1999, chapter II-6.1). Our studies as well as others have shown that quantitative results on flight direction, altitude, and intensity are obtainable by these methods. However, the distance related recordability has to be taken into consideration and adjusted accordingly (chapter II-6.1.4). On the other hand it is not possible to obtain any information neither on the species nor on the flock size. Swells and precipitation also have a negative effect because low flying birds will melt in with these signals. Birds flying further away than 2 km cannot be counted any longer. The altitudes, which cannot be covered by visual or acoustic methods, are, however, very well covered with these methods. This also includes those birds, which cannot be detected with the military surveillance radar due to the curvature of the earth. During darkness, the use of mobile or stationary ship radars is the only possible way of recording bird migration quantitatively from just above water level to altitudes of up to 2 km. In addition it is possible to follow avoidance manoeuvres at existing WEP (e.g. Tulp et al. 1999). Radars are, however, not the appropriate instruments to investigate collision risks because of the difficulty in resolving the individuals of flocks, except for when they are very close (see chapter II-12.2).

II-12.1.4 Tracking radar

The working group of Bruno Bruderer (Schweizerische Vogelwarte, Sempach) has successfully collected data using the target tracking radar „Superfledermaus“ in various countries of Central Europe, North Africa and Israel (e.g. Bruderer et al. 1995a). The German Army and the Amt für Wehrgeophysik also carried out several surveys using the „SKYGUARD“-System (e.g. Weitz 1998). Both systems deliver excellent results with regard to measuring precision facilitating the identification of species groups. However, because of an intensive personnel requirement and high purchasing costs, these instruments cannot be used in a study such as this.

As an alternative it is possible to equip ship radar with a parabolic antenna (e.g. Cooper et al. 1991, Dirksen et al. 1998a, Biebach et al. 2000). Preliminary investigations with an instrument kindly lent to us by Dr. Herbert Biebach (Max-Planck Forschungsstelle für Ornithologie, Andechs) did not yield the expected results because of the limited radar beam diameter.

II-12.1.5 Thermal imaging cameras

Infrared cameras, next to radar, are also ideal to quantify migration movements up to 3000 m altitude during clear skies (e.g. Liechti et al. 1995, Zehnder & Karlsson 2001). It is even possible to differentiate between individuals in flocks and at least species groups that are not too distant (Winkelman 1990; M. Desholm, International Workshop on Birds and Offshore Windfarms, Fuglsø, DK, Nov. 2001). This technology is therefore predestined for collision studies (chapter II-12.2). A disadvantage however is the high costs and the poorer possibilities to measure distances.

II-12.1.6 Standardized netting

Catch data using constant methods and constant catch effort permit conclusions on the migratory activity during the previous night. Dierschke (1989) found a good correlation between nightly call activities and catching data of the Song Thrush. Recently Zehnder & Karlsson (2001) also found a good correlation between thermal imaging data of nighttime migration activity and catch data in Falsterbo (South Sweden). However, the weather contributed considerably to the variability (Zehnder et al. 2001). Erni et al (2002) also found that the migratory intensity of birds over central was determined particularly by wind and precipitation. A comparison of the Helgoland catch data with the vertical radar data on migratory intensity mentioned above in conjunction with the weather data (chapter II-9.2.1) would therefore provide additional valuable information. This was, however, not feasible due to the large statistical effort required to analyse the data.

A disadvantage of the method is of course, that the species spectrum is strongly dependant on the habitat in the catching areas. For instance on Helgoland the proportion of nightly migratory calls of waders is very high, whereas this group is seldom caught in the „trapping garden“ (Dierschke 1989). In addition, the migratory intensity can only be determined after the nightly migration has taken place. This means that this procedure is not appropriate for bird strike warnings (chapter II-12.2).

II-12.1.7 Conclusions

The quantification of bird migration over the sea is only possible through a combination of methods. Both visual observations and recording by radar are the most effective. A marked improvement can be achieved by also using thermal imaging cameras, whereby all three methods complement each other. Algorithms applied for the automatic recognition of tracks would also improve the database considerably. Due to the strong fluctuation of migratory intensity from day to day, local investigations should only be evaluated synoptically over longer periods and larger areas.

II-12.2 Methods to investigate and estimate collision risk

The discussions in chapter II-12.1 to a large part cover the recommendations on investigations of bird strike risk. Since it is not possible to collect injured or killed birds at sea, the quantification needs to be carried out visually. During the day this is only possible by direct or indirect (Video) visual observations. Thermal imaging cameras have to be used at night (see chapter II-12.1.5). This is the only way to estimate how many birds fly into a plant and survive unscathed or collide. This is not possible using radar technology. It is for instance not possible to see whether individual birds out of a flock of ducks are hit. However, radar is a very convenient method to quantify large scale horizontal or vertical avoidance reactions. In order to assess the actual collision risk, a combination of methods is necessary, at least at the pilot study sites. Since massive bird strike events only occur under specific environmental conditions, where they may involve many individuals (see below), the investigations have to be carried out continuously for at least one year and assessed quantitatively in connection with the large scale migratory pattern.

The Energy Research Centre of the Netherlands is currently developing an acoustic recording method to monitor bird strike on operating plants (Westra, International Workshop on Birds and Offshore Windfarms, Fuglsø, DK, Nov. 2001): Using stethoscope microphones on the rotor blades it is possible to register the impact of a bird, whereby the strength of the collision sound gives an impression of the bird size. The advantage of this system relative to the infrared cameras is the low cost. A disadvantage is that only birds, which actually collide with the rotors, are registered. It is therefore not possible to quantify the number of birds, which fly through the plants without collision or avoid the WEP.

II-12.3 Overall evaluation of the danger potential of offshore WEPs in relation to resting and migratory birds

With regard to the danger potential of offshore WEPs it is necessary to distinguish between birds which frequent the area over a longer period (resting birds) and those, which only briefly fly through the area. Both groups are subject to collision risk. Resting birds may be disturbed from their resting sites while flying birds in general may suffer energy loss due to avoidance manoeuvres or circling over the plants because of orientation problems.

II-12.3.1 Displacement effects

As mentioned in chapter II.3.2.2 it is expected that the WEPs and their construction as well as supply vessel activity will have displacement effects especially on sensitive species such as e.g. divers and Black Scoter. This is assumed despite the case that very little information is available. After all, a map of the Black Scoter distribution in the area of the windpark „Horns Rev“ seems to indicate these effects (Horns Rev Newsletter - June 2002; www.hornsrev.dk/Engelsk/default_ie.htm). Black Scoter are extremely sensitive to disturbances, particularly during moult. Some will flee from a ship 3 to 5 km away (Noer et al. 2000), whereas Common Eiders for example are much less shy and sometimes fly through the plants at night (Tulp et al. 1999). Particularly for the sensitive species, it can be expected, that they will avoid wind parks, which means that these areas will no longer be available as resting and feeding sites. We have considered the sensitivity to disturbance as part of the integrating Wind Energy Sensitivity Index (WSI, see below) for resting birds.

II-12.3.2 Collision risk

As mentioned repeatedly, the collision risk is the most difficult factor to determine because empirical data on offshore plants are currently not available. Based on the values obtained for plants on land (overview in chapter II-3.2.2), where 0 to 40 birds collide per wind turbine annually, it would mean that 12,000 planned wind turbines would result in up to half a million casualties per year (www.offshore-wind.de/de/projekte/pr_140.html). Calculations for plants close to coast arrived at 0.04 to 0.09 birds per turbine per day. For 12,000 turbines this would mean 175,000 to 390,000 casualties annually. This estimate does not take into account the fact that the rotor diameter of the envisaged plants at sea will be even larger. Collision risk also depends, at least theoretically, on the rotor diameter (Tucker 1996). However, there appears to be no difference between 5 MW-turbines and 0,5 MW-turbines (S. Gleich, pers. com.). In the case of the North Sea area it is expected that the bird strike risk far off the coast is likely to be lower than closer to the coast which would mean less casualties

With regard to casualties it is necessary to distinguish between resting birds (with knowledge of the local area) and migrants. Common Eiders pass WEPs at night; however, their activity decreases during moonless nights and only increases strongly at daybreak (Tulp et al. 1999, general: chapter II-9.2.2). During poor visibility ducks and other waterbirds simply land on the water. This is not possible for terrestrial birds, which cross the sea. It is these birds that are particularly endangered during nocturnal migration (2/3 of all birds migrate at night, Isselbächer & Isselbächer 2001) when the weather worsens and they are forced to fly at lower altitudes (chapter II-7.2.3). This could be enhanced by the lighting on the plants (see below) causing disorientation (Schmiedl 2001).

In summary it can be said that for some species (e.g. divers) there is a continuous risk due to their poor flight capabilities and distribution, which was taken into account in the computation of the WSI. Other species (species migrating over water at night) are not at the same risk. However, in their case a large number may be endangered over a short period (as is well known for illuminated buildings e.g. Schmiedl 2001, Richarz 2001).

II-12.3.3 Barrier effect and illumination of WEPs

Offshore WEPs clearly act as barriers (chapter II-3.2.2, Tulp et al. 1999), which are generally avoided by flying over or around them. This results in additional energy consumption, which might affect condition and indirectly, the reproductive success (review in Hüppop 1995). Currently it is of course difficult to quantify the magnitude of these additional energy costs. For birds flying over the sea, flying around a single park is probably no problem. However, several such plants could result in an energy consuming obstacle course, particularly for heavy birds such as swans and geese which preferably fly low over the water (chapter II-4.3.3 and II-5.3.2). Climbing flights are especially energy consuming (Hüppop 1995).

According to the standardized observations (chapter II-4) dabbling ducks and terns always maintained a flight distance of at least 500 m from the coast. divers, seaducks and auks even fly up to 2 km away from the coast. These species are expected to avoid obstacles particularly strongly.

Offshore WEPs have to be made visible to shipping and aviation. This means that a special identification is required and modifications are only partially possible. Evidently all forms of illumination, even red aviation warning lights, attract birds under specific conditions (Kingsley & Whittam 2001, Schmiedl 2001). More so during moonless nights than when the moon shines (Verheijen 1980). The reasons for this can only be hypothesized and require urgent study. Disorientation due to illumination may cause birds to circle a location for longer periods and result in landings due to exhaustion (Richarz 2001). At sea this would mean the death of terrestrial birds.

II-12.3.4 General assessment

With regard to the expected casualties of birds, it is necessary to consider species protection and animal rights aspects. For the protection of species, it is indispensable to evaluate the effects on stocks under consideration of population dynamic parameters and migratory behaviour (routes and altitude, e.g. Morrison et al. 1998). Currently this is not possible due to a lack of information on collision risk At least for some species it cannot be excluded, that if the current plans are realized, that up to 1% of the biogeographic population will be killed by WEPs annually (1% of a biogeographic population is considered internationally important in the assessment of areas). Low flying birds are particularly endangered (chapters II-4 and II-5). Considering the estimated absolute values above (several hundred thousands), resistance by animal protectionists is to be expected. Especially, for example, in the light of the public pressure concerning the rehabilitation of oiled birds, which is virtually without consequence for the conservation of most species (e.g. Hüppop 2003). Recently, Dierschke et al. (2003) offered different approaches for evaluating (inadmissible) impacts on populations of birds in the North and Baltic Seas.

It is currently not possible to make any reliable statements concerning collision risk and barrier effects. However, for the North Sea, the WSI provides a solid basis for site evaluations, whereby detailed data, particularly on nocturnal migration, could result in another evaluation scheme. In order to obtain an integrated assessment e.g. of survey areas, it is essential to know whether an area attains a high WSI during any season or not. Figure II-70 shows the highest WSI values for any of the maps for the different seasons (Figures II-66 to II-69). Garthe & Hüppop (in press) recommend the 60% percentile of all WSI values (WSI = 23.7) as „level of concern“ and the 80% percentile (WSI = 43.5) as „level of major concern“.

For the Baltic, the data situation is clearly worse. It is not possible to compute a WSI and it is only possible to consult available assessments (Skov et al. 2000). The maps shown here generally support the particularly valuable areas selected by Skov et al. More data are expected soon from the MINOS project (chapter II-15.2).

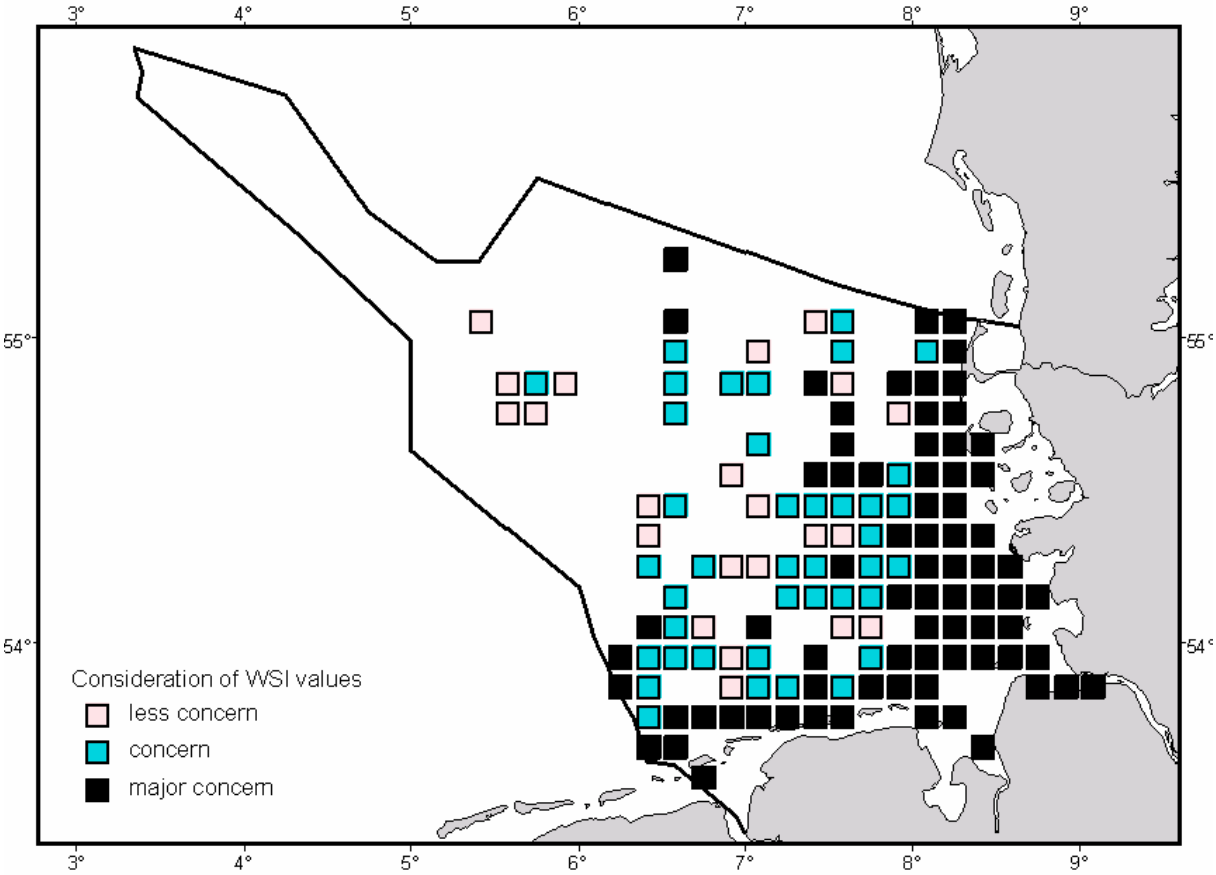


Figure II-70: **Geographical estimate of the seabird concentrations sensitive to offshore WEP within the German North Sea areas during the year. After Garthe & Hüppop (in press).**

II-12.4 Methods of assessing search areas for wind energy plants

Search areas for wind energy plants are to be regarded principally from two perspectives, as mentioned in the previous chapter: (1.) Displacement of nationally and internationally important bird concentrations and (2.) risk for flying birds. Particularly sensitive areas can thus be ascertained according to the following checklist:

1. Is the search area specifically protected with regard to birds (e.g. National Park, Nature Reserve, de facto or established Important Bird Area)? The specification of such areas is generally based on data, which have been collected over several years by independent institutes. Areas that fulfil any of these criteria are not suited for search areas.

2. Does the area have a WSI > 43.5? If the answer is yes, then it is an area in which the construction of WEPs is very critical (chapter II-12.3), and thus is also not appropriate as a search area.

3. Does the area have a WSI > 23.7? If the answer is yes, then this is an area in which the construction of WEPs would be critical (chapter II-12.3), which would only be appropriate as a search area after careful examination.

4. If the search area lies in regions of particularly high migratory intensity, such as the North Sea coast or the Baltic Sea region (particularly the area around Rügen / Pomeranian Bight, western Baltic unclear), it is probably also unsuitable. This decision can, however, only be made when empirical information on bird strike risk is available. According to the current state of knowledge, these areas cannot be declared as search areas without reservation.

In areas suited as search areas, the different environmental impact studies described in chapter II-13 have be carried out carefully at all phases of planning, erection and working of the respective WEP. It is important that an assessment includes the totality of all WEPs and not only individual sites.

II-13 Recommendations for the reduction and avoidance of impacts by WEPs on birds

Recommendations for the *reduction of collision risk* in offshore WEPs are only possible under reservation due to the lack of information on illumination of plants, also on land. Isselbächer & Isselbächer (2001) recommend the following for WEPs on land:

- Alignment of the turbines in rows parallel to the main migratory direction.
- Interference free migration corridors of several kilometres width between wind parks.
- Avoid construction of wind parks between e.g. between resting and foraging grounds.
- Avoid construction of wind parks in zones with dense migration.
- Refrain from large-scale illumination.
- Application of reflectors and signal paints on the plants

These recommendations could most probably be applied to offshore areas, too. The most important measure to prevent bird strikes therefore would be to refrain from building WEPs in areas of high flight activity.

The U.S. Fish and Wildlife Service recommend white or if necessary red flashing illumination on transmitting towers. These should be installed with the minimally permitted number and intensity. The flashes should be of short duration and the intervals between flashes as long as possible. The use of continuous or pulsing of bright red lights should be avoided (Kingsley & Whittam 2001). As long as no better information is available, these recommendations should also be applied to offshore WEPs. Perhaps the most sensible solution would be lighting which is adjusted to the weather conditions: Flashing light in good weather, to avoid the attraction of birds, and diffuse illumination to make the entire plant conspicuous and therefore reduce collisions during fog and mist.

There is considerable evidence that birds are capable of recognising WEPs and other technical obstacles, even at night. On the other hand, it is likely that under specific conditions (sudden fog or rain after good migratory conditions), it could come to massive collisions because the birds are disorientated and/or cannot recognise the obstacles (Isselbächer & Isselbächer 2001, Schmiedl 2001 and chapter II-3.1.1). Such situations are not likely to occur very often, however, it is expected that they will cause many casualties when the numbers and areal extent of planned WEPs are going to be, even only partially, realized. It would be appropriate in this case to consider implementing a bird-strike warning system similar to that of the Airforce, based on actual observations of migration (see II-12.1.2). During the few nights in which a high frequency of bird strikes is expected, the turbines could be turned off and the rotor blades adjusted so that their surface is minimized relative to the main direction of migration.

The only way to avoid *displacement effects* is to refrain from constructing in areas with high concentrations of sensitive species. The areas could first be classified according to the WSI (see above). If this is not possible due to a lack of data, IBAs (also de facto ones) may be an appropriate criterion to select an area. As long as the consequences of habitat loss for resting birds are not known (see research requirements) it is not possible to assess which areas in sensitive regions are appropriate for the construction of WEPs without consequences for birds. The only sensible measure therefore is a precautionary one. There are no measures which will reduce disturbance effects by WEPs and other constructions in marine habitats on animals.

II-14 Research requirements

Literature surveys, own data collection and data analyses have without doubt opened further questions and gaps regarding our knowledge and understanding. As requested, these are listed and discussed in the following.

II-14.1 Migration

It should be remembered that only one autumn and one spring migration season could be investigated and that comparable large-scale data from the literature are scarce. Although the year 2001 did not appear out of the ordinary as far as weather conditions were concerned, it is not possible to decide whether this year was really representative. In order to assess the long-term effects on the environment of WEPs the possible variability of the investigated parameters must be considered. Thus, in conformity with the minimum requirements for accompanying research (chapter II-13) it is necessary to carry out multiyear studies using the same methods, which turned out to be practical during this project.

The *spatial distribution* of migration, using military surveillance radar was not resolved in the temporal and spatial detail, as intended. Since it will not be possible to obtain the primary data in the near future (compare chapter II- 12.1.2) several questions will have to be answered using alternative methods. The military data, despite the constraints, are the only available data on the average spatial distribution for the period of investigation. However, the data need to be processed further in order to make a quantitative comparison of the frequency distribution between stations (Figures II-42 and II-43). Such improvements are being tested in the BIMOS-Project (funded by the Bundesamt für Naturschutz). This project will also enable the analysis of other seasons as well another year (2000).

Information on the migratory *intensity pattern* is only partially to be gained from the military data, contra earlier expectations. This means that additional independent complementary measurements with special vertical radar are required. These should preferably be carried out from locations at sea (see BEOFINO-Project of the BMU), in addition to some on the coast (lighthouses ?). Such a continuous radar network would provide further information, next to migratory activity, on *altitude distribution* as a function of *weather* (important for bird strike prognosis) as well as on the *temporal-spatial distribution* of migration. This would provide a better evaluation, perhaps even correction of the military data. The radar network should be complemented by visual and acoustic observations to improve the knowledge of species involved. In view of the large daily variability in the migratory intensity (chapter II-9.2.1) a continuous recording is essential. It would also serve for comparative purposes for data collected during the accompanying investigations.

To test the applicability of investigations carried out on land for the migratory behaviour at sea, it is extremely important to carry out complementary studies in the actual offshore area (as envisaged in the BEOFINO-Project) In addition it is recommended that the influence of structures on land on migration is also investigated. This is crucial in order to establish precise „migratory corridors“ (Baltic Sea region) with high bird strike risks (also see chapter II-8.2.1.1).

The continuation of analyses on *direction of migration* using military data is particularly important to evaluate collision impacts on populations. These should be substantiated by own visual and radar observations (direction as function of altitude). This information would provide a link to the populations of the most important species. By using species-specific demographic parameters such as population sizes, distribution, reproductive rates and mortality, it will for the first time be possible to estimate impacts on populations under different scenarios. Visualisation of the military data (chapter II-8.2.2) has shown, at least subjectively, that reverse migration (migration in the wrong direction) occurs more often than expected. This is particularly the case during changing weather conditions including snow and frost in late winter, early spring and late autumn. Back and forth movement in areas with WEPs will have consequences with regard to enhanced collision potential. This has been considered in the assessment of effects on populations but has never been quantified.

Studies on the *collision risk* need to be initiated as soon as the first pilot plants have been constructed (for methods see chapter II-12.2). Empirical quantification of avoidance as well as collision potential is essential for the estimation of impacts. It is also necessary to investigate large-scale avoidance manoeuvres as well as circling of plants in order to estimate the energetic consequences.

The effects of illumination (lighting) on birds should also be tested immediately in conjunction with the construction of pilot plants. Experimental studies could actually be carried out beforehand.

The automised systematic recording of *bat* echolocation sounds on Helgoland during the autumn migration of 2001 and the spring and autumn migrations of 2002 (Hüppop unpubl.), have shown the regular migration of the bats Nathusius pipisterelle and Common pipistrelle (*Pipistrellus nathusii* und *P. pipistrellus*), and occasionally the Noctule (*Nyctalus noctula*). In earlier years, further species were recorded on Helgoland. This proves that bats also regularly cross the North Sea during their migration. Bats have also been recorded over the Baltic island Greifswalder Oie (Heddergott & von Rönn 2002). It is also known that bats collide with WEPs (e.g. Osborne et al. 1996). Therefore it is essential that automatic registration stations for systematic investigations be planned to obtain information on intensity and distribution of migration (Hüppop in prep.).

II-14.2 Distribution of sea and coastal birds in the North and Baltic Seas

In order to create maps of wind energy sensitivity indices for the Baltic Sea (chapter II-11), which may constitute important aids for planning and decision-making, it is essential to continue and extend the surveying. This is already taking place within the MINOS project (www.minos-info.de). There is also still a lack of information on the escape flight distances of seabirds at sea. It is therefore essential to obtain more information in order to predict potential displacement effects by WEPs, their construction and the servicing of the plants. This also applies to local bird movements near the feeding grounds (e.g. ducks in the Baltic) since these increase the danger of collision considerably.

Comprehensive mapping and behavioural observation is required soon after the first pilot plants have been constructed, in order to determine their effects on the distribution of birds since displacement effects are expected, at least for the sensitive species (e.g. map in: Horns Rev Newsletter - June 2002; www.hornsrev.dk/ Engelsk/default_ie.htm), the potential loss of habitat and consequences for the bird populations needs to be assessed by modelling.

II-15 Summary

The construction of wind energy plants (WEPs) may result in substantial interference with birds. This applies to both local birds, living at sea as well as waterfowl and terrestrial birds, which regularly cross the sea during migration. In the German Bight, there are two zones, which are of international importance for birds (eastern German Bight and the sea off the East Frisian Islands). In the German Baltic regions it is particularly the Bodden areas of Mecklenburg-Vorpommern including the Stettiner Haff, die Pomeranian Bight as well as large parts of the Lübeck-Mecklenburg Bight and the Kiel Bight, which are internationally important. More than 10 million birds cross the North and Baltic Seas during their migration between breeding and wintering quarters. Both Seas lie in the centre of global migration routes.

Birds are potentially endangered by offshore WEPs due to: (1) Danger of colliding with WEPs (bird strike), (2) short term loss of habitat during construction and or servicing of the plants, (3) long term loss of habitat because of displacement (frightening away) of birds by WEPs, (4) barrier effects on migrants, (5) disruption of ecologically linked units of stationary birds. In order to estimate the potential conflict between the separate parameters, it is essential to know the spatial and temporal distribution of birds as well as details of their general behaviour (migration, foraging, weather) and the behaviour in relation to offshore WEPs; the construction and servicing vessels (fleeing distance, avoidance manoeuvres, consequences of lighting, collision risk).

This project was therefore tried to close gaps in the knowledge on temporal and spatial distribution of migratory and resting birds as well as to obtain more precise information on altitude distribution of migration over the North and Baltic Seas by consulting the literature and applying various field methods. In 2001 we carried out our own observations of spring and autumn migration on the islands of

Helgoland, Fehmarn and Rügen, using visual, acoustic and radar supported methods. The study was supplemented by data from military large range surveillance radar with the support of the Amt für Wehrgeophysik. Long term data sets on the distribution of seabirds and on visual observation of migration over Helgoland were also analysed.

The collected data are intended to support the impact assessment on the risk of WEPs for birds as well as to provide a basis for areal assessment and the classification of the conservational significance of the various planning sites. The combined evaluation of all aspects is intended to result in the development of a method to facilitate the assessment of appropriate zones for construction of wind energy plants taking into account the problem of migratory and resting birds.

According to visual standardized observations, birds migrate over the German Bight near Helgoland throughout the year (this probably also applies for the Baltic Sea, although it is not been substantiated by continuous observations). Departing and return migration are of similar magnitude with regard to bird numbers. Migration mainly takes place from February to May and from August to November.

Standardized seawatching, visual raptor and passerine observations recorded a total of 136.000 individuals belonging to 168 species at the three locations. The migratory intensity varies from day to day. An average of more than 500 birds per hour was, however, recorded at all three sites during the main migratory periods. Raptors, cranes, pigeons, swifts and Hedge Accentors tend to fly primarily at high altitudes (> 50 m). Herons and most song birds fly at mid to high altitude (mainly > 10m) Whereas divers, gannets, cormorants, swans, geese, dabbling ducks, diving ducks, waders, gulls, terns and swallows fly mainly between 5 to 10 m and grebes, tubenoses, seaducks, mergansers, skuas and auks below 10 m. The altitude of migration decreases with increasing wind force and headwinds.

Dabbling ducks and terns always maintained a distance of at least 500 m from the coast. This behaviour was even more pronounced in divers, seaducks und auks, where the distance to the coast was usually over 2 km. These species are expected to show particularly strong avoidance manoeuvres when confronted by obstacles.

Over one million sea and waterbirds as well as waders and coastal birds are estimated to cross the zone up 5 to 10 km around Helgoland and the optically monitored lower 200 to 500 m air space above, during their migration. For 19 species this is more than 1% of the biogeographic population. More than half of the population of Pink-footed Goose and Little Gull migrate past Helgoland. More than 10 % of the biogeographic population of Red-throated Diver, Greylag Goose, Brent Goose and Black Scoter are also estimated to pass through this area.

The observations with ship radar showed that migration took place up to altitudes of at least 3800 m. Since the raw data obtained with ship radars do not yield quantitative altitude distribution, it was necessary to calculate a conversion equation in order to correct for the distribution of echos up to an altitude of 1800 m. According to the radar observations, more than 20% of all birds migrate at an altitude below 200 m at Helgoland and Rügen, while more than 30% fly below this altitude at Fehmarn (taking into account that birds flying immediately above the sea surface cannot be recorded by the radar). During spring, migration generally took place at lower altitudes.

The migration altitude was lowest during the afternoon hours and increased after sunset to attain the highest values two hours after sunset. Thereafter the altitude again decreased and remained relatively low in the second half of the night. However, between 16% and 25% of all echos still occurred below 200 m during the night (main period of migration). During rain and headwinds birds clearly migrate at lower altitudes.

During spring, the main direction of migration was NE, whereby a large proportion of bird movements took place in the opposite direction, particularly on Helgoland. The autumn migration was usually directed to SW to SSW at all locations. Only on Rügen there was also a distinct movement in the opposite direction (NNE). On Fehmarn the main flight direction was at right angles to the coast (birds crossing the Fehmarn Belt). It was almost exclusively parallel to the coast of Rügen. The average speeds of migration on all locations differed with season (distinctly faster during spring than in autumn). The military radar confirmed the main direction of migration but also revealed undirected movements on Fehmarn, north of Rügen and in the Pomeranian Bight during the day. These are attributed to foraging birds (gulls, ducks changing between feeding locality).

The seasonal course of migratory intensity varies markedly and is characterised by a few days of extremely high activity. Half of all birds pass through within 5% to 10% of the total number of days. The migratory intensity is also subject to strong diurnal variation: The least activity was usually recorded in the afternoon hours, independent of location or season, whereas it increased markedly about one hour after sunset. During the course of the night, until sunrise, the intensity again decreased. The highest activity was observed during tailwinds. During calm conditions and slight headwinds (major weather condition!) there was also intense migration. During rain the migration was less or commenced later.

There were significant accordances in migratory intensity determined with different methods for divers, seaducks, finches and thrushes. This was not the case for gulls and raptors. Despite some disparity, the radar data provide a representative picture of current migration of sea and coastal birds as well as of songbirds.

The military radar data confirm that intensive migration takes place soon after sunset, which decreases in the second half of the night but often continues well into the next morning. After sunrise there appears to be more small-scale undirected bird movement, particularly over the Baltic Sea and off the North Sea coast, but also inland along the coast. This diminishes during the afternoon. In the North Sea area it is apparent, that migratory intensity decreases with increasing distance from the coast. However, there is a wide band of intensive migration along the entire coast from the Netherlands up to Denmark. There is also a wide band of almost equivalent intensity in the Baltic, from Schleswig-Holstein and Mecklenburg-Vorpommern to Denmark and Sweden. An exception is the migratory activity (presumably of sea ducks and gulls) in the region north of Rügen and in the Pomeranian Bight.

The coastal regions of the German parts of the North and Baltic Seas up to depths of about 30 m are internationally very, if not exceptionally important feeding, resting, moulting and wintering sites for a large number of sea and waterbirds. Distribution maps of some species are currently being updated. A Windenergy-Sensitivity-Index (WSI) is being used to map resting bird concentrations sensitive to offshore wind energy plants. It shows divers and Sandwich Terns to be particularly sensitive, but that grebes and seaducks also have high values. The near coastal regions up to about 30 m depth are classified as sensitive.

Methods to quantify flight movement, to determine bird strike risk and for the assessment of search areas, were evaluated. Accordingly, the use of a combination of different techniques (visual, radar and thermal imaging cameras) as well as information on distribution at sea (preferably evaluated by the WSI) is unavoidable. With regard to the overall assessment of the risk potential displacement and bird strike are the most critical factors. As yet unclear remain the effects of illumination on WEPs.

Further research is required in order to obtain improved reliability and estimates of the variability in bird migration presented in this report. This means inclusion of more data from more migration seasons, improved evaluation of collision risk and finally the impact of WEPs on the populations of the affected species. There is a need to develop methods to minimize bird strikes, to improve the understanding of bat migration over the North and Baltic Seas and to enlarge the knowledge on the distribution of sea and coastal birds in the Baltic Sea.

Table annex : SP2 Resting and migratory birds

Totals of individual species per location per observation campaign (see chapter II-4)

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
period	14.-15.3.01	24.-31.3.01	4.-13.4.01	16.4.-2.5.01	8.-19.5.01	20.-27.5.01	7.-26.8.01	28.8.-6.9.01	8.-19.9.01	22.9.-6.10.01	9.-15.10.01	17.-23.10.01	
seawatching hours	3.5	5.75	32.75	32	23	22.25	44.75	27	47.75	27.75	6	15	287.5
passerine observation hours	3.5	9.5	1.0	0	22	0	5.5	4	6	30.75	18.25	9.75	110.25
raptor observation hours	0	6.5	0	0	19.25	0	2.25	35.75	8.25	0	14.75	0	86.75
Red-throated Diver	29	2	97	39	0	5	0	0	0	3	0	2	177
Black-throated Diver	0	0	460	4	9	13	0	0	39	0	3	46	574
Yellow-billed Diver	0	0	0	0	1	2	0	0	0	0	0	0	3
Diver spec.	0	2	82	0	5	1	0	0	7	1	0	6	104
Great Crested Grebe	0	1	18	0	0	2	0	1	2	1	0	4	29
Red-necked Grebe	0	0	66	2	2	4	0	1	3	0	0	13	91
Slavonian Grebe	0	0	12	1	0	0	0	0	0	0	0	1	14
Grebe spec.	0	0	0	0	4	0	0	2	1	0	4	3	14
Sooty Shearwater	0	0	0	0	0	0	0	0	0	5	0	0	5
Northern Fulmar	0	0	0	0	0	0	4	0	0	0	0	0	4
Northern Gannet	0	0	0	0	0	0	141	0	0	8	0	0	149
Great Cormorant	0	93	158	48	33	203	99	178	240	229	58	219	1558
Grey Heron	1	7	4	5	2	1	10	10	20	2	6	1	69
White Stork	0	0	0	0	1	0	0	0	0	0	0	0	1
Mute Swan	0	0	17	0	30	59	0	12	3	0	3	6	130
Tundra Swan	0	41	0	0	0	0	0	0	0	0	0	11	52
Whooper Swan	0	8	15	0	0	0	0	0	0	0	6	54	83
Swan spec.	0	0	5	0	0	0	0	0	1	0	0	19	25

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Bean Goose	0	0	0	0	0	0	0	0	0	0	0	2	2
Pink-footed Goose	0	0	0	0	0	0	0	0	0	56	0	0	56
Greater White-fronted Goose	0	56	0	0	0	0	0	0	0	0	20	227	303
Greylag Goose	0	18	2	325	27	165	0	31	5	296	27	1	897
Barnacle Goose	0	0	0	150	64	0	0	8	0	122	6	0	350
Brent Goose	7	1	6	80	2	7	0	0	11	1018	28	4	1164
Canada Goose	0	0	1	0	0	0	0	0	0	0	0	77	78
Hybrid Canada- x Barnacle Goose	0	0	0	0	0	0	0	0	0	0	0	1	1
Goose spec.	0	13	0	0	310	0	0	0	227	159	0	109	818
Common Shelduck	0	0	7	0	5	16	0	14	0	0	0	0	42
Eurasian Wigeon	0	17	69	0	7	0	10	953	4651	549	254	60	6570
Gadwall	0	0	1	0	0	0	0	3	0	0	0	0	4
Eurasian Teal	7	0	8	5	0	0	16	653	883	28	16	0	1616
Mallard	0	0	6	2	0	2	0	121	40	2	3	208	384
Northern Pintail	0	0	0	4	0	0	0	249	376	186	7	3	825
Garganey	0	0	0	0	0	1	0	0	0	0	0	0	1
Northern Shoveler	0	0	3	0	1	2	0	5	58	68	19	11	167
Dabbling Duck spec.	0	0	0	0	0	0	0	30	218	274	0	0	522
Common Pochard	0	0	0	0	1	0	0	0	12	0	0	10	23
Tufted Duck	0	0	2	0	2	15	0	0	42	17	0	68	146
Greater Scaup	0	0	45	1	0	1	0	0	1	0	4	2	54
Diving Duck spec.	0	0	0	0	0	0	0	0	0	0	0	46	46
Common Eider	2	321	788	36	268	109	38	809	4815	840	3874	1030	12,930
Long-tailed Duck	0	41	1135	0	0	0	0	5	0	0	0	541	1722
Black Scoter	126	118	15,803	465	69	1063	147	515	7963	109	7	713	27,098
Velvet Scoter	0	0	46	1	0	14	0	2	63	0	0	50	176
Seaduck spec.	0	0	0	0	0	0	0	0	94	0	0	18	112
Common Goldeneye	1	3	21	2	0	0	0	8	1	6	0	88	130

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Red-breasted Merganser	0	6	222	13	12	9	0	0	195	11	17	141	626
Goosander	0	0	15	1	0	0	0	0	31	0	4	15	66
Merganser spec.	0	0	0	0	0	0	0	0	2	0	0	0	2
Duck spec.	1	0	0	3	355	0	0	409	723	159	0	6	1656
European Honey-buzzard	0	0	0	0	531	0	1	164	3	1	3	0	703
Black Kite	0	0	0	0	4	0	0	0	0	0	0	0	4
Red Kite	0	3	0	0	2	0	0	0	0	0	0	0	5
White-tailed Eagle	0	0	0	0	0	0	0	1	0	0	0	0	1
Eurasian Marsh Harrier	0	6	0	2	24	0	8	25	4	0	0	0	69
Hen Harrier	0	0	0	0	4	0	0	2	0	0	3	1	10
Montagu's Harrier	0	0	0	0	2	0	0	0	0	0	0	0	2
Harrier spec.	0	0	0	0	1	0	0	1	0	0	0	0	2
Northern Goshawk	0	0	0	0	0	0	0	1	0	0	0	1	2
Eurasian Sparrowhawk	0	11	5	0	35	0	0	118	24	3	68	46	310
Common Buzzard	0	141	7	1	12	0	0	287	46	0	7	29	530
Rough-legged Buzzard	0	0	3	0	0	0	0	0	0	0	0	8	11
Buzzard spec.	0	0	0	0	0	0	0	0	0	0	0	11	11
Booted Eagle	0	0	0	0	1	0	0	0	0	0	0	0	1
Osprey	0	0	0	1	1	0	0	7	5	1	0	0	15
Raptor spec.	0	0	0	0	0	0	0	0	1	0	0	0	1
Common Kestrel	0	0	3	0	5	0	0	22	3	5	2	0	40
Red-footed Falcon	0	0	0	0	1	1	0	0	1	0	0	0	3
Merlin	0	0	1	3	4	3	0	1	2	8	8	2	32
Eurasian Hobby	0	0	0	0	2	0	0	0	0	0	0	0	2
Peregrine Falcon	0	0	0	0	0	0	0	2	0	0	0	0	2
Falcon spec.	0	0	0	0	1	1	0	0	2	0	0	0	4
Common Coot	0	0	1	0	0	0	0	0	0	0	0	0	1
Common Crane	0	0	36	0	0	0	0	0	60	0	0	1773	1869
Eurasian Oystercatcher	0	0	2	0	14	0	180	25	2	0	0	0	223

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Pied Avocet	0	0	0	0	5	2	0	0	0	0	0	0	7
Little Plover	0	0	0	0	0	1	0	0	0	0	0	0	1
Ringed Plover	0	0	0	0	4	0	0	10	3	0	0	0	17
European Golden Plover	0	7	0	0	0	0	139	24,058	45	43	0	0	24,292
Grey Plover	0	0	0	0	0	0	21	8	5	20	0	0	54
Northern Lapwing	0	325	0	0	0	0	0	123	0	0	0	21	469
Red Knot	0	0	0	29	0	0	18	4	0	21	0	0	72
Sanderling	0	0	0	2	0	0	5	2	8	0	0	0	17
Little Stint	0	0	0	0	0	0	0	1	2	6	0	0	9
Curlew Sandpiper	0	0	0	0	0	0	0	11	0	0	0	0	11
Dunlin	0	10	0	1	1	7	76	264	18	35	0	0	412
Broad-billed Sandpiper	0	0	0	0	0	0	0	1	0	0	0	0	1
Calidris spec.	0	0	0	0	0	0	16	2	40	0	0	0	58
Ruff	0	1	0	0	17	0	0	0	15	0	0	0	33
Common Snipe	0	10	0	0	1	0	0	2	36	8	0	0	57
Eurasian Woodcock	1	0	0	0	0	0	0	0	0	0	0	0	1
Bar-tailed Godwit	0	0	0	3	0	0	77	1	0	1	0	0	82
Whimbrel	0	0	1	3	4	0	5	0	0	0	0	0	13
Eurasian Curlew	0	0	7	354	0	0	92	4	2	2	0	0	461
Numenius spec.	0	0	0	0	0	0	2	0	0	0	0	0	2
Spotted Redshank	0	0	0	1	1	0	3	0	1	0	0	0	6
Common Redshank	0	2	0	0	0	0	66	13	0	0	0	0	81
Common Greenshank	0	0	0	5	2	0	17	2	0	0	0	0	26
Green Sandpiper	0	0	0	1	0	0	11	0	0	0	0	0	12
Wood Sandpiper	0	0	0	0	1	0	1	0	0	0	0	0	2
Common Sandpiper	0	0	0	0	1	0	1	0	0	0	0	0	2
Ruddy Turnstone	0	0	0	0	0	0	1	0	5	0	0	0	6
Wader spec.	0	0	0	0	0	0	10	0	2	0	0	0	12
Pomarine Skua	0	0	0	0	0	0	1	0	0	0	0	0	1

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Arctic Skua	0	0	0	1	0	1	1	7	17	7	0	0	34
Skua spec.	0	0	0	0	0	0	1	0	10	0	0	0	11
Mediterranean Gull	0	0	0	0	0	1	0	0	0	0	0	0	1
Little Gull	32	0	15	13347	21	0	1	32	179	31	0	10	13,668
Sabine's Gull	0	0	0	0	0	0	0	0	0	1	0	0	1
Black-headed Gull	46	82	55	229	150	18	522	202	16	8	0	0	1328
Mew Gull	1	7	405	30	26	3	53	31	8	32	0	0	596
Lesser Black-backed Gull	0	0	3	3	0	5	0	0	0	0	0	0	11
Steppenmöwe	0	0	1	0	0	0	0	0	0	0	0	0	1
Black-legged Kittiwake	0	0	0	0	0	0	0	0	1	0	0	0	1
Gull-billed Tern	0	0	0	0	0	1	0	0	0	0	0	0	1
Sandwich Tern	1	2	28	24	0	187	271	151	32	35	2	0	733
Common Tern	0	0	0	5	0	5	309	28	3	4	0	0	354
Arctic Tern	0	0	0	58	1	2	18	3	7	3	0	0	92
„Comic" Tern	0	0	0	174	11	3	1890	272	76	9	0	0	2435
Little Tern	0	0	0	0	0	1	0	0	0	0	0	0	1
Black Tern	0	0	0	1	9	4	8	0	2	0	0	0	24
Common Guillemot	0	0	6	0	0	3	2	0	0	8	0	0	19
Razorbill	0	0	0	0	0	3	0	0	0	1	0	1	5
Black Guillemot	0	0	8	0	0	0	0	0	0	0	0	0	8
Auk spec.	0	0	0	0	0	0	0	0	2	16	0	0	18
Stock Pigeon	0	0	0	0	0	0	0	0	0	0	4	0	4
Common Wood Pigeon	3	1179	212	25	7	0	0	19	0	0	0	24	1469
Eurasian Collared Dove	0	0	0	0	1	0	0	0	0	0	0	0	1
Short-eared Owl	0	0	0	0	0	0	0	0	0	1	0	1	2
Common Swift	0	0	0	0	1	54	38	11	1	0	0	0	105
Great Spotted Woodpecker	0	0	0	0	0	0	0	0	0	2	1	0	3
Wood Lark	0	0	2	0	0	0	0	0	0	1	2	0	5
Sky Lark	1	189	41	0	0	0	0	0	27	33	42	36	369

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Horned Lark	0	0	0	0	0	0	0	0	0	3	0	0	3
Sand Martin	0	0	0	0	20	0	0	27	23	0	0	0	70
Barn Swallow	0	0	0	0	37	2	0	185	108	4	2	0	338
House Martin	0	0	0	0	5	2	0	13	0	3	0	0	23
Swallow spec.	0	0	0	0	10	0	0	8018	1	2	0	0	8031
Tree Pipit	0	0	0	0	110	2	34	9	666	60	0	0	881
Meadow Pipit	3	217	19	0	5	0	2	7	118	3902	660	82	5015
Red-throated Pipit	0	0	0	0	3	0	0	0	0	1	0	0	4
Rock Pipit	0	0	0	0	0	0	0	0	2	9	0	4	15
Pipit spec.	0	0	0	39	0	0	0	0	18	1	0	0	58
Yellow Wagtail	0	0	0	0	184	4	35	165	11	8	2	0	409
Grey Wagtail	1	3	0	0	1	0	0	0	0	4	3	0	12
White / Pied Wagtail	13	83	8	0	0	0	2	25	19	40	20	2	212
Wagtail spec.	0	0	0	0	0	0	0	3	0	0	0	0	3
Bohemian Waxwing	0	0	0	0	0	0	0	0	0	0	0	2	2
Winter Wren	0	0	0	0	0	0	0	0	0	0	0	1	1
Hedge Accentor	2	3	2	0	0	0	0	2	3	2	1	0	15
European Robin	0	0	0	0	0	0	0	0	1	0	0	0	1
Northern Wheatear	0	0	0	0	0	0	0	0	0	5	0	0	5
Ring Ouzel	0	0	1	5	0	0	0	0	0	0	0	0	6
Common Blackbird	25	0	0	0	0	0	0	0	0	0	0	8	33
Fieldfare	0	7	0	0	0	0	0	0	8	1	0	2	18
Song Thrush	0	15	6	4	0	0	0	0	347	419	6	2	799
Redwing	2	33	0	11	0	0	0	0	0	324	5	43	418
Mistle Thrush	0	2	0	0	0	0	0	0	0	3	0	2	7
Thrush spec.	0	0	0	0	0	0	0	0	0	41	0	0	41
Common Chiffchaff	0	0	0	0	0	0	0	0	0	1	0	0	1
Willow Warbler	0	0	0	0	0	0	0	0	1	7	0	0	8
Goldcrest	0	0	0	0	0	0	0	0	0	8	2	1	11

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Blue Tit	0	0	0	0	0	0	0	0	0	0	0	4	4
Great Tit	0	0	0	0	0	0	0	0	0	0	0	12	12
Eurasian Treecreeper	0	0	0	0	0	0	0	0	2	0	0	0	2
Great Grey Shrike	0	0	0	0	0	0	0	0	0	0	1	0	1
Eurasian Jay	0	0	0	0	0	0	0	0	12	0	0	4	16
Black-billed Magpie	0	3	0	0	0	0	0	0	0	0	0	0	3
Eurasian Jackdaw	0	31	2	6	0	0	0	0	0	0	26	9	74
Rook	0	5	7	0	0	0	0	4	0	0	29	171	216
Carrion / Hooded Crow	0	0	0	0	0	0	0	0	0	4	0	0	4
Hooded Crow	0	2	2	0	0	0	0	0	0	0	0	6	10
Common Starling	91	614	60	0	0	2	0	27	0	119	22	17	952
Eurasian Tree Sparrow	0	0	1	0	0	0	0	0	0	0	11	36	48
Chaffinch	0	36	42	0	1	0	0	0	25	919	1159	87	2269
Brambling	0	1	20	0	0	0	0	0	1	147	585	29	783
European Greenfinch	0	73	11	0	6	0	0	0	0	0	73	19	182
European Goldfinch	0	1	11	0	0	0	0	0	0	0	23	1	36
Eurasian Siskin	0	13	42	0	1	0	0	8	79	11	171	35	360
Common Linnet	1	138	15	0	0	0	0	114	7	72	467	0	814
Twite	0	0	4	0	0	0	0	0	0	0	0	6	10
Mealy Redpoll	0	0	5	0	0	0	0	0	0	2	14	4	25
Common Crossbill	0	0	0	0	0	0	0	1	0	0	0	1	2
Common Bullfinch	0	0	0	0	0	0	0	0	0	0	0	21	21
Hawfinch	0	0	1	0	2	0	0	0	0	2	0	6	11
Finch spec.	0	0	0	0	0	0	0	0	18	5	63	0	86
Snow Bunting	0	0	0	0	0	0	0	0	0	0	0	1	1
Yellowhammer	0	0	0	0	0	0	0	0	0	0	4	17	21
Ortolan Bunting	0	0	0	0	0	0	3	0	0	0	0	0	3
Reed Bunting	1	46	10	0	0	0	0	0	11	45	23	6	142
Bunting spec.	0	0	0	0	0	0	0	0	0	1	0	0	1

	Helgoland 1	Fehmarn 1	Rügen 1	Helgoland 2	Fehmarn 2	Rügen 2	Helgoland 3	Fehmarn 3	Rügen 3	Helgoland 4	Fehmarn 4	Rügen 4	total
Passerine spec.	0	6	0	0	0	0	1	0	0	13	0	0	20
total	398	4056	20,225	15,555	2504	2012	4407	38,545	22,924	10,683	7880	6421	135,608

III Impact of acoustic noise emitted by offshore wind turbines

III-1 Introduction

The operation of offshore wind turbines is accompanied by persistent acoustic noise immission in the water column. This is the case during both the construction and operational phases. Acoustic noise immission is particularly intense during construction.
The high acoustic noise intensities during construction will only be emitted sporadically and for short periods of hours or minutes. During regular operation of wind turbines, permanent noise will, however, be emitted. Despite the intensity being lower during operation, a large number of wind turbines will emit an intensive large scale and incessant noise strain in the sea.

Whether this noise strain will affect or harm the marine fauna is not yet clarified. It is known that some marine mammals orientate in water, by echolocation. Acoustic sensitivity plays an important role in foraging and communication of some species.

The subproject *„Impact of acoustic noise emitted by offshore wind turbines“* is perceived as an introduction to this problem. The results are expected to be fundamental in formulating continuing essential research.

III-2 Setting of tasks and solutions

The first part deals with a literature survey on available information concerning the subject of noise impacts by offshore wind turbines. Moreover, the different approaches such as studies, first measurements and calculations as well as suitable measures of reducing impacts, to an evaluation of the potential disturbance, form parts of this project.

This sub-project is co-ordinated by the German Wind Energy Institute (Deutsches Windenergie – Institut (DEWI) and carried out together with the Research and Technology Centre (Forschungs- und Technologiezentrum Westküste (FTZ) and the Institute for Technical and Applied Physics at the University of Oldenburg (Institut für technische und angewandte Physik GmbH an der Universität Oldenburg (ITAP)). The FTZ dealt with biological aspects. Questions regarding acoustic noise and oscillation from a physical perspective were dealt with by the DEWI and ITAP.

The physical technical questions are dealt with in the first section (III-3). The intensity, frequency composition and spatial expansion of the disturbance fields were determined by doing acoustic noise and vibration measurements on existing wind turbines as well using emission and propagation computations and comparing these with natural ambient noise.

The biological aspects of this problem are described in detail in section III-5. The acoustic parameters affecting the most important species in the target areas, beginning with invertebrates through fish and finally to marine mammals are presented and evaluated.

The physical measurements and calculations together with the comparable biological parameters enable the derivation and/or the prediction of the degree of impairment or harm on the fauna. This information will allow the possible introduction of measures to reduce emission. Such measures are described and their efficiency assessed in section III-6.

The aims of the project described above are to be realized by carrying out the following steps:

1. Determination of the actual interfering noise field in the water column surrounding an offshore wind turbine (WT).
2. Determination of the potential interference and danger on marine fauna.
3. Presentation of avoidance and reduction measures.

To 1: Determination of the actual interference noise field in the water column surrounding offshore wind turbines

The acoustic noise emission by a WT into the surrounding water occurs mainly via impact acoustic noise transmission. Impact waves from the primary sources in the nacelle are transmitted via the WT tower to below sea level. From here the acoustic noise is radiated to the water.
The acoustic energy transmitted into the water is dependant on the impact acoustic noise emission rate of the power unit in the nacelle, on the conductivity of the impact acoustic noise from the tower and the degree of propagation from the tower under water. The acoustic pressure in the water on the other hand is a function of the distance from the tower. The propagation of acoustic noise in water is mainly governed by the acoustic properties (absorption properties) of the sea floor and water depth.

In order to calculate the acoustic field n the surroundings of an offshore wind turbine the flowing concrete stages are essential:

- Determination of the acoustic energy input to the surrounding water by a WT on the basis of oscillation measurements on the tower and the nacelle of existing on shore WT (Acoustic noise conduction, acoustic noise propagation).
- Determination of the sound pressure field in the vicinity of an offshore-WT (acoustic noise propagation)

The acoustic noise in the water surrounding a WT is only of significance in the marine environment when it is perceivable above the constant existing ambient noise, or not superimposed by it. This ambient noise is dependant on locality, time and weather conditions. In order to assess the interference by off shore WTs it is essential to acquire detailed knowledge of the ambient noise. Reliable and detailed methods of calculation are currently not available and will not be in the future. For this reason a further aim of this project is to carry out measurements at sea.

- Measurement of ambient sound pressure levels at potential sites for offshore wind farm in the North Sea. Measurements have to be carried out at three sites during different seasons and under different climatic conditions.

To 2: Determination of the interference and potential danger for marine fauna.

The measurements and calculations have to be related to the potential endangering of marine organisms. This means that potential dangers have to be identified and assessed for the most important species living in the target areas. A comprehensive literature survey used to describe and assess the state of knowledge was carried out for this purpose.

- Literature survey on the potential impacts of acoustic signals on the marine fauna. Compilation and assessment of the current state of knowledge in relation to physiological and ethological effects of acoustic noise interference on the organisms living in the target areas.

To 3: Presentation of measures of avoidance or minimization

Measures of avoidance or minimization of acoustic noise immission into water are to be recommended using the results from measurements, calculations and literature surveys.

- Presentation of a catalogue of measures to minimize acoustic noise immission into the water column. Calculation and assessment of the effectiveness of the different measures.

Due to the rapid development in the planning of off shore wind energy parks, parallel to this project, it was necessary to bring forward in part the section “Need for further research”. The sub-project described below is to be regarded as the basic project for future research projects such as the future investment program of the Federal Environmental Ministry (BMU).

III-3 Sound and vibration – technical

III-3.1 General remarks on hydro-acoustics

Comments on the physical variables and techniques used are provided prior to presenting the individual hydro-acoustic measurements and calculations.

III-3.1.1 Sound-related fundamentals

Sound pressure p and sound velocity v

Sound can be described by sound pressure p. Sound pressure is a periodic pressure fluctuation, which overlies the ambient pressure (Figure III-1).The sound field is also characterized by the sound velocity v. The velocity is the speed at which water or air particles oscillate about their rest position. This is not to be confused with (and much smaller than) the propagation speed of sound c, which is about 1500 m/s in water.

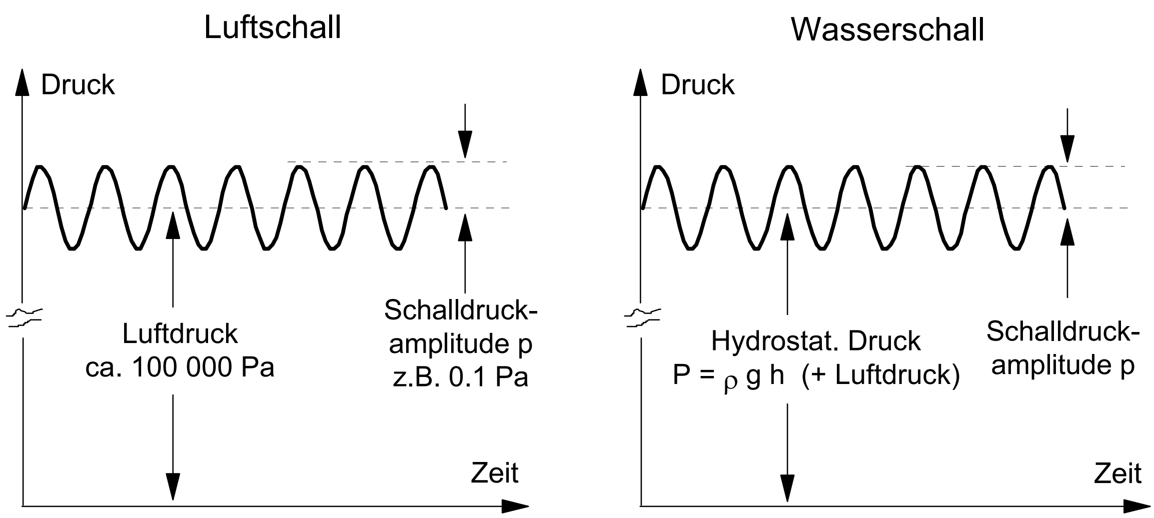


Figure III-1: Air and water borne acoustic noise as a fluctuation of the static pressure.

For a distance r from a point source (spherical wave) it follows for p and v that

$$p \sim i\omega\rho / r$$

and $$\mathrm{v} \sim (ik/r + 1/r^2),$$

where $\omega = 2\pi f$, ρ the density of the medium and k the wave number $2\pi/\lambda$, and where λ is the wavelength. In contrast to the pressure, the sound particle velocity has a second term which does not decrease with 1/r, but with $1/r^2$. In addition it is out of phase by 90° with the first term. The relationship between near-field and far-field amplitude of sound velocity is given by

$$v_{near}/v_{far} = 1/kr = c/\omega r \, .$$

A receiver (may be the auditory system of certain species) –, which does not only respond to sound pressure but also the sound velocity will receive a different spectrum in the near-field of a source; low frequency acoustic noise will be exaggerated, since ω is in the denominator in the above formula.

In the far field, that is for $r > \lambda$, the near-field term vanishes relatively to the 1/r-term. Conditions for the so-called plane wave are prevalent here: Pressure and velocity are “in phase” with one another. The acoustic field can be described both by the sound pressure p as well as the sound velocity v (as long as the propagation direction of sound which is not expressed by the scalar p, is ignored).

Sound pressure level

Usually the sound pressure level L is given, rather than the sound pressure amplitude:

$$L = 20 \log (p_{eff} / p_0).$$

The effective sound pressure p_{eff} is the root mean squared sound pressure averaged over a specific period. For the reference sound pressure p_0, the values $p_0 = 20$ µPa for airborne-acoustic noise and $p_0 = 1$ µPa for water-borne acoustic noise are commonly applied. This results in the levels shown in the following table:

Table III-1: Examples of sound pressure levels in air and water

Sound pressure (rms values)	Sound pressure level in air $p_0 = 20$ µPa	Sound pressure level in water $p_0 = 1$ µPa
1 µPa	-26 dB	0 dB
20 µPa	0 dB	26 dB
1 mPa	34 dB	60 dB
1 Pa	94 dB	120 dB

Sound intensity and sound energy

A frequently used quantity to describe acoustic fields is the sound intensity I:

$$\mathbf{I} = p * \mathbf{v}$$

The intensity is the product of sound pressure and sound velocity. Sound intensity is a vector since the velocity **v** is a vector.

A sound wave transports mechanical energy. The energy transport is in the direction of the sound propagation whereby the transport speed is equivalent to the speed of sound. Energy transport can be characterized by the variables acoustic intensity and sound energy.

- The acoustic intensity is the energy propagated per unit area and time.

The sound impedance Z = ρc, a characteristic of the medium, combines sound pressure with sound velocity. In a plane wave, in other words in the far field of a source, Z = p/v. Thus the magnitude of sound intensity can be expressed both by sound pressure and velocity:

$$I = p^2/\rho c = v^2 \rho c$$

Sound power

Sound power characterizes a sound source and is not a variable of the sound field.

- The sound power is the energy radiated from a sound source per second.

Since the sound power N of a source (or its sound power level L = 10 log (N/ N_0), where N_0 = 1 pW) is not always known or often difficult to derive, sound sources are usually characterized by sound pressure produced in a specific distance. Usually sound pressure levels are calculated for a distance of 1 m, with the source assumed as a point source with negligable volume.

III-3.1.2 Normalization of measurements to a uniform bandwidth.

It is insufficient to convert all sound pressure level data to a single reference value of 1 µPa in order to compare real measurements and values derived from the literature. The measurement bandwidth also influences the level. Spectra are therefore often shown as density levels. That means normalized to a bandwidth of 1 Hz. This results in the unit dB re µPa/$Hz^{1/2}$ or dB re µPa²/Hz, which is equivalent. In this way spectra with a constant absolute bandwidth (FFT; bandwidth ca. distance between spectral lines) and those with a constant relative bandwidth (e.g. 1/3 Octave; Bandwidth approx. f/4) can be displayed together (Figure III-2). Spectral values in dB are to be converted as follows:

$$L_{norm}(f) = L_{meas}(f) - 10 \log B$$

Where L_{meas} is the bandwidth of level B. In the case of a, 1/n-Octave-measurement B is also a function of the frequency f.

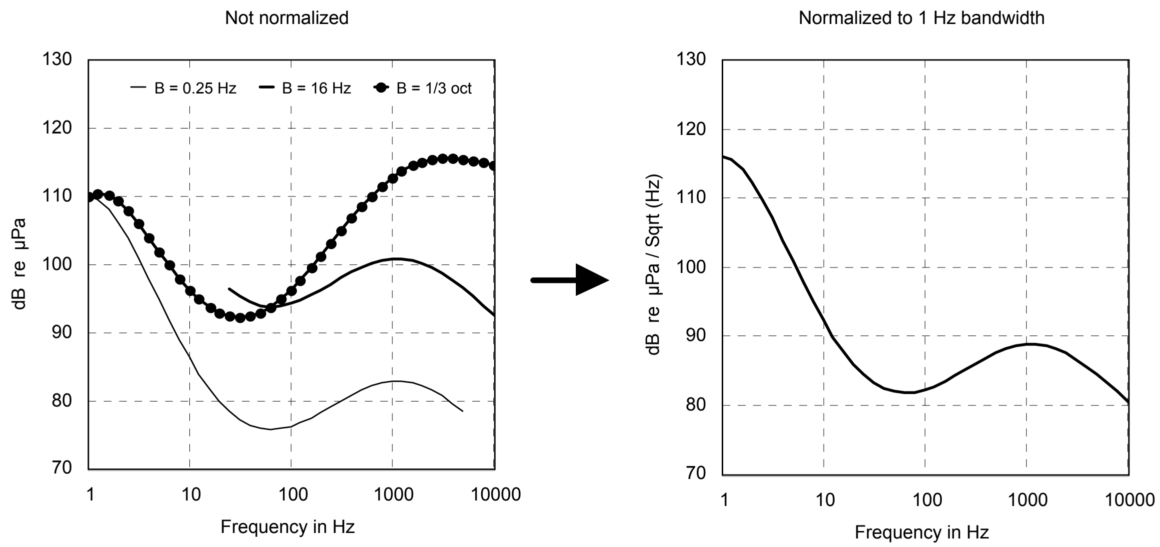


Figure III-2: Spectra recorded at varying bandwidths before and after normalization to a bandwidth of 1 Hz.

The customary normalization to a bandwidth of 1 Hz can cause problems in some cases. If the acoustic noise under investigation has a dominating narrow band component such as noise emanated by machines, the absolute levels become relevant. A subsequent conversion to density levels will result in incorrect mostly to low levels (Figure III-3). The conversion of spectra to 1 Hz bandwidth for comparative purposes is only justified if all original spectra were recorded at the same bandwidth (e.g. 1/3 octave).

A way around the problem associated with density spectra could be to present non-normalized 1/3-octave spectra.

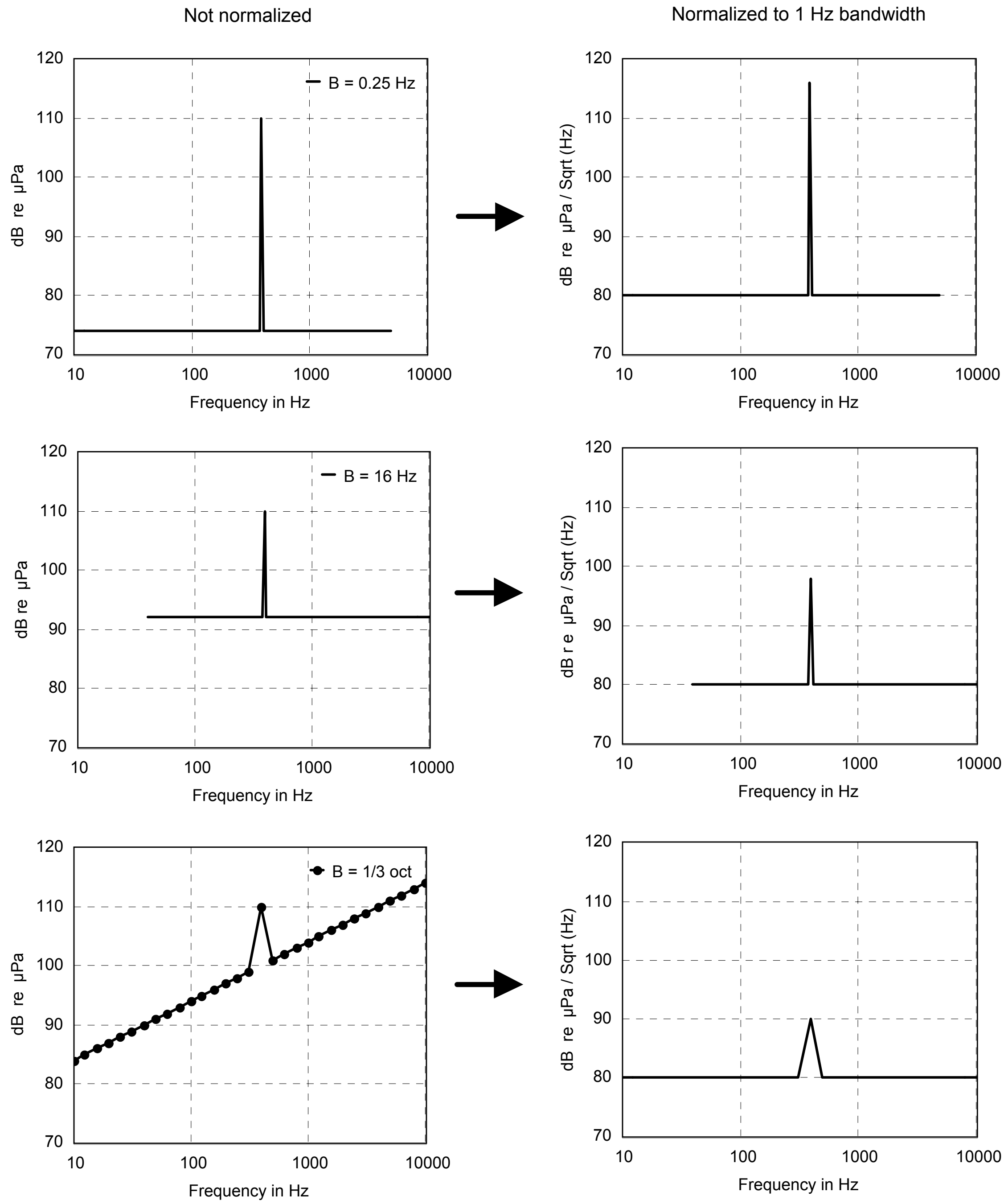


Figure III-3: **The subsequent normalization of tonal sounds to 1 Hz (schematically represented by a white noise of 400 Hz) will result in different levels depending on measured bandwidth.**

III-3.1.3 Sound propagation in shallow water

If the ocean were an isotropic infinite medium in all directions and if the water absorbed no sound, sound pressure and sound velocity would be inversely proportional to the distance r from the source. $I \sim 1/r^2$ would represent the intensity. Expressed as „Transmission Loss“ TL, a reduction in the level in dB from r_1 to r_2:

$$TL = 20 \log (r_2/r_1) \quad dB ,$$

The spherical wave propagation describes the decrease in levels quite accurately. The sea, however, is regarded as a medium with approximate coplanar upper and lower limits. In the ideal case acoustic noise will propagate according to the laws of a cylindrical wave. The level does not decrease by 6 dB per distance doubling, as in a spherical wave, but by 3 dB:

$$TL = 10 \log (r_2/r_1) \text{ dB} .$$

Both the sea surface and sea floor are not totally reflecting interfaces. In addition, acoustic noise in water is absorbed at higher frequencies, so that neither the pure spherical wave propagation nor the cylindrical wave propagation describe the situation accurately.

The Federal Armed Forces Underwater Acoustic and Marine Geophysics Research Institute (FWG) in Kiel carried out extensive studies on propagation absorption in the North and Baltic Seas. The formula of Thiele (2001) provides a good approximation:

$$TL = (16.07 + 0.185 \text{ FL}) (\log(r) + 3) + (0.174 + 0.046 \text{ FL} + 0.005 \text{ FL}^2) r$$

Where $FL = 10 \log_{10}(f / kHz)$ and r is the distance in km. the equation applies to sandy bottoms in winter, distances between 1 m and 80 km, water depths from 30 to 100 m, frequency between100 Hz and 10 kHz and for wind speeds of less than 20 knots. Figure III-4 shows contours of equivalent propagation absorption (TL) as a function of distance and frequency.

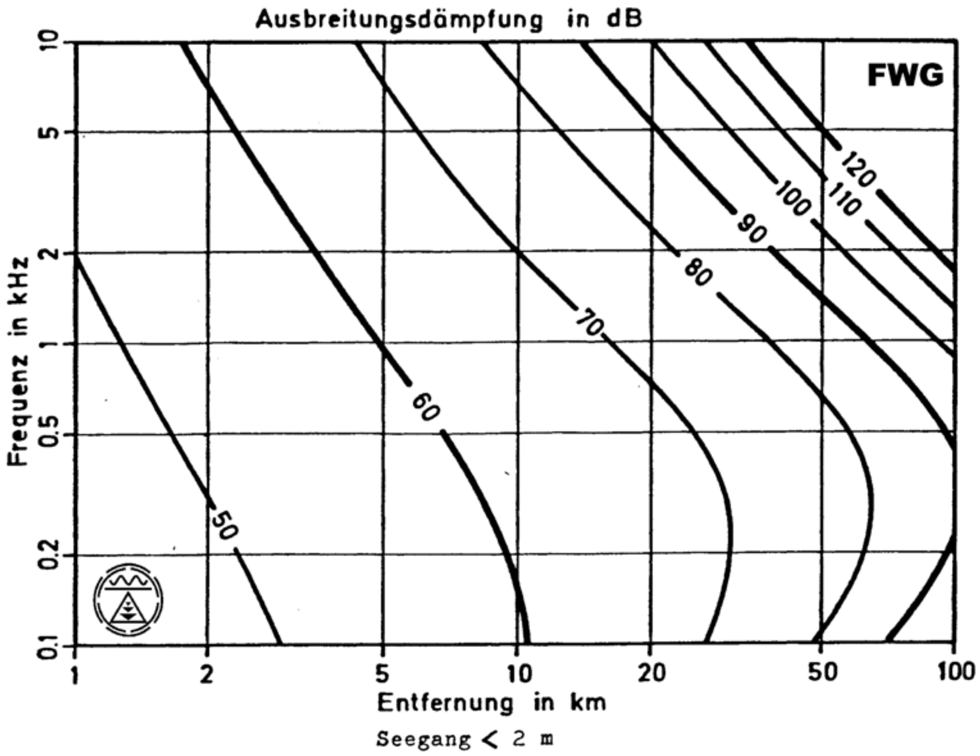


Figure III-4: **Computed propagation absorption (TL) for the North and Baltic Seas (Thiele 2001)**

III-3.2 Current state of knowledge on the acoustic noise problem

A literature survey was carried out to introduce the acoustic noise problem in the subproject *„Acoustic noise“* and to obtain available information on the topic of the impact of acoustic noise from offshore wind turbines. The studies were conceived as a starting point for own studies in this project. Sources of information on the following topics were sought:

- Acoustic noise from offshore-WTs (Measurements, assessments),
- Levels to be expected during ramming of foundation piles,
- Assessment from a biological aspect,
- Hydro-acoustic preloading (Ambient noise), boundary conditions for sound propagation under water in North and Baltic Sea.

Information on the latter point is provided in the subsection *„Sound propagation in shallow water“* in the section *„Technical aspects of sound and vibration”*.

A higher acoustic noise immission into the sea is generally expected to occur in connection with the construction and operation of offshore wind turbines. The most significant sound sources are the actual construction and the running of the wind turbines. An additional sound source will be the increase in shipping activity during all phases (ships used for scientific research prior to and subsequent to the operation, maintenance and supply ships).

This study will deal with the intensity, frequency spectrum and temporal variability of the mentioned acoustic noise immission as far as this information is available. However, up to now there is very little information available on the acoustic noise immission by offshore WTs into the sea. The immission of acoustic noise by the wind turbines will vary with size of the turbines, the construction type and the type of foundation.

The information on the ambient noise (acoustic control situation prior to construction) will be presented before the information on the acoustic noise produced by the WTs.

III-3.2.1. Ambient noise

Generally all acoustic noise immission occurring over longer periods or with regular repetition can be regarded as a component of the overall marine acoustic noise and thus constitutes the ambient noise. All short term and non-repetitive acoustic noises can therefore be regarded as distinct acoustic noise sources (Gisiner 1998). According to this definition all sounds produced by waves or ships along a shipping route can be regarded as environmental or ambient noise.

In recent decades the increasing utilization of the seas, by man has resulted in a continuous increase of ambient noise levels. Anthropogenic acoustic noise sources are:

- Ships – engines, propellers, hydrodynamic noise (Transport, recreation, icebreakers)
- Oil exploration and exploitation as well as marine geophysical investigations (seismic)
- Sonar – Echo sounder, Fish finder
- Under water construction
- Scientific investigations
- Explosions
- Military research
- Aeroplanes, Helicopters (Sound propagation from air into the water)

Ambient noise may be subjected to directional components and changes in its spectral and temporal composition. Ambient noise comprises both natural as well as anthropogenic noise. The prevailing sources for these kinds of acoustic signals according to Wenz (1962) and Richardson (1995) are:

(1 - 100 Hz):	natural seismic noise (Volcanic and tectonic activity)
	Ocean currents and internal waves
(10 Hz - 10 kHz):	Shipping activity
	Industrial activities (incl. geophysical research)
	Sea ice activity (movement, calving of glaciers and icebergs)
(10 Hz - 100 kHz):	Biological sources (acoustic signal of marine mammals)
(100 Hz - 20 kHz):	Wind, waves, air bubbles and spray
(100 Hz - 30 kHz):	precipitation
(30 kHz - mind. 100 kHz):	Thermal noise (molecular)

The intensity, with which the individual acoustic noise sources contribute to the ambient noise in a particular location, depends on the source volume, the source itself, the frequency, distance and direction (Richardson 1995) (see Figure III-5).

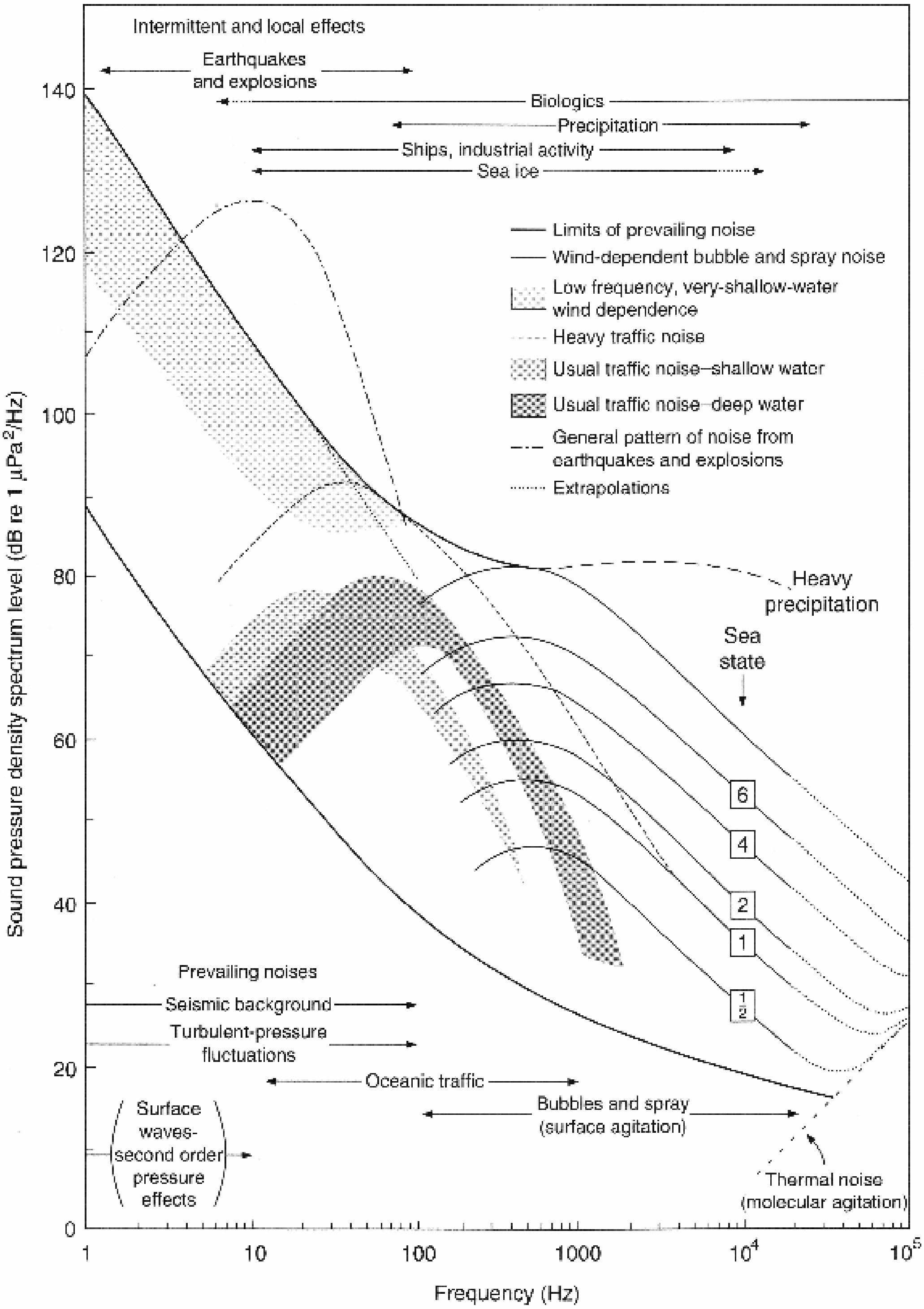


Figure III-5: **Generalized graph of ambient noise spectrum in deep water and the contributing acoustic noise sources; compiled by Wenz (1962) and presented in actual units. (Source: Perrin et al. 2002)**

The water depth in which measurements are carried out also affects the sound level of the ambient noise. The noise level is partially attributable different sound transmission characteristics with the result that, in constant wind and wave conditions, the distance of propagation in shallow water (<200 m) is larger than in deep water (Richardson 1995). At frequencies over ~500 Hz the levels in shallow water often lie about 5-10 dB above those over deep water (Urick 1983). The main sound sources in shallow water are:

- Distant ship sounds, industrial noise or seismic surveys
- Wind and wave noise
- Biological noise

In deep water the acoustic noise between 1 and 20 Hz usually originates from distant shipping activity and ocean currents. Over and above this the noise caused by wind and waves and above 500 Hz including precipitation increases (Richardson 1995).

Ambient noises are subjected to strong temporal fluctuations. The sound level can change by 10-20 dB both in the short and long term resulting in the different perception of specific sounds.

Acoustic noise immission from ships (Figures III-6 and III-7) is caused primarily by the propulsion noise e.g. propeller noise. Other sources are the ships' engines and gearboxes as well as hydrodynamic effects of the ship.

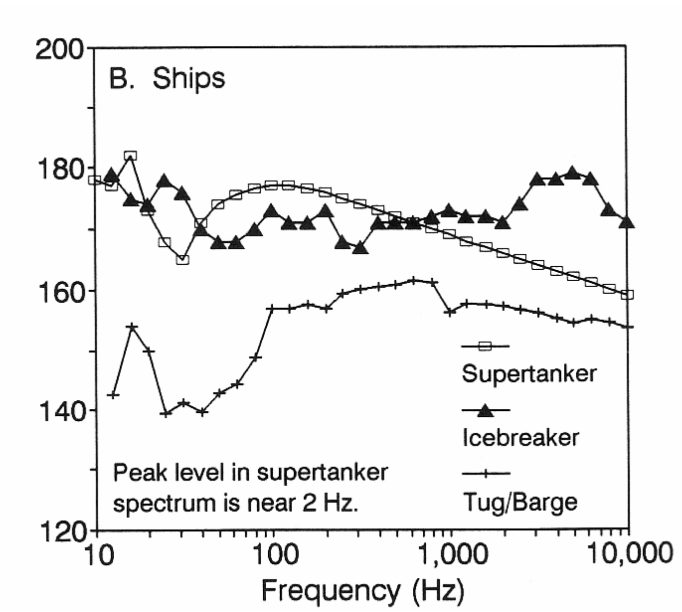


Figure III-6: **Sound pressure levels of various ship types without the measured or reference distance, Source: Richardson et al. 1995)**

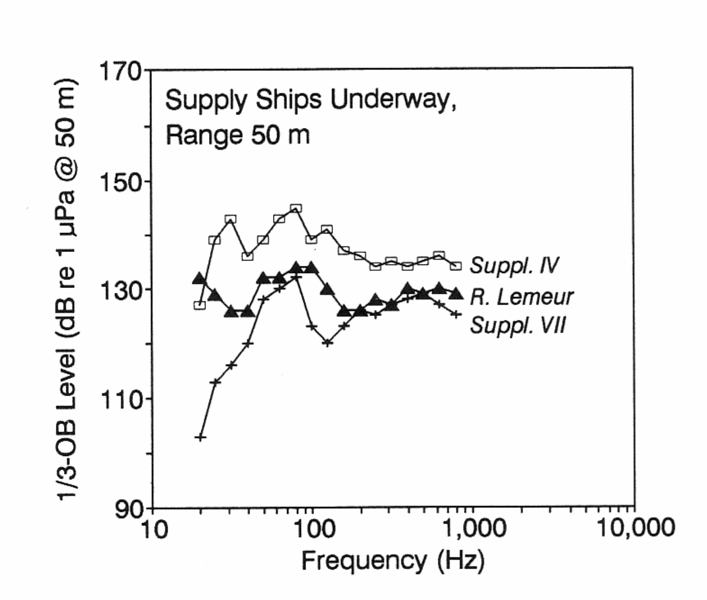


Figure III-7: **Sound pressure levels of ships underway; Suppl. IV and VII = Oil platform supply ships (Source: Richardson et al. 1995)**

III-3.2.2 Immission during construction of wind turbines

Acoustic noise immission resulting from the ramming of monopiles (Figures III-8 and III-9) was recorded during the construction of offshore WTs in Utgrunden (Sweden). The wind turbines were constructed on sand/mud sediment.

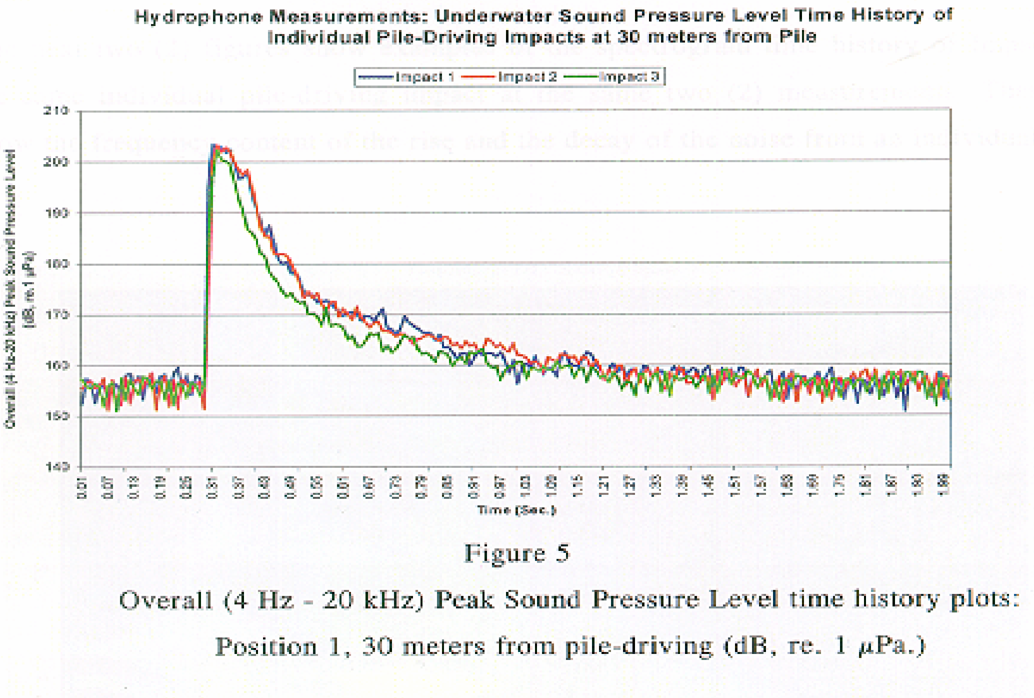


Figure III-8: **Sound pressure level measured under water during ramming events. (Source: Ødegaard Danneskiold-Samsøe A/S 2000 (DK))**

At a distance of 30 m from the source a maximum sound pressure level of approx. 203 dB caused by the ramming was recorded. The calculated value (supposing a transmission loss of 15 log r) for a distance of 1 m is approx. 225 dB re 1 µPa. The pattern shows a rapid increase to the maximum level as well a duration of >0,5 s.

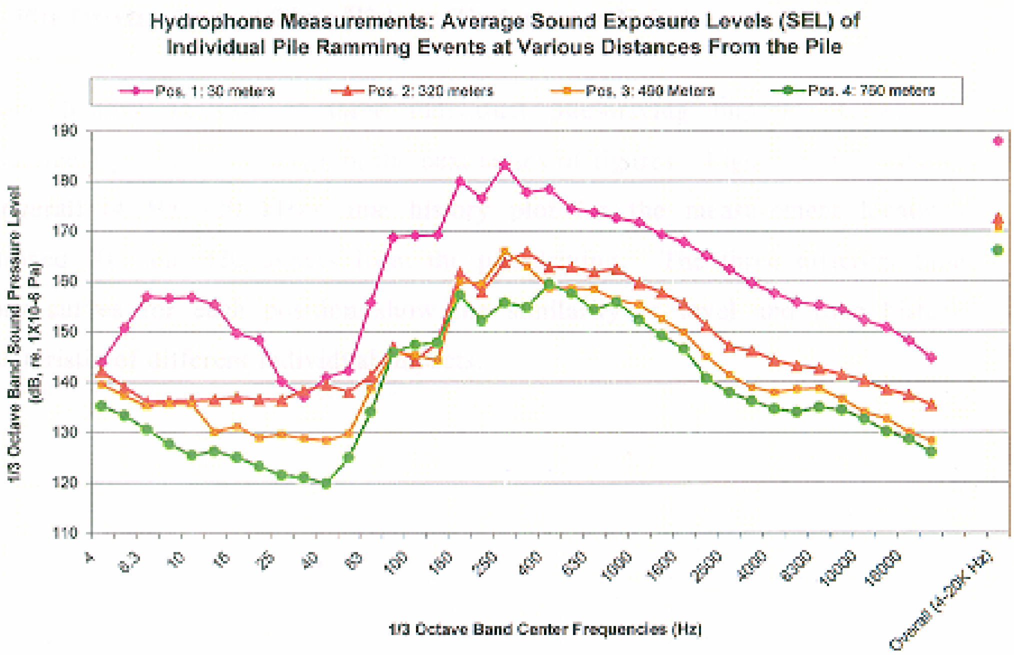


Figure III-9: **Average sound exposure levels (SEL) of individual pile ramming events 30 m (pink line), 320 m (red line), 490 m (orange Line) and 760 m (green line). (Source: Ødegaard Danneskiold-Samsøe A/S 2000)**

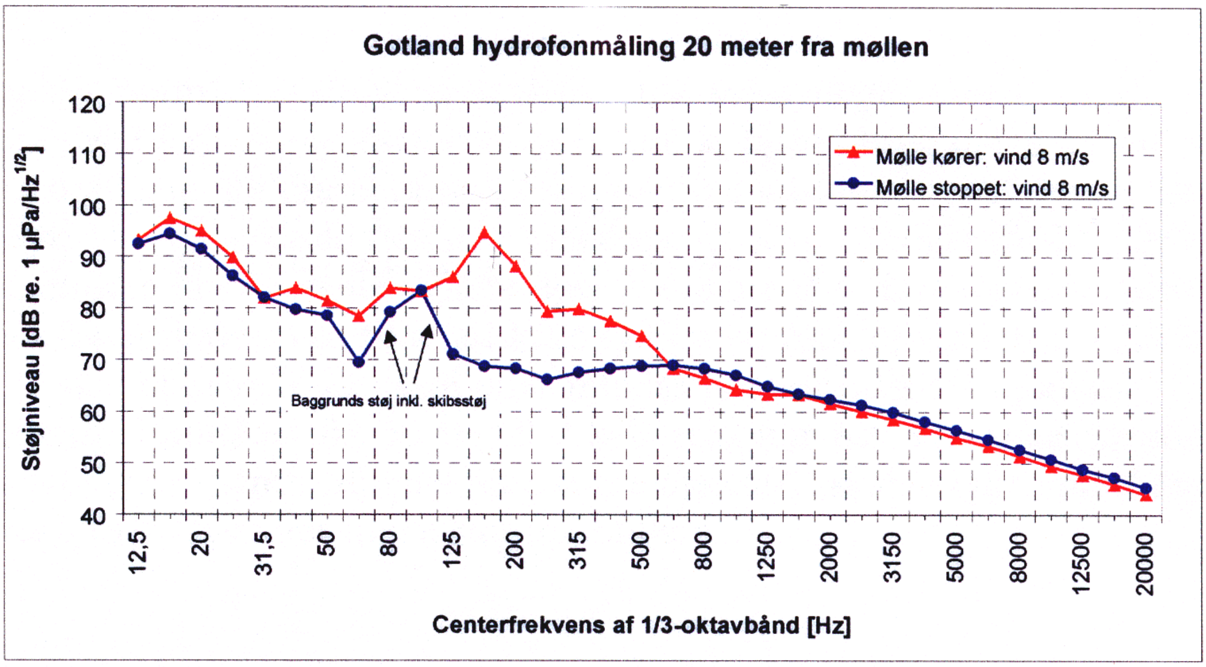
The frequency analysis of the ramming pulses reveal a broad band spectrum covering the frequency range (4 Hz – 20 kHz) with a maximum at approx. 300-400 Hz.

III-3.2.3 Immission during operation of offshore wind turbines

Measurements of noise immission during operation were obtained on three different types of offshore wind turbines.

550 kW WindWorld on steel Monopile; "Bockstigen-Valar" Windpark; Gotland, Sweden
450 kW Bonus on concrete- / Gravity foundation; "Vindeby" Windpark; Lolland, Denmark
2 MW Bonus on concrete- / Gravity foundation; "Middelgrunden" Windpark; Copenhagen, Denmark

The following figures show some examples of results:



Figur 4.7 Støjmåling i vandet 20 m fra mølle.

Figure III-10: **One-third octave spectra measured 20 m from a 550 KW WT (Monopile) (Source: ELSAMPROJEKT, Havmøller Horns Rev, Vurdering af Virkninger pa Miljøet, VVM-redegørelse)**

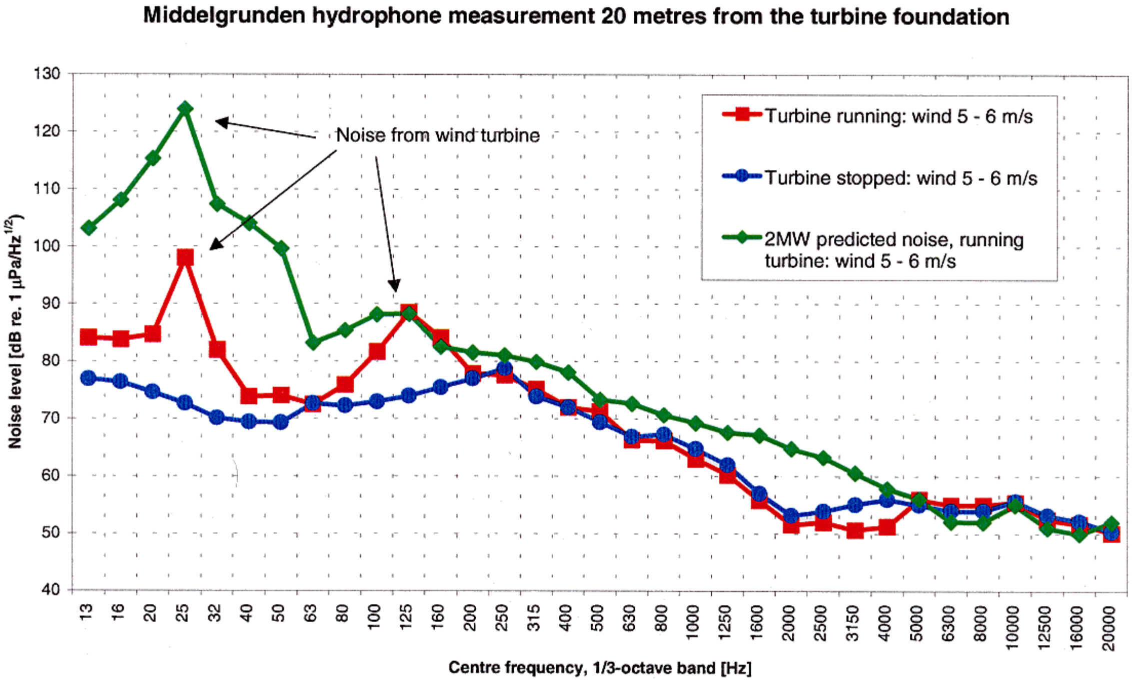


Figure III-11: **One-third octave spectra measured 20 m from a 2MW-WT with gravity foundation (source: Ødegaard & Danneskiold-Samsøe, Report no.01.1058)**

In these presentations it becomes clear that the operational noise of the wind turbines is higher than the ambient noise only at the frequencies (< 200 and < 500 Hz). The peaks at 160 Hz (and 25 Hz as well as 125 Hz) are attributed to tonal components of the turbine noise. These spectral characteristics are similar to those measured on the many different WTs on land and currently on the market. Tonal components of airborne noise are also recognisable. Single tones produced by meshing frequencies of the transmission and which typically lie in this frequency range may be transmitted externally. It becomes apparent that in order to assess the perceptibility of a WT, a spectral analysis of the noise immission is unavoidable. The occurrence of exceptional single tones necessitates a narrow band analysis and assessment.

Figure III-11 shows a prognosticated spectrum next to the sound pressure levels measured on running and turned off WTs. Measurements were also done on different foundation types. The source level of 2-MW-Offshore-WT was determined, based on measurements from smaller WTs and a 2-MW-Wind turbine on land.

For the interpretation of results: Higher values will be caused by normalization to 1 Hz (see III-3.1.2).

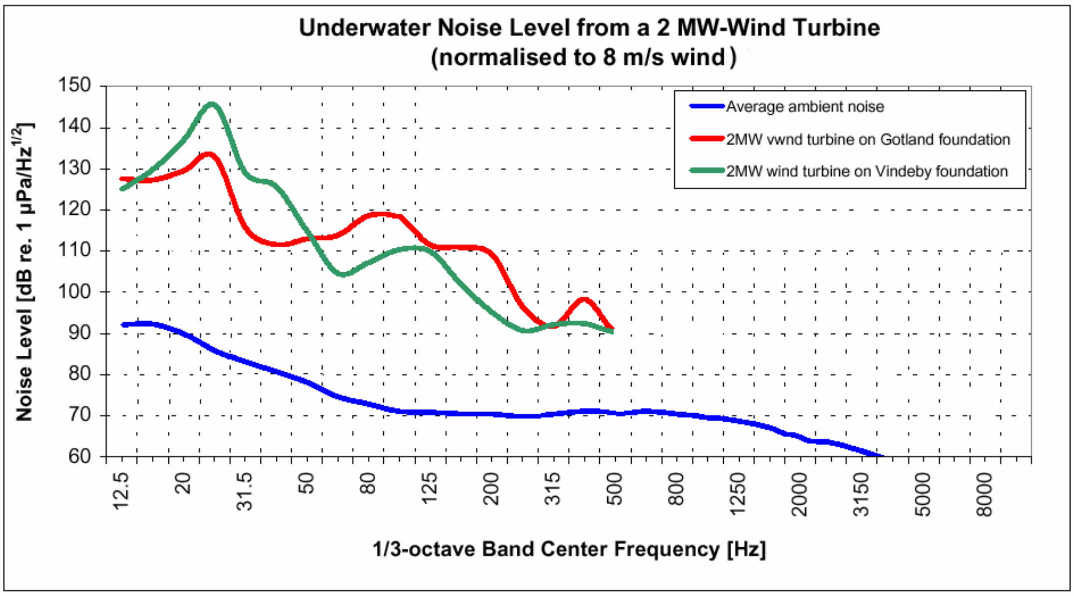


Figure III-12: **Ambient noise level and calculated sound level (at SPL converted to 1 m distance from source) of operational noise from a 2 MW wind turbine on two different foundations. (Source: modified after Ødegaard Danneskiold-Samsøe A/S 2002 (DK).)**

Figure III-13 summarizes the results obtained for several measurements. The underwater sound pressure was measured at 10 - 40 Meters from the foundation during turbine operation and when not running. The ambient noise level was subtracted from the turbine sound levels. A standard source sound level of 1 m from the foundation was calculated assuming cylindrical propagation absorption of (10 log r_2/r_1). Also shown are ambient noise levels, which are of cause not normalized.

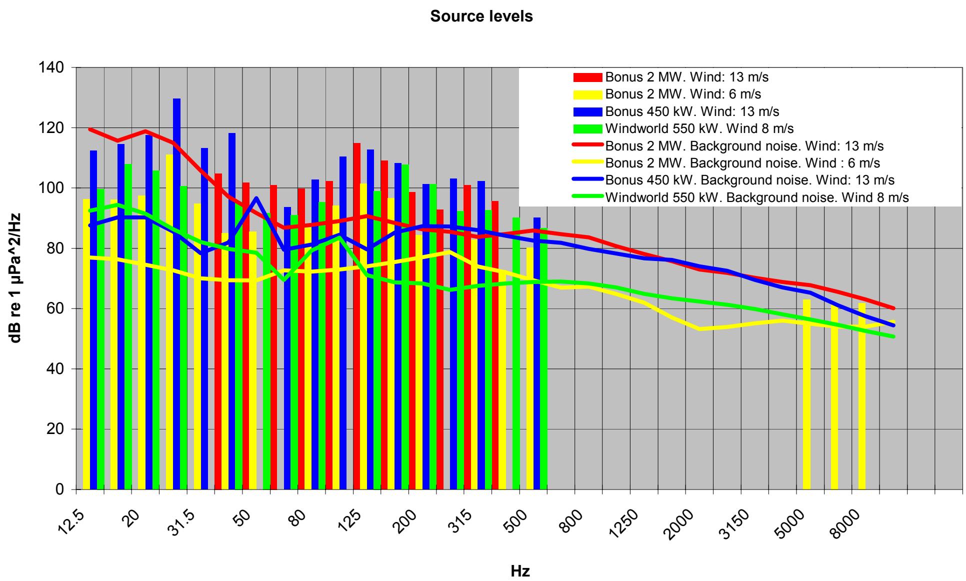


Figure III-13: **Ambient and source sound levels of 3 running WTs (different types) at different wind speeds (shown as 1/3 Octave band width). (Source: O. Damsgaard Henriksen, NERI (DK))**

The following maxima were determined for the sound pressure levels:

2 MW Bonus auf Stahl-Monopile:
Wind 13 m/s: 115 dB per 1 µPa^2/Hz @ 125 Hz
Wind 6 m/s: 111 dB per 1 µPa^2/Hz @ 25 Hz
101 dB per 1 µPa^2/Hz @ 125

450 kW Bonus on concrete / gravity foundation:
Wind 13 m/s: 130 dB per 1 µPa^2/Hz @ 25 Hz
113 dB per 1 µPa^2/Hz @ 125 Hz

550 kW WindWorld on concrete / gravity foundation:
Wind 8 m/s: 108 dB per 1 µPa^2/Hz @ 16 Hz
108 dB per 1 µPa^2/Hz @ 160 Hz

Only the relevant WT was running during each measurement. Noise measurements for an entire operating offshore wind farm are not available.

III-3.3 Measurement of ambient noise in the sea

III-3.3.1 Methods

Piezoelectric hydrophones were used to measure underwater sound. Two methods can be used from a ship: (a) simple lowering of the hydrophone, or (b) hydrophone held at defined height above sea floor by a float (Figure III-14). Method (a) has the advantage that it works from a drifting ship. In the case of method (b) the ship needs to be stationary.

A fluctuation in submergence depth of only 1 mm is equivalent to a sound pressure of 10 Pa or 140 dB since the hydrostatic pressure P is a function of depth h where $P = \rho g h$ (ρ is the water density). This can result in a pseudo sound, which can be minimized through mechanical alleviation of the cable (Wenz 1972). Both methods were applied during the measurement cruises.

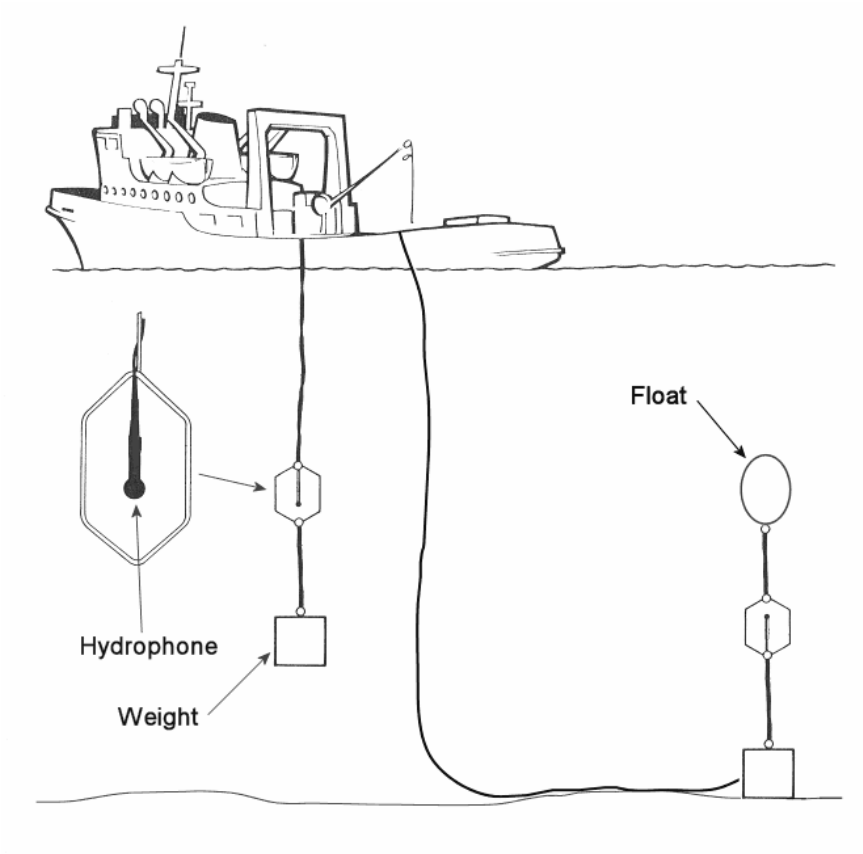


Figure III-14: **Left: Hydrophone lowered from ship. Right: hydrophone with float in a defined depth above sea floor.**

During some measurements, strong currents caused the hydrophone to vibrate and produce low frequency pseudo sound. Furthermore, during unfavourable conditions, a current-induced pseudo-sound can be generated at the hydrophone, comparable to wind noise on normal microphones.

Two types of piezoelectric hydrophones were used: Brüel & Kjaer 8105 and a Reson TC 4032. The B&K8105 is a broadband sensor, covering a frequency range from 0.3 Hz to more than 100 kHz. The TC 4032 general-purpose hydrophone offers a high sensitivity, low noise, and flat frequency response over a wide frequency range. The high sensitivity and acoustic characteristics makes TC 4032 capable of producing absolute sound measurements and detecting even very weak signals at levels below "Sea State 0". The usable frequency range is from 5 Hz to 120 kHz, and the high-pass behaviour near the lower frequency limit is favourable for measurements of mid and high frequencies since it filters out the very intensive low frequency signals and thus enables a higher sensitivity.

Figure III-15 shows a block diagram of the measurement set-up on board. The signals were recorded on a multi-channel tape unit and evaluated spectrally in the laboratory. A spectral analyser was sometimes also used on board for testing and for preliminary analyses. 1/3-octave spectra from 0.4 Hz to 20 kHz were plotted. To avoid interference from equipment (waves on the ships side, banging of ropes and cables and other ships noises) the following measures were taken: the spectral values were in each case averaged over 8 s. during the period of observation of 15 to 90 minutes, the minimum energetic mean values were recorded. Such a spectrum was 3 to 8 dB lower than a spectrum with an energetic mean over several minutes (Figure III-16).

A hand anemometer was used to measure the wind velocity and on another cruise an additional cup anemometer with data logger.

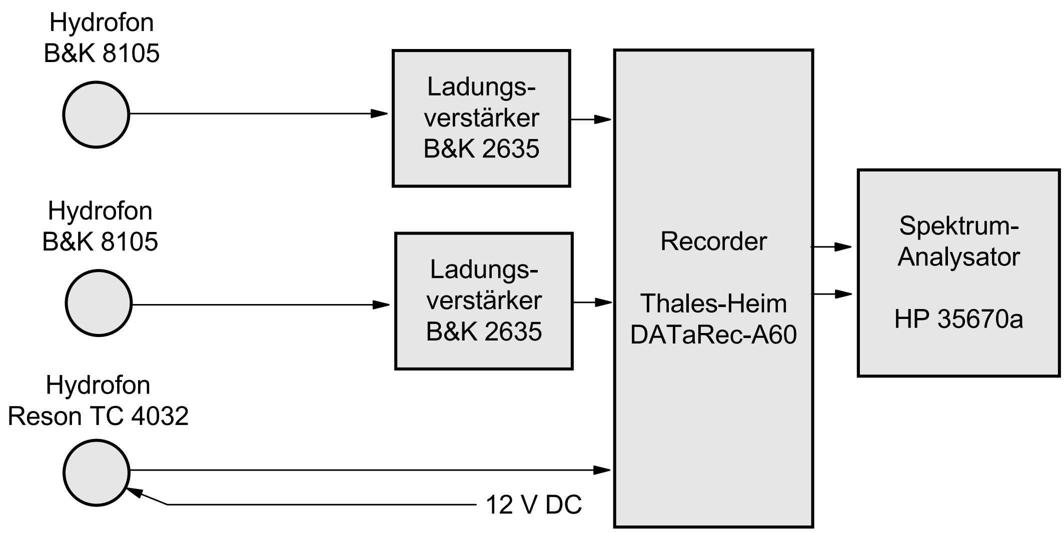


Figure III-15: **Block diagram of the measurement set-up. The B&K 8105 hydrophone type needs a chrage amplifier (here B&K 2635 where used), while the Reson TC 4032 has a built-in amplifier with voltage output.**

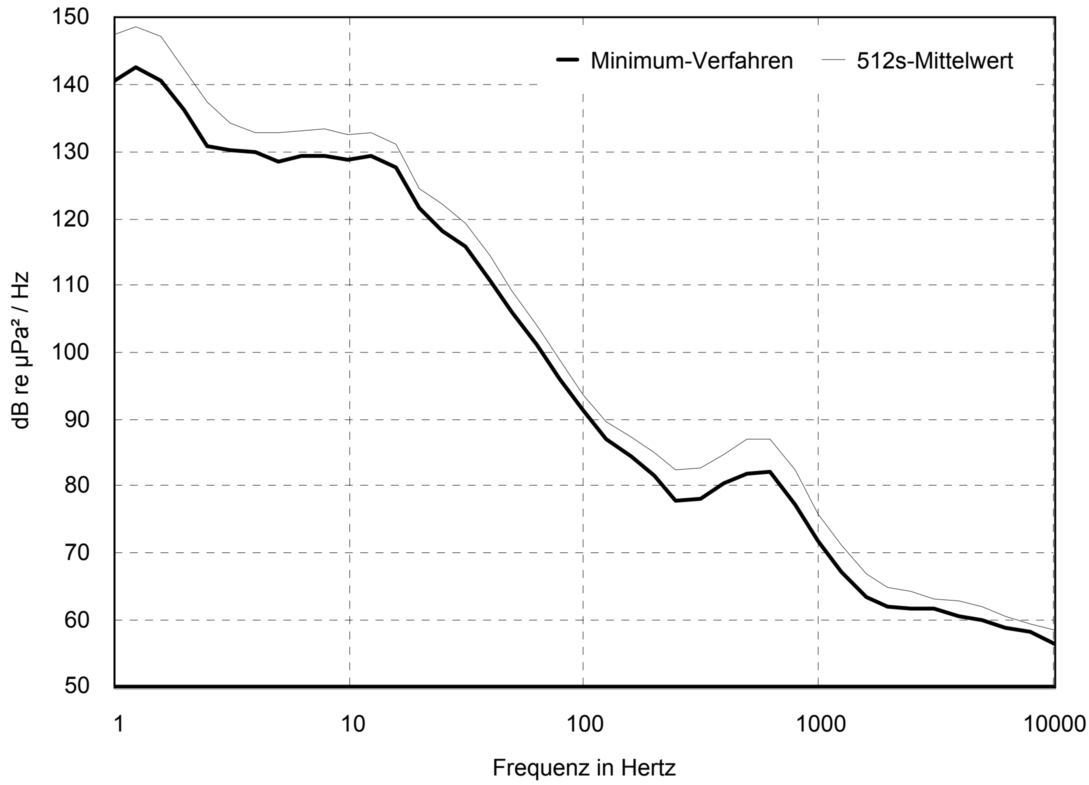


Figure III-16: **Typical ambient spectrum, as energetic 512s-mean and after the described 8s-minimum-procedure. The values from the minimum-procedure are 3 to 8 dB lower. The cause of the peak at 700 Hz is not known.**

III-3.3.2 Measurement sites

Ambient noise measurements were carried out at the following locations:

Date	Coordinates	Area in figure III-17
22.09.2001	53°50’n 08°09’e	1
17.10.2001	53°47’n 08°06’e	2
24.11.2001	54°04’n 07°09’e	3
02.05.2002	53°45’n 08°05’e	2

Area 1 lies on the southern fringe of the zone “Nordergründe”, where a relatively small windpark is planned close to the coast. Area 2 (Oldoog-Plate) was visited for equipment tests and investigations of the current influence on the hydrophones. Area 3 lies between the ships operating areas, approximately 40 km north of Juist and Norderney. With the exception of the measurements on the 17.10.2001, all measurements were taken from a sailing yacht (Milan, DD3895). A surveying ship (MS Harle Echo, DCZB) was chartered for the measurements on the 17.10.

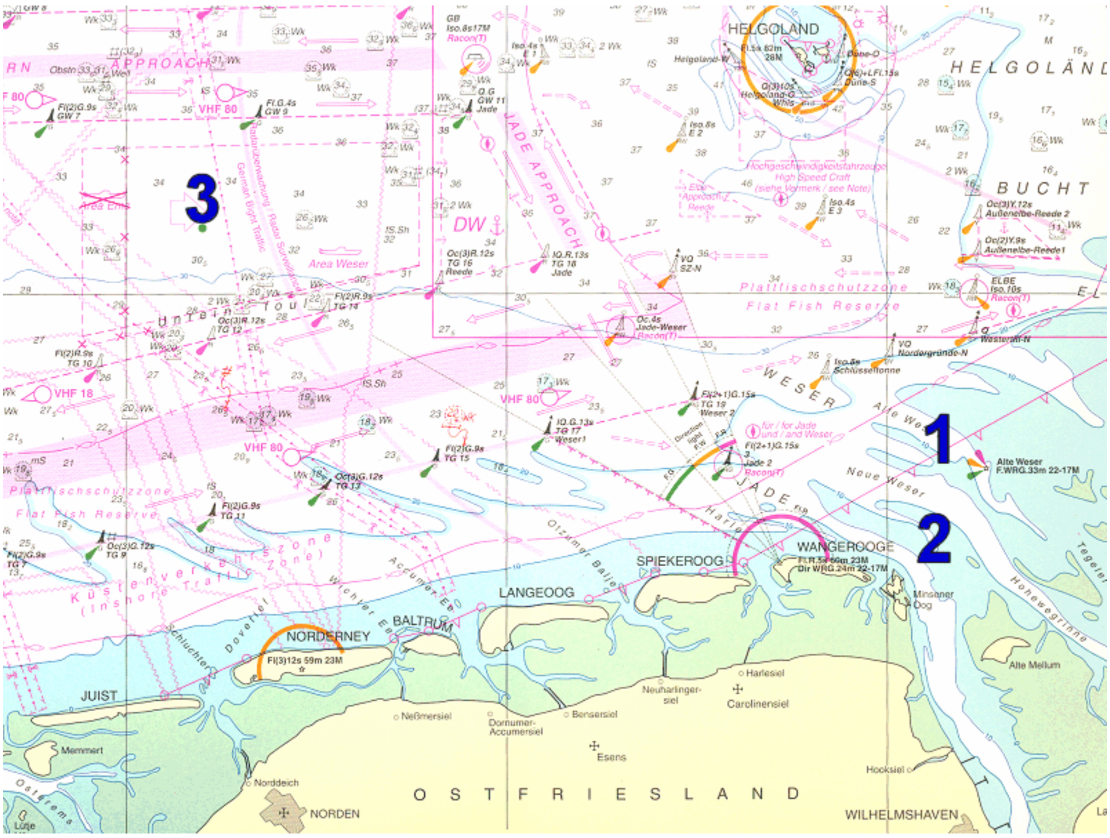


Figure III-17: Measurement sites

III-3.3.3 Results

Figures III-18 to III-21 show the results obtained on the different cruises. Generally, the frequency range was from 0.4 Hz to 20 kHz, with the exception of the measurement in figure III-20 where the upper frequency limit was 5 kHz.

The synopsis of the measurements in figure III-22 also includes spectra measured by SEAS near the Baltic coast (Degn 2000, 2002). Furthermore the "Sea state 0" level often found in reports and technical data is also included (Wenz 1962). This describes the sea surface at wind velocities below 1.5 m/s and significant wave height of 5 cm (the significant wave height is the mean height of 1/3 of the highest waves observed during a specified time). The curve is based on data obtained in relatively deep water and far from the coast and our measured spectra lie well above this curve.

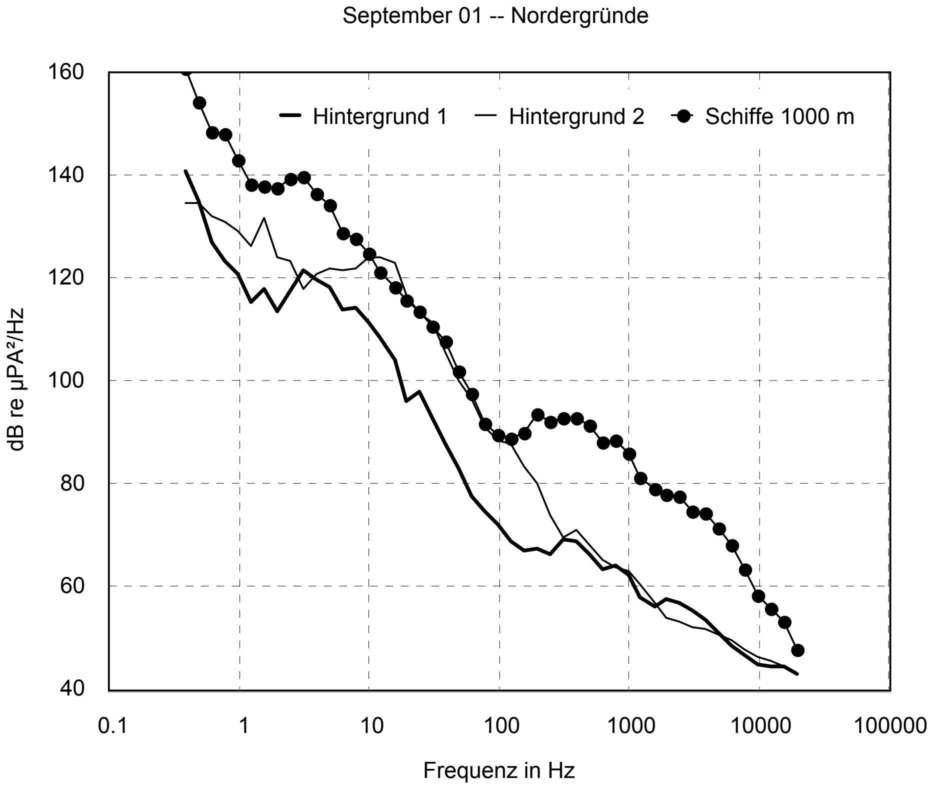


Figure III-18: **Measurement carried out during September 2001 in Area 1. Water depth 10 - 12.5 m, Hydrophone in 6 m depth. "Ambient1": No wind, ship drifting. "Ambient 2": Recording ca. 3 h later. Wind velocity 5 m/s, Ship anchored. Wave height in both cases ca. 0.4 m. "Ships": Container carriers in the Weser shipping channel**.

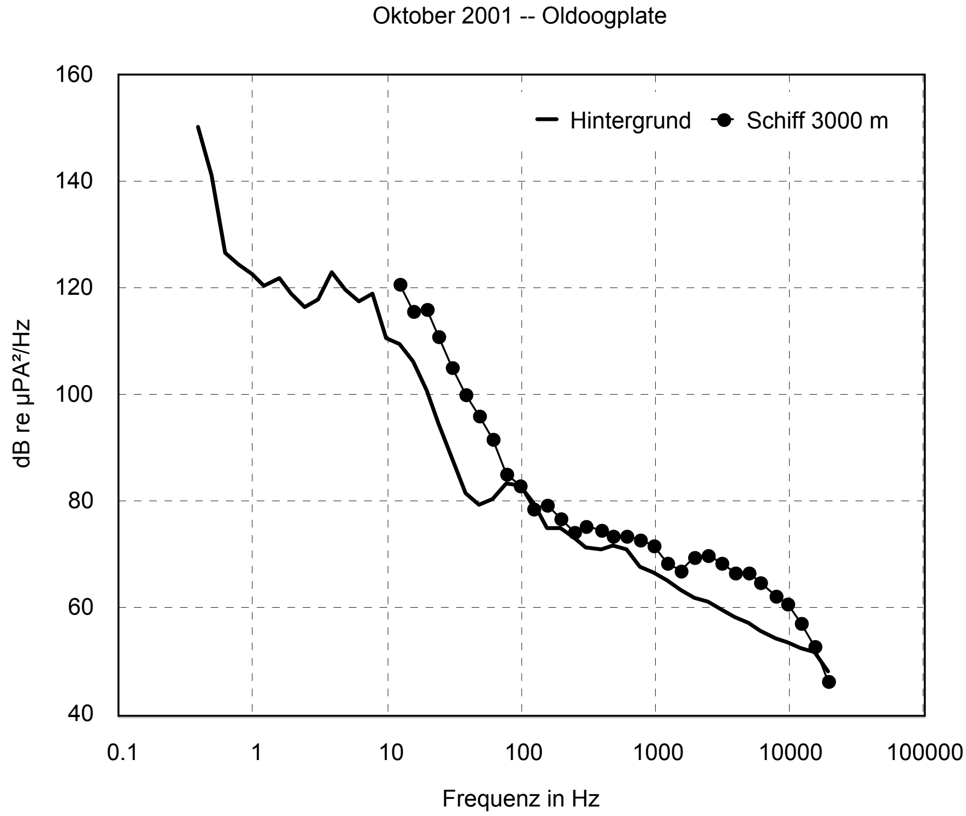


Figure III-19: **Measurement carried out during October 2001 in Area 2. Water depth 12 m, ydrophone in 6.5 m depth. Wind 6.5 - 7.5 m/s. Ship anchored. "Ambient1" and "Ambient 2": Recording at hourly intervals. "Ship": Container carriers in the Weser shipping channel. Hydrophone on the bottom**

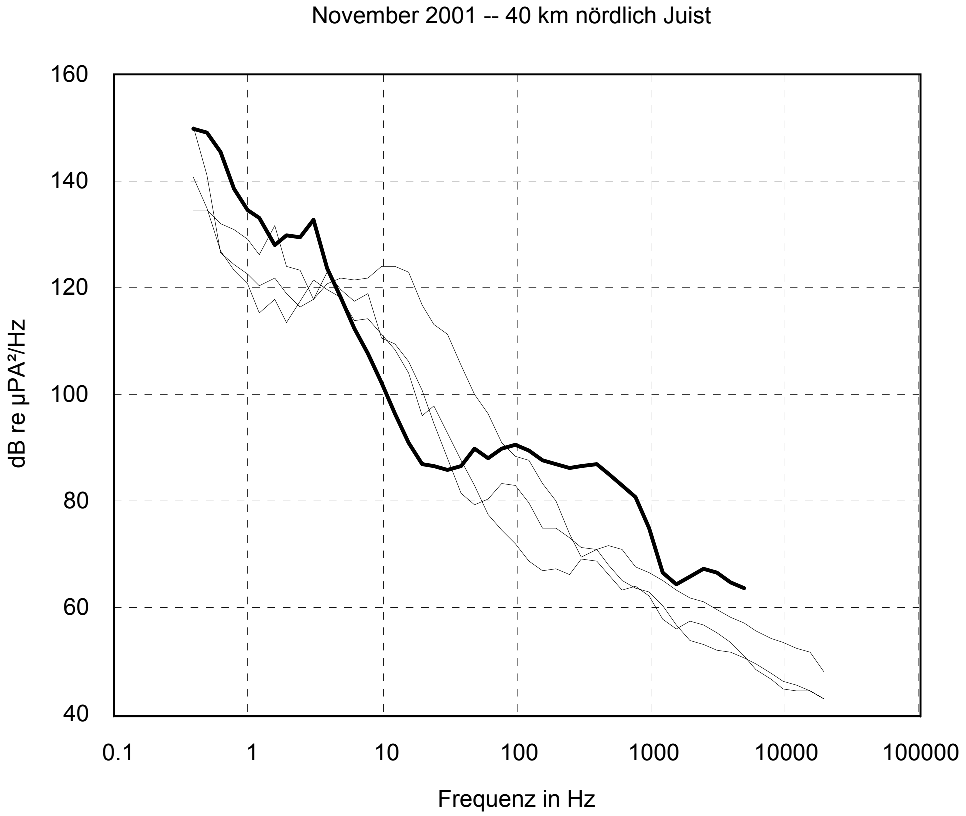


Figure III-20: **Recording in November 2001 in Area3. Water depth 35 m, hydrophone in 15 m depth, Wind 2 m/s, Wave height 0.6 - 1 m. thin lines: Spectra from figures III-18 and III-19 (no ships spectra).**

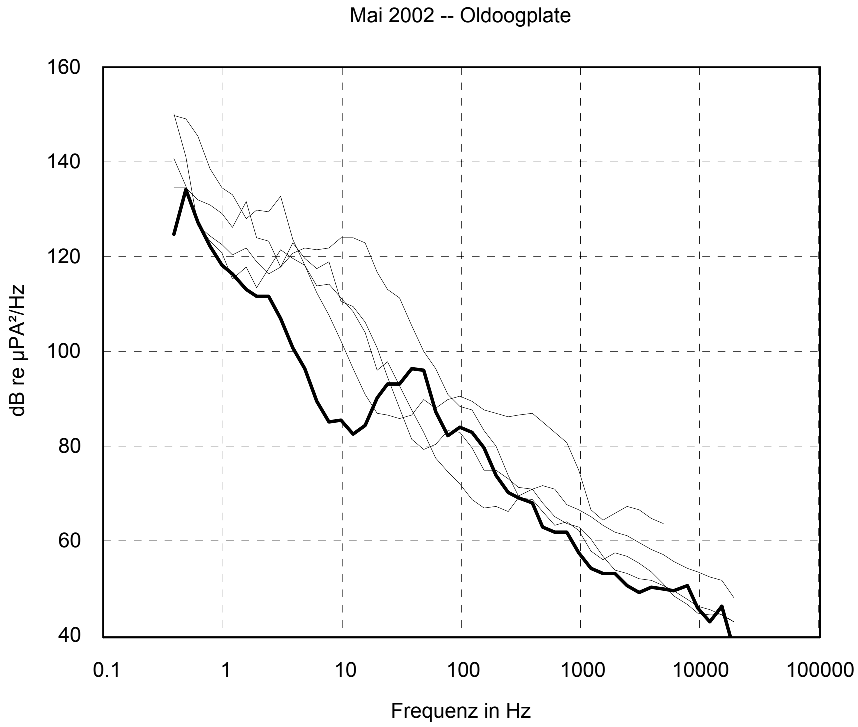


Figure III-21: **Recordings in May 2002 in Area 2. Water depth 14 m, Hydrophone 1.5 m above sea floor, no wind. Thin lines: Spectra from figures III-18 to III-20.**

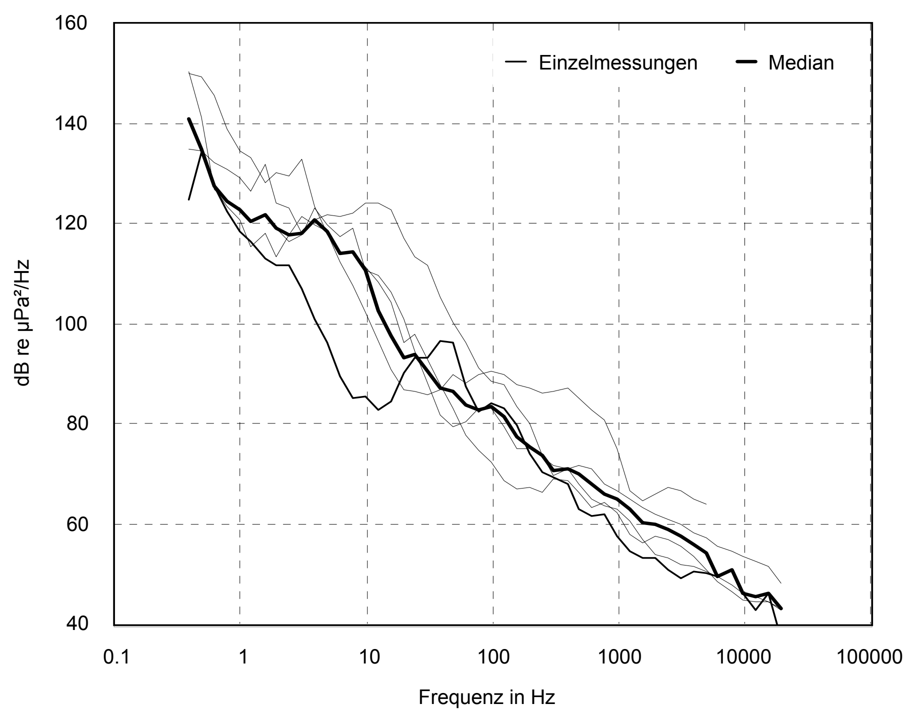


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Figure III-22: **Top: Spectra from figures III-18 to III-21 and Median value. Bottom: Comparison with results from the Baltic (Degn 2000, 2002) and "Sea state 0" (Wenz 1962).**

III-4 Sound propagation by wind turbines into water

This chapter describes the principal computation of noise emission into water during the operation of a wind turbine. The treatment deals with the acoustic noise emitted by tower vibration into water. The emission of airborne noise by the rotor blades and nacelle is negligible (Gerasch & Uhl 2001). It has to be emphasized that an exact estimate of the radiation of the tower oscillation is complex due to a row of problems and uncertainties. The difficulties will be outlined in this chapter and provide a first estimate of the expected sound pressure levels in water.

III-4.1 Vibration modes of an wind turbine Tower

Bending vibration of the tower probably exclusively causes the noise emission by a tower. These are in turn are the result of excitation by the source in the nacelle, mainly the impact noise of the gearbox and generator. (Figure III-23). In addition the tube form of the tower emits discrete natural frequencies (Modes). If the natural frequencies combine with excitation frequencies, this will result in particularly strong tower vibration.

Figure III-24 shows natural vibrations on a model. For this purpose a steel pipe of 78 mm diameter, 0.2 mm wall thickness (this is an approximate scaled down WT tower) and 1 m long was caused to vibrate using electrodynamics excitation near the top of the tube. The bottom end of the tube was fixed. The radial oscillations were recorded at a height of 0.35 m, using a Laser vibrometer. Higher frequencies than those shown in the figure were also recordable, however, could not be resolved because of the 10° intervals chosen in this experiment.

The calculated eigenfrequency densities for two geometries, after (Guicking & Boisch 1979), are shown in figure III-25. Only radial modes (0,n) for $n > 1$ were considered. If you add the – more difficult to calculate – longitudinal modes (m,n) with $m = 1, 2$, you obtain a larger range of natural frequencies. The typical dimensions of a WT tower already yields a high modal density due to low frequencies with the result that every excitation frequency corresponds to the natural frequency. To calculate the noise emission, the natural oscillation of the tower can be disregarded and concentrate only the emission from the bending waves of the tower walls.

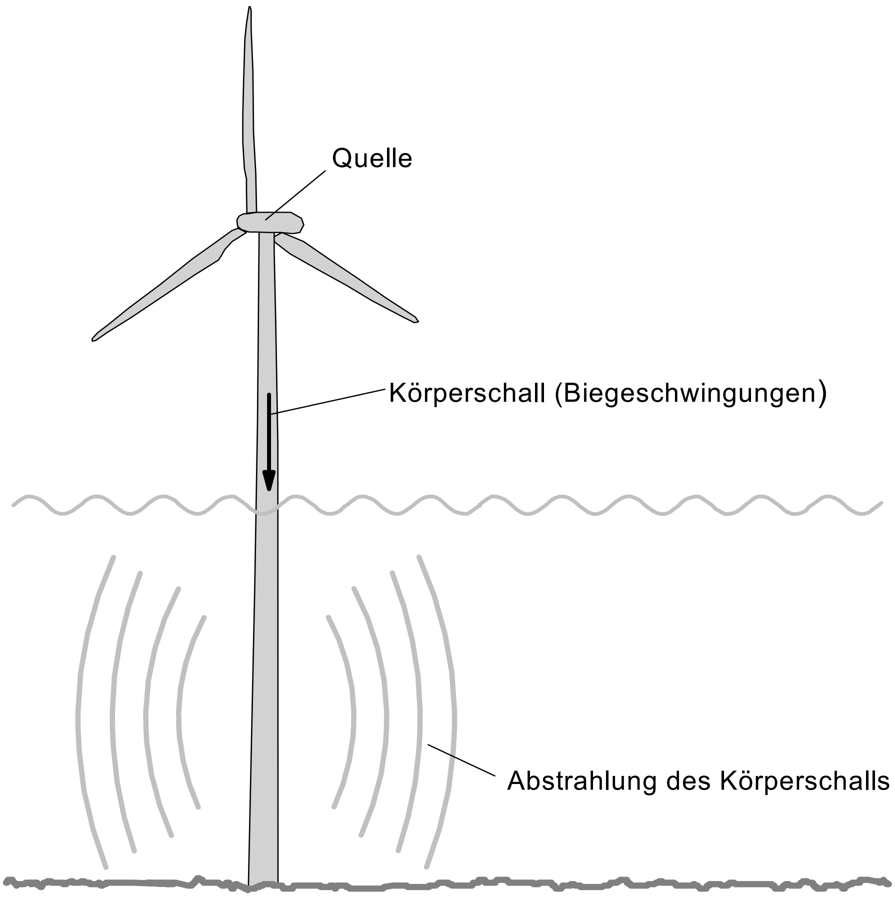

Figure III-23: Noise emission into the water occurs mainly through the tower walls, which are excited by the gearbox and generator.

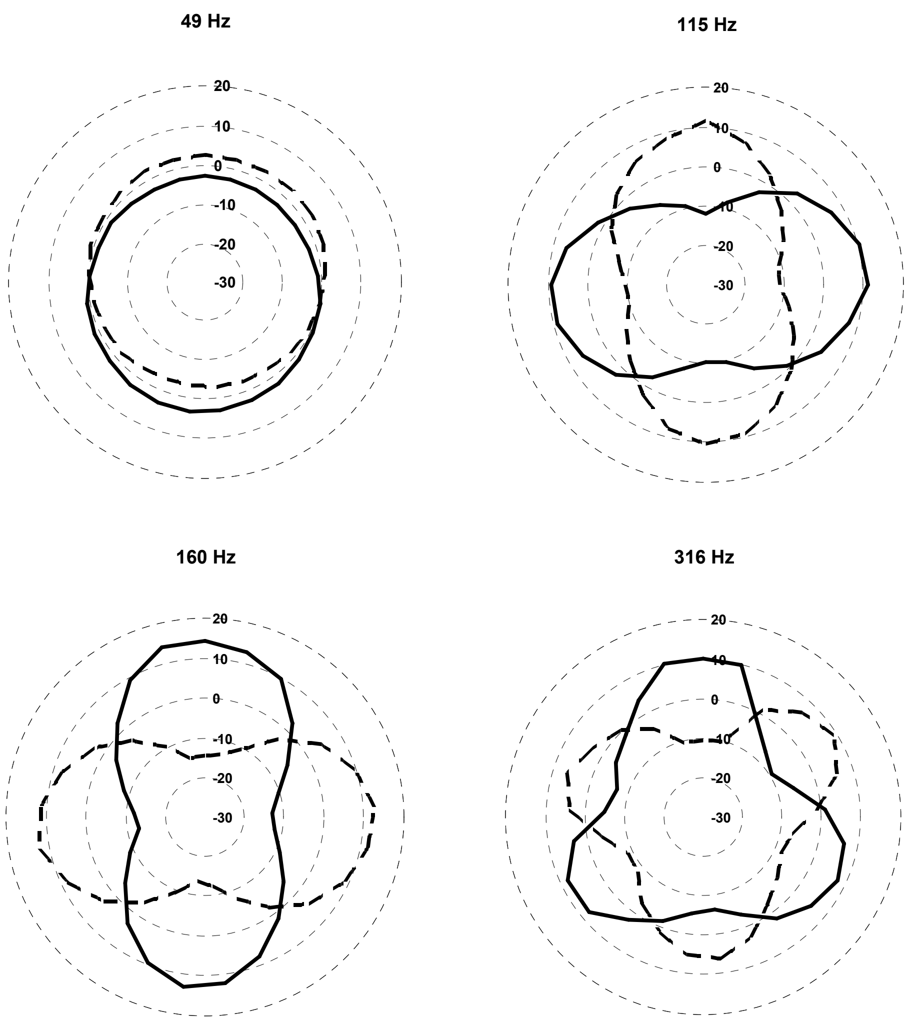

Figure III-24: **Optically measured natural oscillation of a tube (diameter = 78 mm, Wall thickness = 0.2 mm, L = 1 m). Shown is the fast amplitude of deflection in mm/s (the oscillation shape at 49 Hz at the top left is not a real natural frequency, but describes a back and forth oscillation of the tube).**

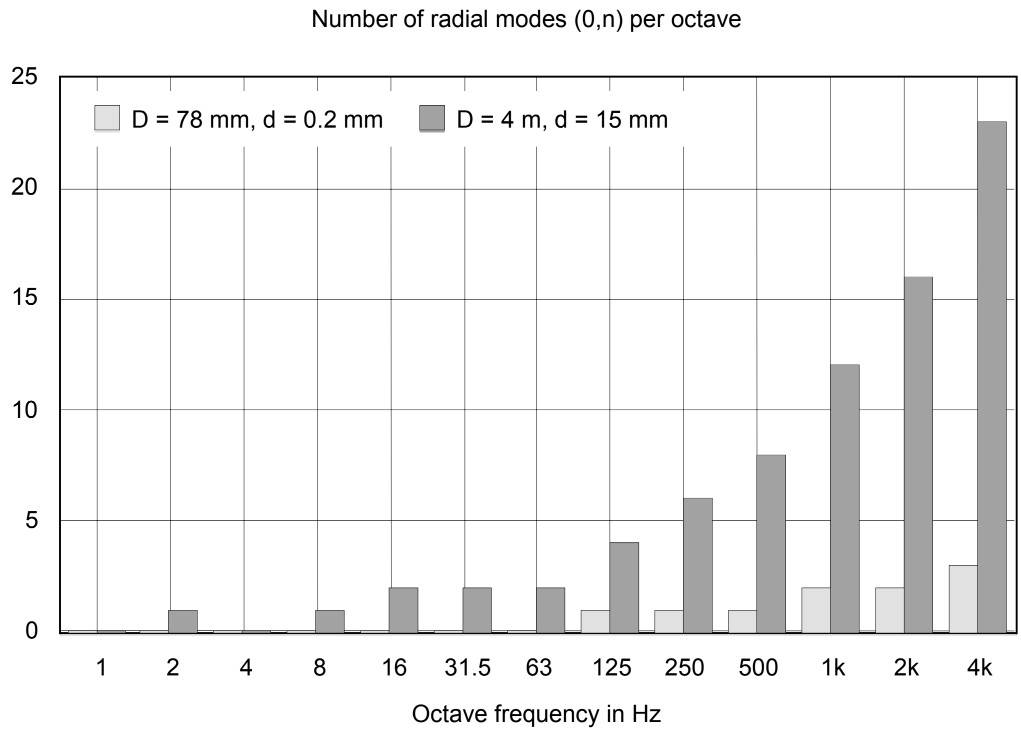

Figure III-25: **computed density of radial natural frequencies for two cylinders a) Diameter 78 mm, wall strength 0.2 mm, b) Diameter 4 m, Wall strength 15 mm.**

III-4.2 Measurement of tower vibrations on a land based tower

In order to compute the noise emission from a WT it is essential to know the source strength. Thus, data on the oscillations of the tower walls need to be acquired. These can be obtained from impact acoustic noise measurements. Ideally such measurements should also be carried out on offshore WT and real offshore foundations since these values are expected to depend on the type of foundation and choice of measuring sites. As a first step orientation measurements were carried out on a WT on land.

Selection of a WT

In order to obtain meaningful data, the measurements should be carried out on offshore relevant wind turbine. Information available so far indicates that wind turbines with a capacity of up to 5 MW are planned in the offshore areas of North and Baltic Seas. WTs of such capacities are currently not available for measurements. In order to ensure that the difference in capacity between planned and tested WTs care should be taken that the capacity of comparative WTs is not less than 1.5 MW. Such a WT exists on the testing ground of the German Wind Energy Institute (DEWI) in Wilhelmshaven.

Measurements carried out

Vibration measurements were carried out on this wind turbine on the 22.06.2001 and 20.09.2001. The only vibrations that need to be known for the emission of a tower into the water are the wall oscillations since only these emit energy to a measurable extent. Longitudinal oscillations of the tower can be ignored since these produce a shear wave, which rapidly dissipates. The measurements were therefore restricted to normal wall oscillations. In order to also record the influence of oscillation modes, measurements were carried out at simultaneously at different points in the tower.

The positions of the sensors during the measurements on the 22.06 are shown in figure III-26. They were placed in the positions shown on the inner walls of the tower. The height (h) of the sensors was 6 m. Accelerometers of the type DJB A120/VT were used. The signals were recorded on a six-channel DAT/DDS-2 (digital audio tape and high-density tape (Racal-Heim DATaRec-A60) and analysed in the laboratory on a Hewlett Packard 35670A Dynamic Signal Analyser.

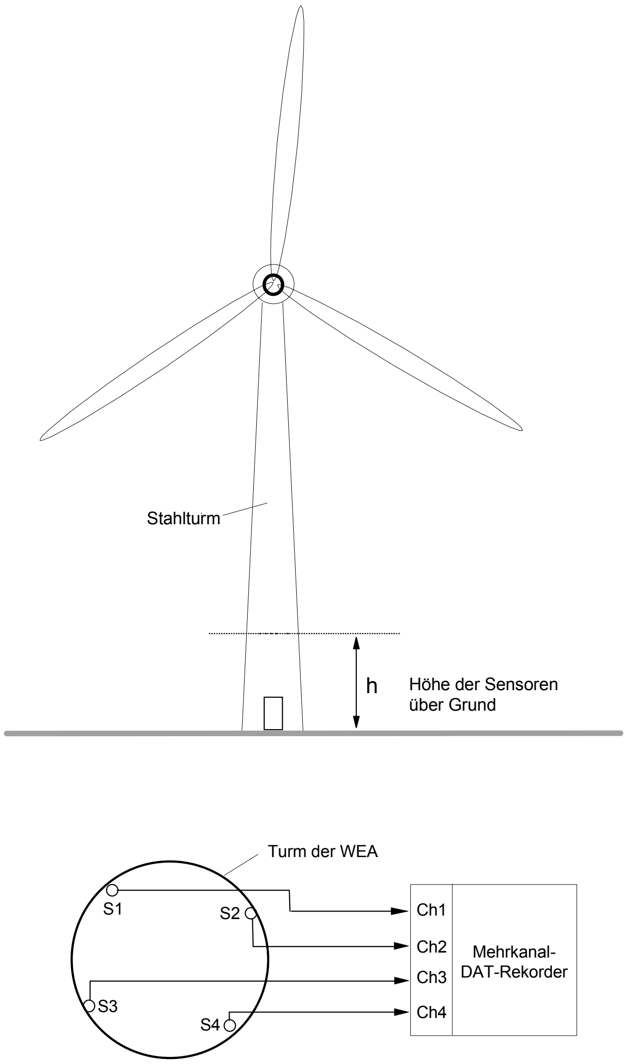

Figure III-26: Placing of sensors for the vibration measurements

Other positions were chosen for the measurements on the 20.09. The sensors were placed parallel on two points of the inner wall at different heights. In the horizontal position they were placed on the luff side so that the sensor was closest to the rotors of the WT. The point of measurement 1 (MP1) corresponds to the position S1 in Figure III-26. The height (h) of MP 1 was at approx. 8 m. The second point (MP 2) was at h = 20 m. Accelerometers of the type DJB A120/VT were also used here. The signals were recorded using a Brüel & Kjaer 2143 Real Time Frequency Analyser and saved on data tape (SONY TCD-D10 Pro II, DEWI Nr.2). A calibration signal was obtained at the beginning and end of the recording using a Brüel & Kjaer 4284) calibrator. The effective power produced by the turbine, wind velocity at hub height, wind direction, air pressure and air temperature were monitored synchronously to the vibration measurements. The measurement parameters are provided in the following table:

Period of measurement	20. September 2001, ca. 13-15 hours
Position of sensors	MP1: h = 8 m, MP2: h = 20 m; Luff-side
Wind velocity (hub height)	6.6 - 10.5 m/s (30-s-mean)
Wind direction	East
Average temperature	11° C
Average air pressure	1005 hPa
Capacity of the WT	420 - 1380 kW (30-s-mean)

In the results of the orientation measurements are shown in figure III-27. The proportional acceleration signal recorded at S1 was subjected to a spectral analysis and is shown in the figure on a semi logarithmic scale. The three curves are based on the same raw data, which were analysed at different frequency ranges. The data show clearly that the tonal components of the impact acoustic noise determine the levels. These peak at up to 20 dB above the broadband spectral component. In the frequency range below 5 Hz the reciprocal effect of the rotor blades with the tower is prominent in the spectrum. During the measurements, the turbine rotated at approx. 15 min^{-1}, resulting in a blade frequency (= revolutions x blade number) of 0.75 Hz. The basic frequency and first harmonic blade frequencies are clearly discernable.

The turbine has a transmission with a ratio of 1:67,9. This results in a line at 17 Hz. The line at 23 Hz is probably that from the generator. The number of cogs in the transmission causes the lines above 100 Hz. The number of poles in the generator are also of significance.

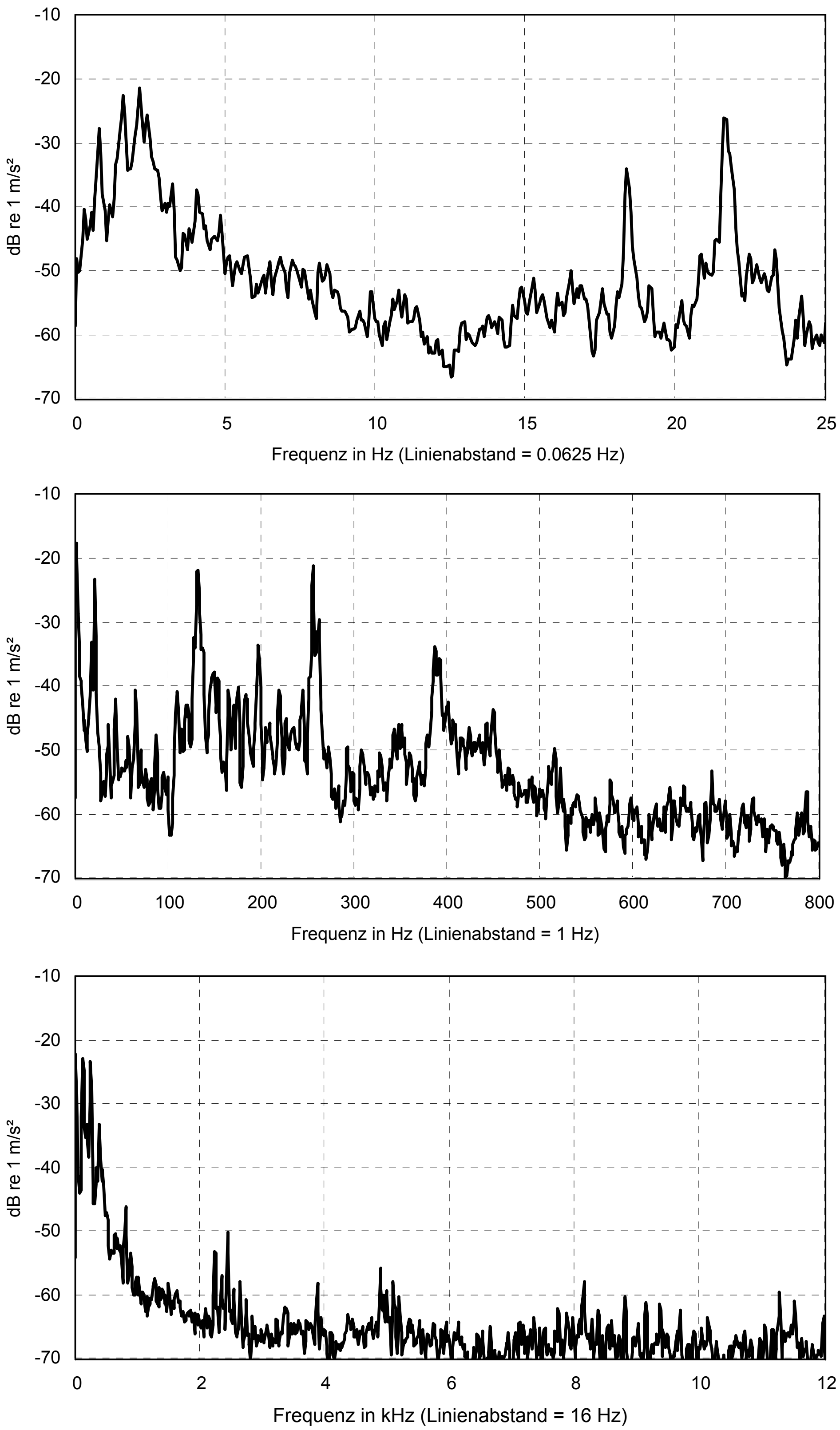

Figure III-27: Results of the vibration measurements on 22.06.2001.

Figures III-28 and III-29 show the results of the measurements on 20.9.2001 for three different operational modes (20%, 35% and 50% power rating of the WT). The averaging time was 30 s. As shown in figure III-27 the major portion of the signal energy is at frequencies up to a few hundred Hz. This is why the analysis range was set to 800 Hz.

Since the turbine has a variable rotation frequency, the spectral components shift to the right with increasing power/wind. The levels of the different lines vary by up to 8 dB, depending on how precisely the tonal components coincide with natural frequencies of the tower. However, there was no significant difference between the levels of vibration for the measurements taken at 8 m and 20 m height.

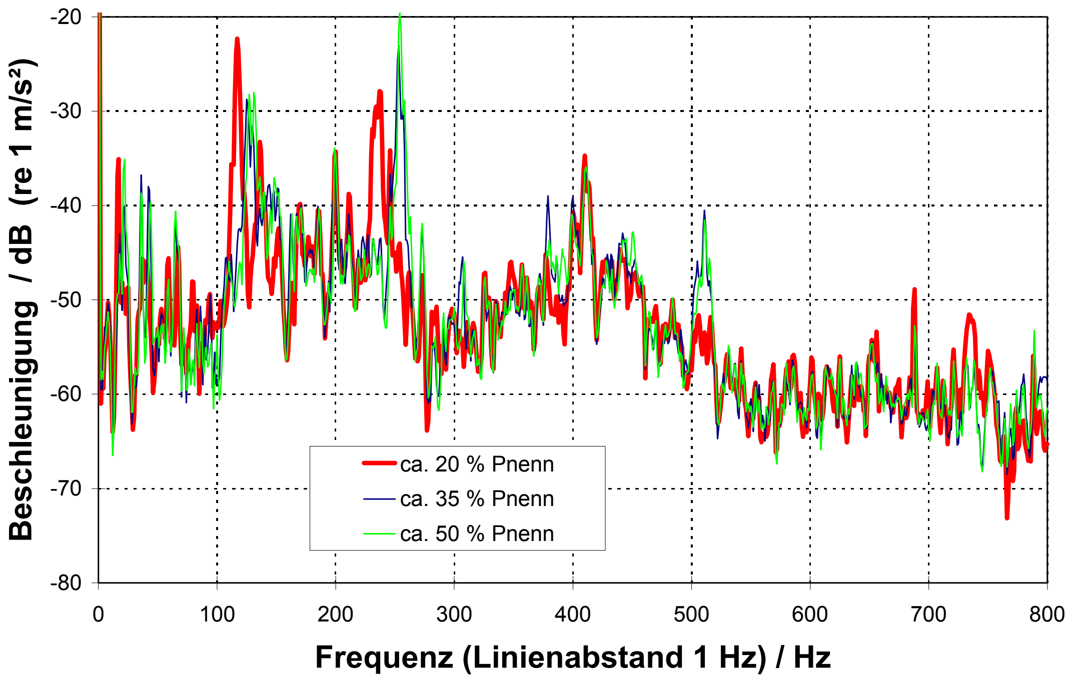

Figure III-28: Spectra measured at point MP1 (h = 8 m).

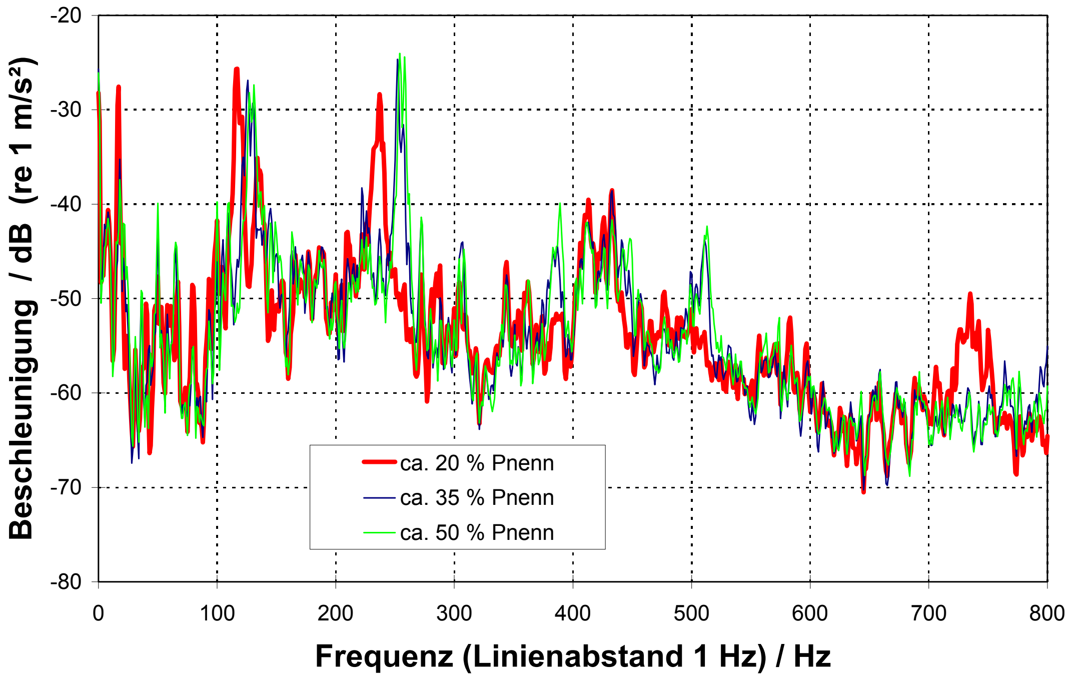

Figure III-29: **Spectra measured at point MP2 (h = 20 m).**

III-4.3 Computation of noise radiation by offshore wind turbines

Sound radiation under water is caused by bending waves arising from the tower jacket. Bending waves are dispersive, i.e. their speed of propagation is frequency dependent and more or less proportional to the square root of the frequency f. There is a cut-off frequency f_G, where the bending wavelength is equal to the sound wavelength of the surrounding medium. The radiation of bending waves can be described as follows:

$f < f_G$: "hydrodynamic short circuit"; poor sound radiation
$f > f_G$: good radiation

The following approximation applies to the cut-off frequency

$$f_G = \frac{\sqrt{3}\, c_0}{\pi c_L h} \qquad \text{(Equation III-1)}$$

Where c_0 ist the sound velocity in the medium, c_L sound velocity (longitudinal waves in plate material and h the plate thickness. In air this theoretical value corresponds well with the observed values. For more dense media (water), however, the deviations are considerable; an analytic derivation of the cut-off frequency is almost not possible. Guicking & Boisch (1980) give the following value for steel plates in water:

$$f_{G\,water} = 1.34\, f_{G\,Air} \qquad \text{(Equation III-2)}$$

The cut-off frequency for 20 mm thick steel plates would thus be approximately 800 Hz.
It is therefore appropriate to define a radiation loss factor

$$s = N / N_0 \qquad \text{(Equation III-3)}$$

after (Gösele 1953), where N is the radiated sound energy of the bending wave and N_0 sound energy of a piston emitter with the same areal dimensions. This is given by

$$N_0 = \frac{\rho c}{2} v^2 A \qquad \text{(Equation III-4)}$$

where ρ is the density of the medium, c the sound velocity in the medium, v the speed of oscillation at the surface of the radiation source and A the area (Gösele 1953). In the ideal case of an infinitely large unmuted plate s is exactly equal to 0 for $f < f_G$. Muted waves also have a measurable radiation below the cut-off frequency (Figure III-30). A similar result is obtained for a finite plate size. An exact computation – particularly for the complex structure of a tower jacket with stiffeners. – is difficult and only possible through approximation using numerical methods. The sound radiation was therefore computed using the progression of the degree of radiation shown in figure III-31

It applies for an isotropically radiating sound source, that

$$N = 4\pi r^2 I = 4\pi r^2 p^2 / \rho c \qquad \text{(Equation III-5)}$$

where N is the sound energy of the source and I the intensity at a distance r, which in the far-field of source is $p^2 / \rho c$. With equations III-3 and III-4, the resulting sound pressure p is:

$$p = \frac{\rho c v}{r}\sqrt{\frac{s A}{8\pi}} \qquad \text{(Equation III-6)}$$

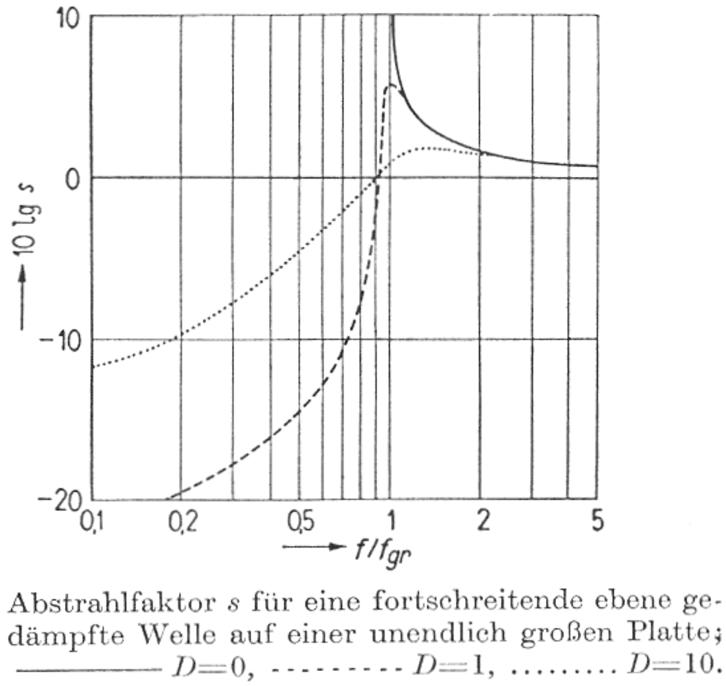

Figure III-30: **Radiation efficiency of bending waves in dB below and above the cutoff frequency f_G and for different damping factors D. From Westphal (1954)**

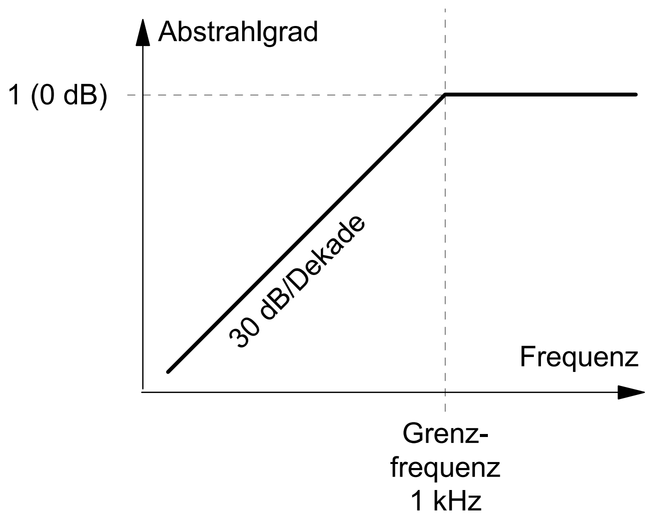

Figure III-31: **Assumed model radiation efficiency of bending waves for the computation of sound radiation: Cut-off frequency 1 kHz, radiation efficiency above equal to 1, below at 30 dB/decade decreasing.**

Model measurements

Computation of the sound radiation using equation III-6 requires surface velocity v. The question is to what extent the values derived for a turbine on land, i.e. airborne measurements (Section III-4.2) are applicable, and whether a reduction in amplitude in water can be expected? A precise calculation is difficulty and only possible using numerical techniques (FEM) whereby the surface velocity would depend on the emission rate of the nacelle. The relationship can be demonstrated in a model, however:

A 1 m long tube was fitted with a shaker. An accelerometer was attached at a height of 0.35 m and the tube was suspended in the air or water. (Figure III-32).

Figure III-33 shows the velocity spectra for two different wall thicknesses (measured acceleration converted to speed by simple integration i.e. division of all spectral values by $\omega = 2\pi f$). The speed, particularly for a thin walled cylinder, does not decrease noticeably at constant source strength.

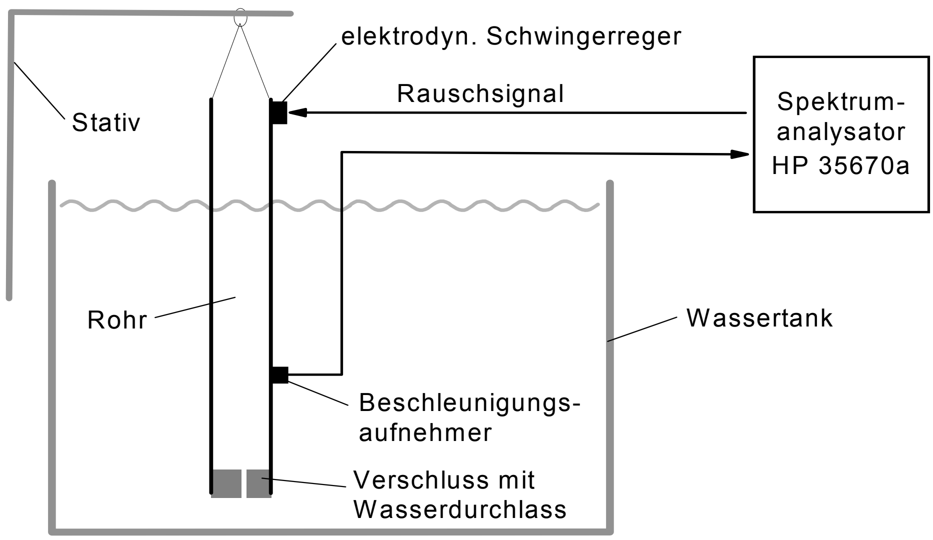

Figure III-32: Experimental set-up to measure velocity at a cylinder surface in water.

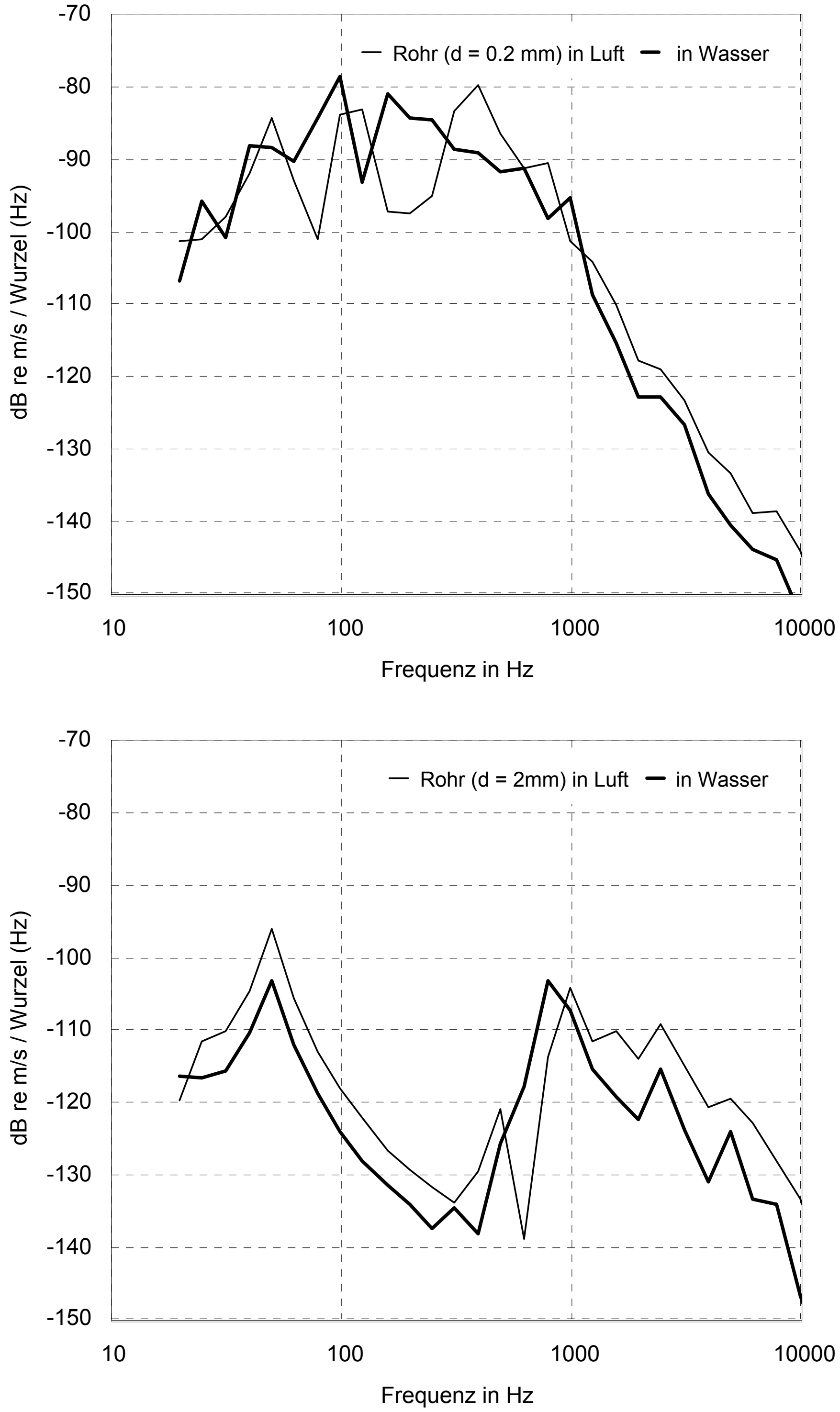

Figure III-33: **Velocity at cylinder surface in air and water, measure on a model. Cylinder diameter 78 mm, length 1 m. Top diagram: 0.2 mm wall thickness, bottom diagram: 2.0 mm. Electrodynamic excitation at the top of the tube with pink noise.**

Results of the computations

The measured tower vibration (energetic mean of the sensors S1 to S4) in section III-4.2 were used as input values. Further assumptions in the computation were:

Radiating tower surface area A: 50 m²
Distance r from the wind turbine: 100 m

A mentioned the computation of the degree of radiation is difficult, particularly for the new type of WT with double walls filled with concrete. The radiated sound energy is proportional to the surface area A, I.e. a doubling of A increases the level by 3 dB. A also includes the surfaces directed away from the observer and should possibly be set further than 50 m. An isotropic radiator was chosen for simplification. Here the level decreases by 6 dB per doubling of distance, however in reality a decrease of only 4 to 5 dB is expected (see also section III-3.1). The consideration of these propagation laws would likewise lead to higher prognosis levels.

Figure III-34 shows the sound pressure levels of thawed in water as computed using equation III-6. Accordingly the noise produced by the wind turbine exceeds the measured ambient levels in some frequencies by about 20 dB. The curves are comparable since the line width of the narrow band prognosis spectrum lies at 1 Hz This example, however, shows the problem of normalizing to 1 Hz band width, as mentioned previously in section III-3.1.2. In figure III-35 the ambient spectra are also shown as non-normalized 1/3-octave spectra and the prognosis spectrum as if it were determined by 1/3-octave analysis. Figure III-36 shows all the spectra from figure III-35 converted to 1 Hz bandwidth. None of the three diagrams is ”false”. They simply show different treatments of the same physical facts.

Figures III-35 and III-36 indicate that the ambient levels at 125 Hz and 250 Hz are exceeded by 12 dB. In this case a decrease in levels of 4.5 dB per doubling of distance would result in the wind turbine noise being higher than the ambient, up to a radius of 600 m from the wind turbine. With regard to the question of audibility, sensory and psychoacoustics facts need to be considered. Apart from the absolute auditory threshold, the bandwidth of the volume integration is also important. In humans is termed the critical bandwidth.

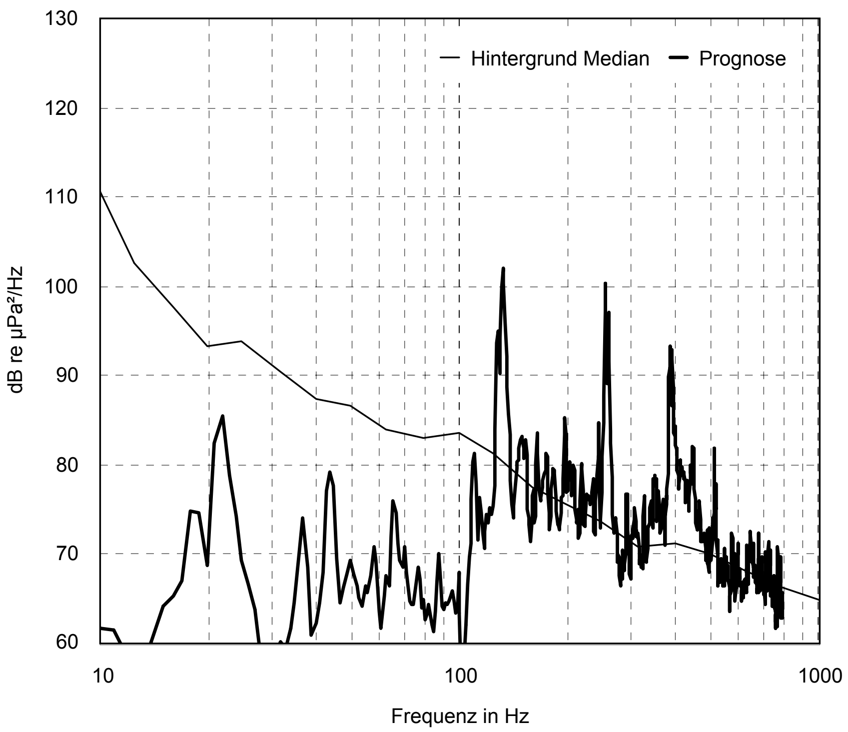

Figure III-34: **Result of the prognosis computation in comparison to the measured ambient levels from section III-3.3.3**

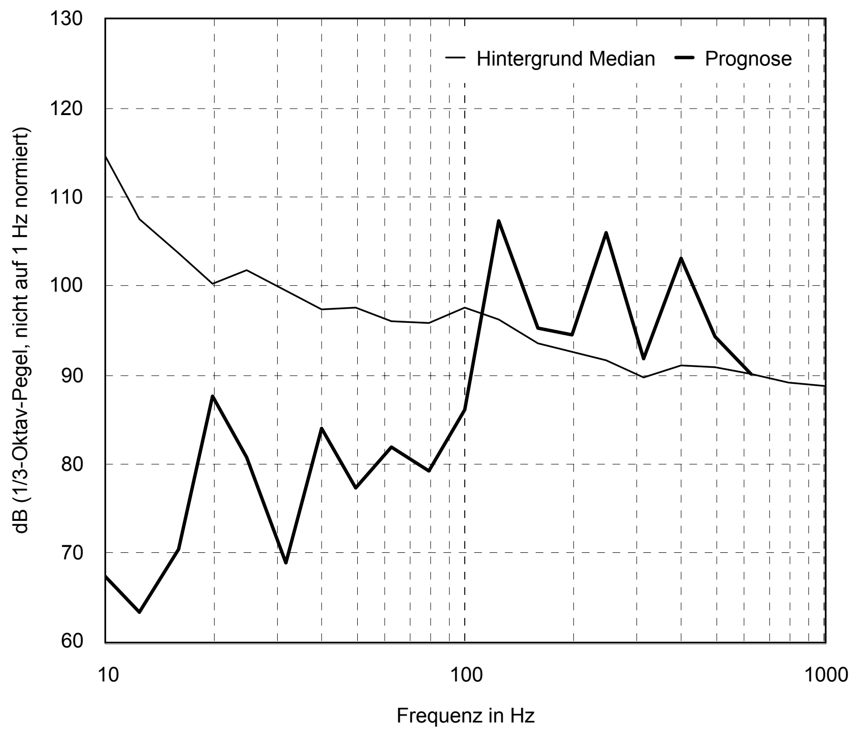

Figure III-35: **Result of the prognosis computation. As in figure III-34, but wind turbine and ambient noise shown as non-normalized1/3-Octave-spectra.**

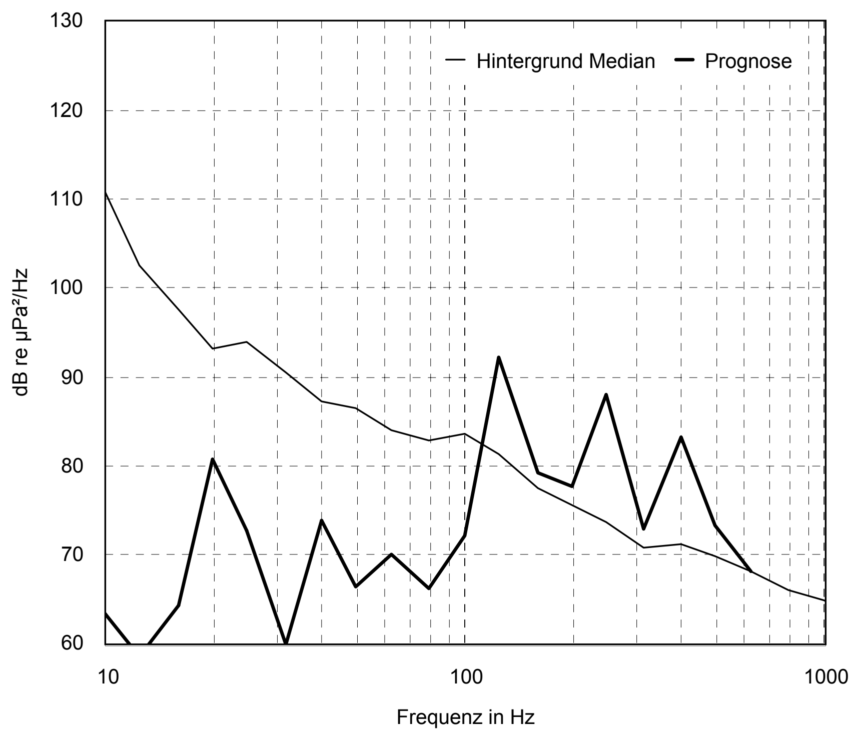

Figure III-36: **result of the prognosis computation. As in figure III-34, but with wind turbine and ambient noise normalized to 1 Hz 1/3-Octave-Spectra.**

III-4.4 Summary of sound and vibration measurements

Measurement of ambient levels

Ambient noise in the frequency range 0.4 Hz to 20 kHz was measured at various locations along the North Sea coast. The values determined were very dependant on the weather and shipping activity and varied strongly. This was particularly so for frequencies below 50 Hz where it varied by over 20 dB. Fluctuations of more than 30 dB were observed although no measurements were done during storms. The levels are also dependant on water depth. Due to the larger effects of gravity waves, higher levels are recorded in shallow depths. This needs to be taken into account in view of the standardised recording procedure. Overall the measured spectra levels are clearly above the „Sea State Zero“ curves; however, this curve is derived from the literature and is based on measurements from much greater depths than those found in the North Sea. Systematic and continuous long-term investigations at two or three locations are needed to study the ambient levels in the North Sea.

Computation of the turbine levels

Acoustic noise entry into water by operating WTs is primarily due to the radiation of bending waves from the tower jacket. Based on this observation and using tower vibration measurements from land-based wind turbines as input values a first calculation of noise radiation into water was attempted. Some physical parameters such as degree of radiation are difficult to record with the result that the estimates presented here are fraught with large uncertainties. The computation does show, however, that there is a zone around a WT where the levels emitted by the wind turbine are higher than the ambient levels. A simple single walled steel tube was used for the investigation. It is not known if double walled constructions with a concrete filling in between, such as those being tested at the moment, will produce a significantly lower noise radiation. It is absolutely essential that measurements of under water noise emission on real WTs be obtained concurrent to the recording of tower vibrations

III-5 Biological Aspects

III-5.1 General comments on the biological sub-project

Problems and aim

The construction and operation of WTs are accompanied by the immission of noise into the water column. The release of acoustic energy can in theory have effects on marine organisms

The available information on potential effects of noise and vibration immission by offshore wind turbines (WT) will be evaluated and discussed in the framework of the sub-project "Sound and vibrations – acoustic effects on marine fauna". The main goal is to establish limit values for WTs and to ascertain knowledge gaps and research requirements.

If possible it should be established whether and to what extent marine organisms are actually affected by the immission of noise into the water column. In addition an attempt is made to quantify the effects.

An extensive literature survey as well as discussions with experts (international) and representatives of the institutes, legislators and authorizing institutions form a part of this sub project.

Key taxa

The assessment of possible acoustic effects on marine fauna in this study is confined to those species that regularly occur in the German sections of the North and Baltic Seas. The investigation includes pelagic and benthic organisms and excludes marine algae.

The available data on the acoustic sensitivity i.e. aural sensitivity for every species in question are presented and the relevant information on acoustic impacts discussed. This enables the identification of individual organisms or groups, which react most sensitively to noise and vibration immission by WTs.

The marine fauna comprises the following organism groups:

- Invertebrates
- Fish
- Marine mammals

Acoustic perception in water and air

At 1,03 g/cm^3, the density of water is approximately 800-times higher than air which has a density of 0,0013 g/cm^3. The speed of noise in water is faster by a factor of 4,5 than in air (1530 m/s vs. 340 m/s).

The intensity of a sound wave is a function of both the density and sound velocity. It is defined as

$$I = p^2/\rho c$$

with intensity (I), pressure (p) density (ρ) and sound velocity (c). The product ρc is the characteristic impedance of the medium. In order to hear a sound at the same intensity in both mediums ($I_{air} = I_{water}$), the sound under water would have to have a 59,7-times greater sound pressure. Whereas intensity is usually given in Watt/m^2 the auditory thresholds of the Sound Pressure Level, SPL is used as an indirect measure (see Au 1993).

Sound pressure levels are defined as:

$$\text{dB SPL} = 10 \log (p_m^2/p_r^2)$$
$$= 20 \log (p_m/p_r)$$

with the measured sound pressure (p_m) and a reference pressure (p_r). Two different reference pressures are currently used in acoustics. For airborne sound the value is 20 µPa rms, whereas it is 1 µPa for sound in water. The data on the sound pressure level are presented in dB, a logarithmic measure based on the corresponding reference pressure. Based on the comparison of sound pressure in water and air, the sound pressure under water would have to be 59,7-times or 35,5 dB above that in air in order to detect noise at the same intensity. In order to compare the perception of sound in both water and air, the differing reference pressure needs to be considered so that a noise under water would lie 35,5 dB + 20 log (20) dB = 35,5 dB + 26 dB above the sound pressure in air. With regard to the perception, therefore, a sound pressure of 61,5 dB re 1 µPa is equivalent to 0 dB per 20 µPa in air (Ketten 1998a).

III-5.2 Current state of knowledge

III-5.2.1 Impacts of sound and vibrations

Impact zones

The potential impacts of acoustic signals on marine fauna can be of a physiological, behavioural and physical nature. They may have non-lethal consequences for the organism such as interference or injury, or be lethal. In order to determine the potential effects of specific acoustic immission on animals, it is essential to estimate the distance in which the effect is expected. The impact range of acoustic signals can be demonstrated schematically according to the concept of 4 impact zones (Figure III-37) (modified after Richardson 1995).

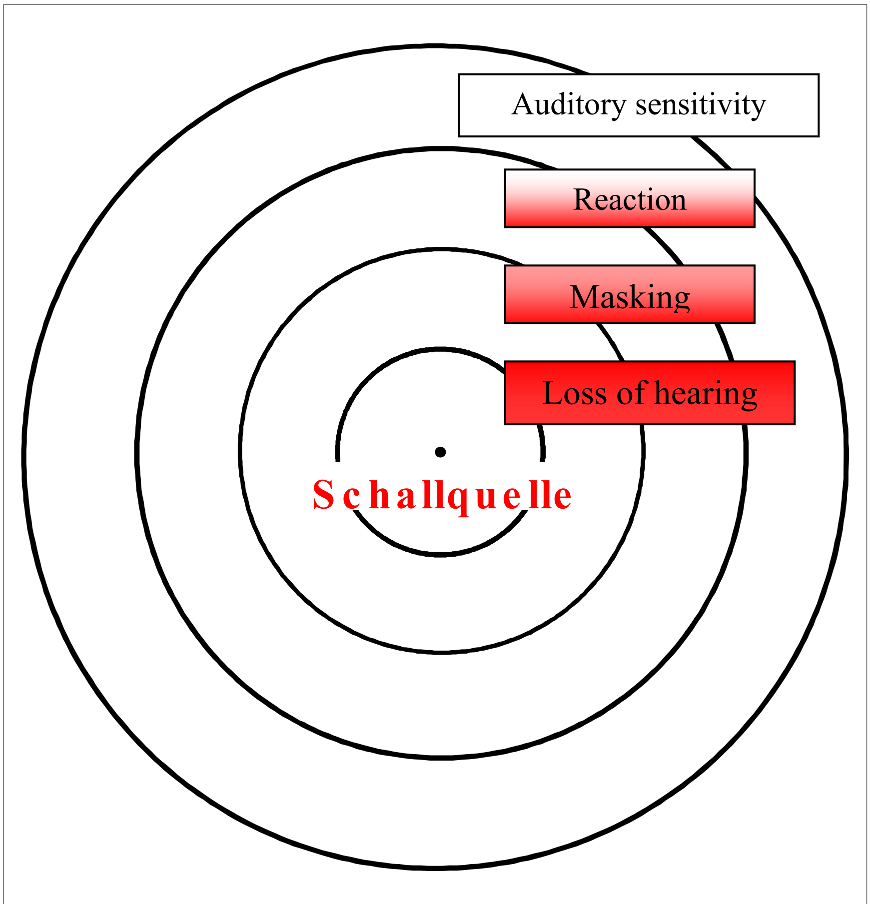

Figure III-37: Schematic presentation of the propagation of the 4 impact zones of acoustic signals from a sound source.

Zone of auditory sensitivity:

An animal is capable of hearing the noise emitted by a sound source within this range. No interference with the animals is expected to occur within this range. The propagation in this zone depends on the sensitivity of the animal to the frequency range, the sound pressure and the level of the signal as well as the ambient noise.

Reaction zone:

Within this zone, animals may reveal physiological and behavioural reactions. This zone is narrower than the zone of sensitivity since marine animals normally do not react to weakly perceived noise.

Masking zone:

Within this zone the noise is sufficiently intensive to mask the perception of biological relevant acoustic sounds such as communication noise or echolocation signals as well as those made during feeding or adversary organisms. The animals are therefore not capable to perceive these important signals. The masking of sounds can therefore result in a significant impairment of the animals or a population of animals and thus have indirect lethal consequences.

Zone of hearing loss (tissue damage):

This zone is in the proximity to sound sources which emit very intensive sound that can result in temporary or permanent physiological impairment or damage to the hearing organs or body tissues of marine organisms.
While it is extremely difficult to assess quantitatively the behavioural or physiological reactions in most free living marine organisms, it is possible to obtain information on possible physical impairment or injury from investigations under controlled conditions.

Damage mechanisms

Tissue damage can result if:

- The energy remaining after reflection, at a boundary between 2 tissues (e.g. connective tissue/ bones), cannot be absorbed or converted. This can result in tearing or rupture (bones) of the affected tissue.
- During distension (a form of conversion of acoustic signals) the distension coefficient of the affected tissue may be exceeded i.e. the potential distension of tissue per unit time is exceeded. A further possible effect is the general over distension of tissue. Both cases would lead to the rupture of the affected tissue.
- Metabolic processes become overloaded and cannot function properly until all components become available again or the synoptic contacts are restored.
- It results in damage of the cell structure in the sensory tissue (e.g. hair cells).

Potentially endangered organs

The acoustic hearing organ as well as the gas filled compartments of the respiratory and digestive tracts in animals are generally the most sensitive to changes in pressure (Office of the Surgeon General 1991). In fish, the swim bladder and the related gas filled compartments may be affected.

In mammals the ear is the most sensitive organ. A number of investigations on animals have shown that the hearing organ may be damaged at lower sound intensities than other organs (Office of the Surgeon General 1991). The strongest impairment was loss of hearing.

The passive and active auditory complex in many marine mammals has undergone extreme adaptation during the course of evolution, compared to other terrestrial relatives. This resulted in a shift in the frequencies used in communication into the infrasound as well as ultrasonic range. Of major significance, is the increase in acoustic sensitivity to a broad range of frequencies. An assessment of the potential impacts of sound on marine mammals therefore has to be primarily concerned with the potential impairment or damage of the auditory system of these animals. The reason is that in contrast to other organs, the auditory organs have the lowest intensity threshold of impairment or damage.

Pathological investigations on victims of explosions and experimental animals (Goertner 1982) have provided additional information on the effects of large pressure changes on lungs

Fish also have special acoustic organs (to create and perceive acoustic signals) that are extremely sensitive to pressure changes. The functional acoustic significance in fish and more so in marine invertebrates is comparatively lower than in marine mammals.

Possible evaluation parameters

The precise impact mechanisms of sound on the organs of marine mammals are not well understood. Currently, the response time and peak pressure of the sound impulse as well as the energy i.e. the energy flux density of the sound impulse, are regarded as significant parameters in the quantitative assessment of possible effects of acoustic impulses. (Gordon et al. 1998, Finneran et al. 2002).

A rapid increase in pressure to high values is regarded as being the cause of mechanical injury to tissue and organs, the extent of which is responsible for severity of the biological impacts. (Richardson 1995). This type of effect is, however, only significant in close proximity to a sound source exception: UW-explosions), since the pressure gradient of the primary pressure phase decreases with distance and the shock wave thus weakens. A quantitative assessment of the effects requires data on maximum sound pressure [Pa] or [PSI] as well as the exact pressure pattern.

Energy or energy flux density of the impulse becomes more important further away from the sound source. It is possibly responsible for auditory effects on the animals further a field. The energy of an impulse is equivalent to the squared pressure over time (duration of impulse). Audiometric data have shown that the human cochlea is comparable to a series of acoustic filters with a bandwidth of 1/3 octave (Fay 1988). Johnson (1968) obtained similar results for dolphins. To assess the effects on the hearing organ of marine mammals it is essential to provide the energy impulse values in relation to 1/3 Octave bandwidths.

III-5.2.2 Invertebrates

Species

The invertebrates in the North and Baltic Seas are represented by a large number of species. In the following, however, only the macro zoobenthos will be discussed with regard to the acoustic effects on invertebrates.

Conflict potential

The following points of conflict arise with regard to the potential effects of acoustic immission on invertebrates:

- Impairment due to sound immission
- Injury due to sound immission
- Effects on reproduction
- Effects on food availability
- Effects on predation

Sound expression

There is almost no systematic information available on the sound expression by marine invertebrates. However, it is known that particularly crustacea create stridulating sounds by rubbing together hard parts of there carapaces i.e. rubbing or rasping sounds (Freytag 1968). These are almost exclusively vital sounds produced in connection with muscular activity. The noise is broadband and can attribute to a noticeable increase in the ambient sound levels. According to Freytag (1968), species, which belong to the swimming crabs and crayfish, possess features that allow them to produce chirping and rasping sounds. Mussels and clams produce broadband mechanical noise by snapping shut the shells and the breaking of their byssal threads. These contribute to a constant ambient sound in mussel beds. The beaks of Cephalopods produce other vital sounds during feeding. Barnacles also produce noise while filtering and so do the Shipworm (*Toredo navalis*) and sea urchins. These virtual sounds are produced as secondary noise and have no functional significance.

One exception is the Snapping Shrimp (*Alpheus heterochaelis*), which lives in tropical and subtropical waters. It produces a cavitation bubble (by negative pressure) using its snapper claw. The implosion results in a snapping sound (up to 150 dB re 1 µPa in 1 m, Versluis et al. 2000). Since snapping shrimp use this mechanism to protect themselves against predators, for territorial purposes and to kill prey, this sound production has a functional significance.

Aural sensitivity

Since the sounds produced by snapping shrimp males serves to acoustically protect territory against other males, this means that this shrimp must be able to perceive sound. It is assumed that they detect particle movement.

Cephalopods (*Sepia officinalis, Octopus vulgaris* and *Loligo vulgaris*) are also capable of detecting particle movement (Packard et al. 1990). These animals have a large number of sensory hair cells on the head and tentacles (Hanlon & Budelmann 1987) that enables them to perceive infrasound vibrations (<10 Hz).

Effects of anthropogenic sound and vibrations

Branscomb & Rittschof (1984) discovered that the settlement of Barnacle larvae (*Balanus amphititre* Darwin) was reduced in the presence of continuous very low frequency noise (30 Hz). Acoustic radiation also had a negative effect on the rate of metamorphosis in the animals.

With the shrimp (*Crangon crangon*), a constant increase in the ambient sound level in the frequency range between 25 and 400 Hz resulted in a significant reduction in growth and reproductive rates (Lagardère 1982).

McCauley et al. (2000) carried out a focussed study on the effects of seismic signals on marine fauna. The sound produced by "Airguns" short signal impulses characterized by a rapid increase and extremely large sound pressure level. A large proportion of the acoustic energy of these signals is in the low frequency range, with lower intensities also reaching 20+ kHz. The direct subjection of the Southern Reef Squid (*Sepioteuthis australis* to sound radiation resulted in obvious escape behaviour (emptying of ink sack and jet start) when the airgun was triggered in close proximity (SPL 174 dB re 1 µPa). Behavioural response was observed in animals at a SPL of 156-161 dB re 1 µPa equivalent to a distance of 2-5 km from a large Airgun-Array (Grouping of several air pulsers). The squid chose to flee to the surface where the SPL is markedly reduced by the Lloyd-Mirror-Effect, (12 dB) lower than in other depths.

Further studies are cited in Vella et al. (2001):

- Signals in the frequency range 10-75 Hz result in a reduction of the heart pulse rate in the Lobster (*Homarus americanus*) (OFFUT 1970)
- Brittlestars (*Ophiura ophiura*) are capable of detecting near and far field low frequency vibrations (MOORE UND COBB 1986)
- MANIWA (1976) showed that the squid *Todarodes pacificus* is attracted by 600 Hz sounds at an SPL of 160 dB.

Conclusion

It cannot be excluded that the pile foundations of WTs will not be colonised by invertebrates to the expected extent, due to low frequency vibrations. However, it is not yet clear whether the results obtained by Branscomb & Rittschof (1984) on barnacle larval settlement can be extrapolated to field conditions, other species, orders or even on algae. The results of Leonhard (2000) cited by Vella et al. (2001) on WTs in Horns Rev do not give any indication of the colonisation of WTs or dumped gravel in relation to the effect of sound immission and vibrations since these wind turbines were only constructed in 2002.

In addition the extrapolation of observed reduction of growth and reproductive rates in shrimps, observed by Lagardère (1982), is also to be done with caution. Such effects are only expected in the immediate proximity of the wind turbines.

Should the WT foundations be introduced by ramming, it can be expected that cephalopods will flee from the area up to distances of several kilometres since the observations by McCauley et al. (2000) appear applicable to the North Sea.

Further statements on likely injury, sensitisation or habituation, change in reproductive patterns or effects on food availability such as predation of invertebrates due to the acoustic immission by WTs, can currently be made in the light of current available information

III-5.2.3 Fish

Fish fauna

The fish fauna far off the North and Baltic Sea coasts is comprised primarily of Teleosts (bony fish) (taxonomic unit: Teleostei) (Taxonomy after: Fiedler 1991, Krane 1986, Fish base). Cartilaginous fish (taxonomic unit: Chondrichthyes) and lampreys (taxonomic unit: Cyclostomata) are scarce in these areas. A compilation of potentially endangered fish species, based on the occurrence and fish catches of single species (KIJN et al. 1993) as well as their acoustic sensitivity (Fish & Mowbray 1970, Fay 1988, Popper & Fay 1993), is provided below. The protective status (Red List after Fricke et al. 1995 for the German North Sea and Fricke et al. 1996 for the German Baltic Sea area) and noteworthy behavioural features of individual species are also taken into account. This is preceded by a fundamental analysis of physiological and morphological background information on threat to fish by acoustic immission

Conflict potential

An assessment of effects due to sound immission and vibrations by WTs on fish can be based on the following aspects:

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- The presence of a swim bladder, its size and other morphological aspects may affect aural sensitivity.
- Is there a behavioural response to sound immission?
- If animals are disturbed, will this result in long-term consequences, next to short-term, for the fish, for example during reproduction or when juveniles are disturbed in their nursery grounds“).
- Can fish become accustomed to sound immission?
- Is reproductive success reduced by sound immission?
- Are fish injured by sound immission?
- Are such injuries of a temporary or permanent nature and what ecological significance do they have for the fish?

The following conflict potential exists for fish with regard to consequences of acoustic immission:

- Loss/gain of habitat
- Effects on food availability
- Changes in predation
- Masking
- Reduced growth
- Reduced reproductive success
- Interference by sound immission
- Injury through sound immission

The significance of hearing in fish

Many fish species are capable of producing sounds as well as detecting acoustic signals (Tavolga et al. 1981). However there are large species-specific differences between mechanisms of sound production as well as the type of sound. In addition, the acoustic sensitivity and the reaction of the fish to sound also vary considerably. The manner in which fish utilize acoustic signals, perceive them or react to them is critical for the assessment of justifiable anthropogenic noise source.

Auditory organs in fish

Fish posses two different structural units, which allows them to detect pressure changes in water: the paired auditory system and the lateral line.

The lateral lines which are situated on the sides of the fish up to the head, are only capable of detecting particle movement of water and thus perceive the motion of their bodies relative to their aquatic surroundings. It concerns very low-frequency oscillations (below 200 Hertz (Hz; 1 Hertz = 1 oscillations per second), caused by surface waves, the gradient in amplitude of particle movement in the near field of a moving object, self induced currents along the body as well as other currents. The lateral line consists of a row of pores in the skin's surface (sub epidermal) that open to a canal containing an equal number of "neuromast organs." Water moving against the side of the fish causes fluid in this canal to vibrate, which stimulates the neuromast organs. . This

The inner ear in bony fish (Teleostei) is comprised of three semicircular canals and three otolith chambers (Utriculus, Sacculus and Lagena) (Fiedler 1991). The semicircular canals and the Utriculus are vestibulary sensory organs (position control, "equilibrium organ") whereas the, Sacculus und Lagena are used for acoustic perception. The Teleosts, however, have different morphological ear types, which results in the non-uniform functional allocation of otoliths.

Thus, in clupeids (Herring) the Utriculus is used primarily for acoustic perception (Fay & Popper 1998). In the non-ostariophysi the Sacculus perceives sound pressure as well as particle displacement. In the Otophysi and Mormyridae the Sacculus is so tightly combined with a pressure detecting structure resulting in the acoustic isolation of the Lagena. Thus the Sacculus in the Otophysi represents a highly specialized receiver for weak sounds at low sound pressure, where the Lagena is used to localise the sound source (Fiedler 1991).

Teleostei possess an otolith, embedded in endolymph and sensory epithelium, in each pocket shaped otolith chamber. The sound pressure waves excite the otoliths and due to the different inertia of the otoliths, create shear forces between them and the underlying hair sensory cells. These cause a deflection of the sensory hairs and evoke nerve impulses via the sensory cells.

Sound transmission

At least two pathways of sound transmission to the inner ear have been identified.

The first and more primitive is the direct transmission of sound in water to the tissue and bones. The vibrations are transferred directly to the inner ear where it excites the acoustic sensory apparatus. This mechanism of sound perception also enables the recognition of the direction of the sound source.

The second mechanism of sound transmission is indirect; the swim bladder is caused to vibrate by acoustically produced pressure waves. Special coupling mechanisms (see below) transfer the oscillations to the otoliths (Fay & Popper 1998). Since the indirect signal is always transmitted in the same manner and independently of the position of the source, it is not possible to obtain directional information on the sound impulse via the inner ear.

Acoustic sensitivity

The indirect transmission of signals in some fish is enhanced by the acoustic coupling of the swim bladder with the inner ear. Clupeids (Herring species), Mormyrids (Nile Perch) as well as some other species have small gas-filled saccules on the otoliths that are connected to the swim bladder by small canals. (Fay & Popper 1998, Yan & Curtsinger 2000). The Otophysi (Cypriniformes – carp-like fish, the Characiformes – Carasins, Siluriformes – catfish) have a mechanical coupling of the swim bladder with the auditory organ via the Weber's apparatus. Most of these fish species have a high sound pressure sensitivity. Their hearing capability in the high frequencies is much broader than in other species. .

Electro physiological investigations by Yan et al. (2000) indicate that the swim bladder only leads to a change in hearing capacity through the mechanical coupling with the otoliths. The simple existence of a swim bladder does not have an effect on the hearing capacity.

The acoustic sensitivity in fish varies with species and perhaps even within individual species. Depending on the acoustic sensitivity and the acoustic spectrum, fish can be grouped into generalists or specialists with regard to hearing. While generalists are only capable of perceiving acoustic signals directly and react with low sensitivity to noise in the frequency range (300 – 500 Hz), specialists show a high sensitivity (50 – 75 dB per 1µPa) over a greater range (200 – 2.000 Hz and higher) (Fay & Popper 1998).

In flatfish such as the Plaice (*Pleuronectes platessa*), Dab (*Limanda limanda*), Flounder (*Platichtys flesus*), Lemon Sole (*Microstomus kitt*) and the Turbot (*Psetta maxima*), Brill (*Scophthalmus rhombus*) and Topknot (*Scophthalmus punctatus*) the swim bladder degenerates after the larval stage. These fish exhibit a low hearing sensitivity and are counted to the generalists. The functional acoustic detectability of the Plaice and Dab ranges from 30 Hz to 250 Hz, with the highest sensitivity (i.e. Hearing threshold) of 95 or 86 dB re 1 µPa at110 Hz. Karlsen et al. (1992 b., cited Enger et al. 1993) found a sensitivity to infrasound in the Plaice.

A degenerative absence of a swim bladder is also found in the Eelpout (*Zoarces viviparus*), Gobies (Gobiidae) and Sand eels (Ammodytes) (Engell-Sørensen 2002). The only fish in the North Sea for which acoustic measurements are available, is the Black Goby (*Gobius niger*). This species had a sensitivity of 103 dB re 1 µPa at 100 Hz (Fay 1988). These species and families can be classified as generalists due to their anatomic and physiological features.

The cod (*Gadus morhua*), a fish of high economic importance in the North and Baltic Seas, is capable of perceiving acoustic signals within a frequency range of between 10Hz and 600 Hz and a highest sensitivity of 61 dB re 1 µPa at 20 Hz (Fay 1988). The cod is also known to be sensitive to infrasound (Sand & Karlsen 1986) and capable of detecting intensive ultrasound (Astrup & Møhl 1993).

The European Eel (*Anguilla anguilla*), which is on the Red List of endangered species (Fricke et al. 1996), shows avoidance reaction to infrasound of (11,8 Hz) (Sand et al. 2000). The upper hearing limit in European Eels is at 300 Hz (Jerkø et al. 1989, cited in Engell-Sørensen 2002). Both species possess a swim bladder, however, without the connection to the inner ear.

The economically important Herring (*Clupea harengus*) have a low auditory threshold (50-75 dB re 1 µPa) and a wide auditory range (200-3.000 Hz) (Engell-Sørensen 2002). They are classified as auditory specialists (this also includes the highly endangered Baltic "Autumn Herring"). Two other species of the order Clupeiforms, the American Shad (*Alosa sapidissima*) and the Gulf Menhaden (*Brevoortia patronus*), of the Family Alosinae showed a detectability of ultrasound up to 80 kHz (Mann et al. 2001) and even 180 kHz (Mann et al. 1997, 1998). According to Mann et al. (2001) this characteristic auditory feature is limited to the Alosinae. In the German North Sea, the Allis Shad (Alosa alosa) classified as threatened by extinction as well as the endangered Twaite Shad (*Alosa* *fallax fallax*) are representatives of this Family. Mann et al. (2001) found that other clupeid species are able to detect sound up to 4 kHz.

The unique acoustic sensitivity of the Clupeiforms appears to due to the otic air bubble (auditory bulla), which is connected to the swim bladder via a thin tube.

Some of the Cypriniform fish in the Baltic are Red listed- (Fricke et al. 1996), however, no audiometric data are available for these species. Amongst these are the Zope (*Abramis ballerus*) which is classified as "endangered migrant", the "endangered" species Bleak (*Alburnus alburnus*) and Asp (*Aspius aspius*) as well as the "highly endangered" Baltic Vimba (*Vimba vimba*). The above species are expected to have a high sensibility over a wide frequency range.
Acoustic stimuli play an important role in the life of sharks particularly for the location of prey, rivals and predators. Using play back experiments, it was shown that at least 18 species could detect acoustic signals in the infrasound range up to ~1.000 Hz. In sharks the optimum was found to lie in lower frequency range (e.g. 300 Hz in the Lemon Shark *Negaprion brevirostris*, Banner 1967, 40 Hz and in the Horn Shark *Heterodontus fransisci*, Kelly und Nelson 1975 - both cited in Fay 1988). Sharks do not possess a swim bladder nor do they have acoustic coupling mechanisms. Due to these anatomic features and currently available audiometric data, sharks are categorized as auditory generalists with a rather low auditory sensibility.

Sound generation

The ability to generate sound has been found in several hundred fish species (Fish & Mowbray 1970). The sounds serve mainly for communication (courtship, territorial behaviour, fight etc.) or are used in connection with foraging or flight reaction. Tavolga (cited in Fiedler 1991) for the first time showed that a fish, the Hardhead Catfish (*Arius felis*) uses echolocation.

Sound generation in fish may follow diurnal or seasonal rhythms, be sex or species specific and depend on the situation.

Fish generally use three different mechanisms to generate sound: mechanisms-mechanisms, stridulating sounds and swimming sounds (Fiedler 1991, Sprague 2000).

Sound generation with the swim bladder is based on the contraction of external and internal muscles, which result in a change in swim bladder volume. All sounds are amplified by the swim bladder, particularly those that lie within the resonance frequency range. Sounds produced in this manner are non-harmonic and in a frequency range between 100 – 3.000 Hz and a sound pressure level of 140 dB (McCauley 1994, cited in Vella et al. 2001 without reference pressure). The highest amplitude is in the lowest frequency range.

Stridulating sounds may have frequencies (from 0,1 Hz) up to 6.000 Hz and a sound pressure level of 140 dB (McCauley 1994, also cited in Vella et al. 2001 without the reference pressure). Rubbing bones or teeth against each other produces these sounds. These sounds are also amplified by the swim bladder.

Low frequency sounds are produced by turbulences and movements caused by swimming. These sounds are size dependant but usually lie between 40-50 Hz. Hydrodynamic sounds of higher frequency (up to 300 Hz) may arise when individual fish or entire shoals undergo rapid turns (e.g.. flight reflex) (Hoffmann et al. 2000).

Sound generation was found in the following North and Baltic Sea fish species (Fish & Mowbray 1970):

- Herring (*Clupea harengus*) – low frequency (<200 Hz), impulses sounds

- Cod (*Gadus morhua*) – loud low-frequency grunting, highest intensity 50 Hz, 0,2 s duration, repetitive
- Pollack (*Pollachius virens*) – low frequency (<200 Hz), impulses, repetitive
- Mackerel (*Scomber scombrus*) – hard grunting sounds

Representatives of the Orders Anguilla, Merluccius and Myxocephalus in the North and Baltic seas also produce sounds. The impulse-like sounds of the American Eel (*Anguilla rostrata*) lie within low frequency range. However, some sounds attained levels of 1,2 kHz. The sounds generated by the Silver Hake (*Merluccius bilinearis*) are also low frequency impulse-like and (<100 Hz), whereas those of the Sea Scorpion (*Myxocephalus aenus*) are both of short and long duration (up to 4 s) low-frequency sounds (<200 Hz). It is questionable though whether similar sounds are produced by the representatives of these species in the North and Baltic Seas.

Effects of acoustic immission

Only anecdotal reports and no published results on the effects of acoustic immission during the construction or operation of offshore wind turbines are currently available. Engell-Sørensen (2002) report that Turbot and Flounder avoid an offshore wind energy farm (Vindeby, Denmark) during windy weather.

Behavioural reaction

Due to a lack of pilot investigations it is appropriate to apply the knowledge gained from comparable sound sources. In principle it can be assumed that a disruption of the behaviour in fish will only occur at higher sound pressure levels and by showing a higher alertness.

Behavioural reactions caused by acoustic disturbances may be an attraction of the fish or be aversive, directed away from the sound source.

1. Attractive effects

Increased occurrence of Cod near oil platforms

Investigations by Valdemarsen (1979, cited in Vella et al. 2001) showed that Cod numbers increased in proximity to oil platforms.

Attraction of Herring by „Pinger“

Acoustic deterrents („Pinger“) are used as instruments to reduce the by catch of Harbour porpoises in fisheries. An investigation on the effect of different pingers on Herring (Culik et al. 2001) revealed that significantly larger numbers of the Herring (*Clupea harengus*) were caught in nets fitted with pingers of a specific fabrication. These pingers emitted 76-77 signals per minute and a sound intensity of 115 dB at an ambient frequency of 2,7 kHz and harmonic frequency up to 19 kHz.

2. Aversive reactions

Construction noise frightens off fish

Myrberg (1990) cites a Japanese Study (KONAGAYA 1980) on the effects of construction noise on fish. Accordingly, intensive noise produced during building construction and in the auditory range of fish, may lead to the fleeing of fish out of the affected area (e.g. 90 dB – *no reference pressure* - SPL at a distance of 160 m from source and a spectrum between 500-600 Hz).

Prior to the renewal of the San Francisco-Oakland Bay Bridge (SFOBB) a demonstration project (PIDP) was used to ram piles in the Bay of San Francisco, U.S.A., with two sizes of rammers. An air-bubble veil (aerating mechanism) as well as a water permeable textile curtain (fabric barrier system) were tested as damping methods. This method has already been used successfully by Würsig et al. (2000). The effects of the ramming were investigated by using a fish echo sounder („Fathometer"), observing the feeding activity of gulls near the platform, counting and analysing the dead fish floating near the ramming work as well as acoustic radiation experiments („Environmental Documents" for „East Spans Replacement Project", California Department of Transportation 2001, http://www.dot.ca.gov/dist4/envdocs.htm). The combined deployment of a „fabric barrier system with aerating mechanism" resulted in a sound reduction of ~10 and ~25 dB (as a function of the frequency).

The exposed fish species were Clupeidiforms (Northern Anchovy *Engraulis mordax*, Herring *Clupea harengus*, Pacific Sardine *Sardinops sagax caeruleus*) as well as several Surf Perches (Embiotocidae).

The ramming did not result in any flight reaction by the fish. Shortly after the ramming, there was a significant increase in the number of gulls and in the hunting success (fish were caught on or near the sea surface). A few of the floating fish were investigated more closely. The damage to the fish ranged from internal bleeding, open wounds and burst swim bladders as well as badly damaged internal organs.

The direct sound radiation did not reveal any conclusive results. However, the results do show a similar trend to that observed in the bird as well as the pathological investigations of the fish.

Reactions to ship noise

Both Cod and Herring showed reactions to ship noise during a study. Signals between 60-3000 Hz SPL of 118 dB re 1 µPa did not result in an avoidance reaction in fish. Signals in the frequency range 20-60 Hz also did not cause any reaction (ENGAS et al. 1995). Many studies have shown an influence of ship noise on fish (OLSEN et al. 1982a, 1982b, DALEN UND RAKNES 1985, 1986, McCauley et al. 1994 – all cited in Vella et al. 2001). Based on these results, Vella et al. (2001) describe a reaction threshold of 120-130 dB (assumed sound pressure in dB re 1 µPa) in Herring and Cod.

Mitson (1995) reports on several studies which confirm that different fish species (Cod, Polar Cod, Capelin, Sprat, Herring and others) show a lateral and vertical avoidance movement in the water column and swim faster in the presence of different ship types (DINER und MASSE 1987, MISUND und AGLEN 1991, NEPROSHIN 1979, OLSEN et al. 1971, 1983a+b, ONA and CHRUICKSHANK 1986, ONA 1988, SHELVELEV 1989 – all cited in Mitson 1995). The reaction distance was at 100-200 m and 400 m near very sound intensive ships.

Haddock showed a significant reaction to a 300 Hz ship sound that could be turned on and off (Nicholsen et al. 1992, cited in Mitson 1995). This signal lies within the maximum acoustic sensitivity of the Haddock (Chapman 1973).

Infra sound as acoustic barrier for Salmon

Knudsen et al. (1992) tested the effectivity of sound as acoustic barrier for juvenile Salmon (*Salmo salar*) Knudsen et al. (1992) presented all values in relation to particle acceleration (measured in dB per ms^{-1}). The criteria used were enhanced alertness of the fish [Reduction in heart rate and breathing] and avoidance reactions. The highest alertness was initiated by low frequency signals of 5-10 Hz, whereas a 150 Hz-signal (corresponding to the highest acoustic sensitivity in salmonids (Hawkins & Johnstone 1978)) did not cause a reaction in the fish, even at a high SPL. However, an avoidance reaction was triggered by a 10 Hz signal and a 10-15 dB higher sound intensity. The fish only displayed a higher alertness to 150 Hz signals at clearly elevated sound intensities of (+48 dB). The salmon did not show any avoidance of 150 Hz signals and a SPL of up to 114 dB higher than the auditory threshold, both in the field and during the experiment (Knudsen et al. 1994).

Habituation in salmon

Habituation was already noticeable after the first subjection to sound immission with a 150 Hz signal although the heartbeat only slowed down after the 3rd to 7th immission at 10 Hz. In the field, however, there was no habituation even after 8 subjections to 10 Hz signals. (Knudsen et al. 1997) in a further study, showed that the salmon (*Oncorhynchus tshawytscha*) revealed a distinct avoidance reaction even after being subjected to repeated sound immission (20x). However, the initial flight reaction was no longer observed after the 12th immission.

Startle response in salmon

Engell-Sørensen (2002) cites a study in which juvenile Chinook salmon show a startle response when exposed to 150 Hz and 180 Hz signals [C-Start; reflex like reaction in fish – caused by stimulation of the lateral line on one side of the fish which results in a contraction of all lateral muscles on that side and rapid sideways propulsion of the fish]. The acoustic intensity was 160 dB, however, no reference value is provided. In the same study it was found that infrasound signals (10-35 Hz) as well as a combination of 300-400 Hz signals did not result in avoidance reactions.

Effects of infrasound on the European Eel – an acoustic generalist

Infrasound signals of (11,8 Hz) caused a startle response as well as an extended stress reaction [Increased heart rate] in the European Eel (*Anguilla anguilla*) (Sand et al. 2000). The threshold to trigger the reaction was the same as that in young salmon (Knudsen et al. 1992, see above).

Westerberg (1999) using catch numbers and telemetry transmitters investigated the reaction of eels to Offshore WTs. Significant differences in the catch of eels were only observed during high wind velocities. Less eels were caught behind the wind turbines (swimming direction of the eels towards wind turbines) than in front. However, it is not apparent whether the higher turbulence in the water or the sound emission was the actual deterrent. The telemetry data did not reveal a systematic difference in migratory pattern of the eels during both the operation and shutdown of the wind turbines. In fact Westerberg discovered a species independent attraction of fish to within several hundred meters of the windpark. During operation, the total catch within an area of 200 m around the wind turbines, of Cod, Roach and Sea Scorpion amongst others, dropped. However, Westerberg emphasizes that the significance of the results is questionable since no data are available on the effects of the area on variance prior to construction.

Simulated Orca sounds result in behavioural reactions

Simulated echolocation sounds of the Orca (*Orcinus orca*), a meat and fish eating toothed Whale, cause the interruption of feeding behaviour followed by diving and aggregation into shoals in the Pacific Herring (*Clupea pallasi*) (Wilson & Dill 2002).

Ultrasound frightens off herring species

DUNNING et al. (1992) (cited in Popper & Lu 2000) proved that ultrasonic signals (126 kHz) frighten off Clupeid (Herring species). Furthermore, Domenici & Batty (1997) also showed that Herrings within a shoal react quicker to sound signals than individuals. This phenomenon is attributed to the rapid transmission of stimuli via the lateral line, between closely associated fish.

Auditory impairment in Goldfish – a hearing specialist

Popper & Clarke (1976) found that Goldfish (*Carassius auratus*) exposed to sonic signals at 300 Hz, 500 Hz, 800 Hz und 1.000 Hz and a sound pressure level of 149 dB re 1 µPa for 4 hours, exhibited a temporary shift in the auditory threshold which lasted for 2 to 4 hours. Repetitive exposure also did not cause any permanent damage.

Seismic signals result in behavioural reactions in fish

Investigations on the effects of seismic surveys and ships noise have shown that fish clearly exhibit avoidance reaction as soon the noise exceeds the auditory threshold of the fish in the corresponding frequency by at least 30 dB (Engås & Løkkeborg 2001). The reaction distance was a function of the sound pressure level, the temporal structure of the sound signal, the ambient sound levels as well as the propagation in the area of investigation. The avoidance reaction range from enhanced swimming velocity, aggregation, descent to the bottom and finally to fleeing the area of exposure. A reduction of fish catches with trawl and long-line fishing (between 45 – 85%) was observed in connection with seismic surveys (Engås & Løkkeborg 2001, Engås et al. 1996). Whereby the reduction in number of large fish was greater than that of smaller ones, which could be attributed to the size dependant difference in resonance frequencies of the swim bladder.

At the same time, however, it seems possible that the fish will concentrate on the sea floor due to ship noise and thus improve the catch ability for bottom trawlers under some conditions.

A startling reaction was observed in Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*) up to a distance of 29-33 km from seismic investigations. (Engås et al. 1993, cited in Sverdrup et al. 1994).

Comparable reactions of fish were seen during an Australian study (McCauley et al. 2000). The study was carried out on Australian fish species: Bream (*Crysophrys auratus* and *Acanthopagrus butcheri*) as well as a Trevally species (*Pseudocaranx dentex*). An exposure to seismic signals produced by airgun resulted in the following:

- Startle response after exposure to high sound pressure
- Size dependant response (stronger reaction in small fish)
- Habituation, i.e. reduction in startle response with time
- Decent, increase in swimming speed, formation of groups when subjected to sound pressure from 156-161 dB re 1 µPa.
- Return to normal behaviour within 14-30 minutes after exposure
- No significant stress induced physiological reactions (elevation of cortisone levels in the blood)

In subsequent investigations McCauley et al. (2001) discovered, that the reaction of fish was possibly attributable to the damage of sensory hair cells.

Wardle et al. (2001) on the other hand did not see any avoidance reaction in reef fish after repetitive exposure to seismic impulses (up to 210 dB re 1 µPa received sound pressure). They only observed a startle reaction, which was not subject to habituation.

Physical effects

Auditory impairment from acoustic signals

McCauley et al. (2001) found that the hearing epithelia in fish was destroyed by intensive sound impulses emitted from seismic instruments.

Enger (1981) (cited in Hastings et al. 1996) exposed Cod (*Gadus morhua*) to sound signals between 50 and 400 Hz and a receiving sound pressure level of 180 dB re 1 µPa (100-110 dB above the auditory threshold), over a period of 1-5 hours. This resulted in a destruction of the hair sensory cells (sensitive to frequencies between 150 – 250 Hz)

Denton & Gray (1993) showed that the hair sensory cells in the lateral line organ of Clupeids (Herring species) were destroyed by sound signals with a frequency between 1 – 200 Hz and received sound pressure of 153-170 dB re 1 µPa.

Hastings et al. (1996) observed that sound signals below 180 dB re 1 µPa as well as interrupted sound signals did not cause any injury to sensory hair cells in the Oscar (*Astronotus ocellatus*). Only after exposure to 300 Hz-tone and a received SPL of 180 dB per dB per 1 µPa did injury occur. The authors conclude that the injury threshold for the auditory generalists amongst the fish is much higher than in the auditory specialists.

Regeneration of acoustic sensitivity

The significance of the investigation by McCauley et al. (2000) particularly for this study is the fact that the regeneration of the sensory hair cells after destruction of the epithelia, took place after 58 days. The capacity of regenerating the auditory sensitivity in fish was also shown by von LOMBARTE et al. (1993) (cited in Engell-Sørensen 2002).

Sound induced injury to tissues

A received sound pressure level of 240 dB re 1 µPa resp. Explosion like signals may lead to tissue damage in fish (Engell-Sørensen 2002). Underwater explosions are also considered to be the cause of high mortality in Cod (*Gadus morhua*) and Salmon (*Salmo salar*), observed in Altafjord, Norway in 1989. The examined fish had injuries to their blood vessels and pericardium (Larsen 1990, cited in Sverdrup et al. 1994). However the simulation experiment in the laboratory by Sverdrup et al. (1994) did not confirm an acoustic cause of injury to fish.

Effects on survival and growth rate in fish larvae

Banner & Hyatt (1973) found that continuous exposure of fish eggs and larvae of the Minnows (*Cyprinodon variegatus* and *Fundulus similis*) to sound reduced the survival rate of embryos and resulted in a significantly slower growth rate. The SPL was about 20 dB above the ambient levels in the sea.

Conclusion

A general problem in fish is the definition of "hearing" since low frequency acoustic signals close to the source do not only generate pressure waves but also cause a clear particle movement. The latter is not an auditory impulse, which could be perceived by sensory organs sensitive to touch.

A clear distinction between acoustic sensitivity by the sensory hair cells and the perception of particle movement by the lateral line in fish can probably only be made by electrophysiological deductions from the auditory nerve (i.e. by measuring the „Auditory Evoked Potential", AEP) resp. in combination behavioural investigations. Due to the lack of appropriate measurements it is not possible to separately evaluate the effects of sound and oscillations.

- Are fish capable of detecting sound immission and oscillation?
  This depends primarily on the acoustic sensitivity of the animals. The presence of a swim bladder, its size and other morphological aspects can influence the sensitivity.

- Will sound immission by WTs cause behavioural response in fish?
  Apart from short-term reactions, long-term consequences may arise in fish when these are disturbed during reproduction or as juvenile stages in „nursery grounds“; Herring, Cod, Haddock, Whiting und flatfish such as Flounder and Plaice, use such nursery grounds.

- Is there a habituation effect in fish subjected to sound immission?

- Does reproductive success decrease due to sound immission?

- Are fish injured by sound immission?

- Are such injuries temporary or permanent and what ecological significance do they have for the fish?

The available information on audiometric investigations shows that fish in general are only sensitive to the frequency range of 20 Hz to 3 kHz. The perception of sound is species specific. Some species are capable of detecting ultrasound (>20 kHz), whereas others respond extremely sensitively to infrasound (<20 Hz). It is currently not possible to assess which sensory mechanism is responsible for the different perceptions.

It is definite, that all the fish species living in the German regions of the North and Baltic Seas are capable of detecting the high intensity sound spectrum of the sound emission caused by ramming during the construction activities. The distance of perception around the construction platform will be less for the auditory generalists than for the specialists. For the latter, it is probably the ambient sound level, which is the limiting factor.

Since the continuous operating sound pressure level (SPL) of the WTs is in the low frequency range and clearly above 100 dB re 1 µPa in 1m depth, these could also be detected by a number of fish. For auditory generalists such as flatfish this range is probably restricted to a few meters.
The elevated number of fish near WTs observed Westerberg (1999) probably reflects a “reef effect”. The fact, however, that the number of fish within 200 m of a wind turbine is reduced during operation, could be attributed to acoustic effects. Should this effect be transferable in general, it could mean a more severe effect of larger wind turbines. The sound spectrum produced by the planned wind turbines will probably be much lower than that of the wind turbines used by Westerberg. This means that a transfer of results is equally questionable and only conditional.

Large objects in water often attract fish and results in aggregation and the formation of shoals in the vicinity or below the object. This can also be expected for the working platform during construction of WTs; this is the conclusion drawn from the studies in the bay of San Francisco (California Department of Transportation 2001).

The attraction or frightening off due to sound appears to be species dependant. Thus, impulse like noise will evoke a definite avoidance behaviour (also size dependant) in Cod and Haddock (Engås et al. 1996). Herring species and bass, however, appear to be attracted or at least not frightened by such sounds (California Department of Transportation 2001).

It is generally expected, that the composition of the fish fauna will change during construction work. Since the magnitude and duration of such reactions by individual fish or species cannot be assessed, it remains uncertain to what extent such changes will take place.

Furthermore it is currently not possible to assess the effects on reproduction or growth.

Should the presumption by Mann et al. (2001) regarding the particular acoustic sensitivity in the Alosinae be correct, then the highly endangered Allis Shad (*Alosa alosa*) Fricke et al. (1995), would be specifically threatened by acoustic immission.

It is conceivable that noise created by ramming and the operational of WTs may mask the sounds created by fish in the short and long term, respectively. It is not clear whether fish are capable of compensating this problem by increasing their own sound volume or if the noise by the WTs can be functionally neutralized. Should the territorial behaviour or sexual display etc. depend on acoustic communication, then this would not be possible in an area subjected to sound immission the area would no longer be appropriate as a habitat.

Due to the masking of low frequency sound, potential prey fish will not be able to detect predators and thus be subjected to a higher predation risk (Enger et al. 1989).

Should the repair mechanisms reported in several studies apply to all fish species, this would have an effect on the assessment of potential impacts of acoustic immission by WTs on the fish fauna. Injury to the Acoustic sensitivity of fish would be regarded as temporary although by definition, a change in the acoustic threshold is regarded as being permanent if still detectable after 30 days. This definition, however, applies to humans and other terrestrial mammals and may have to be altered for fish.

Pathologic injuries as well as fatalities in fish are expected to occur in the immediate vicinity of ramming activities. (See: California Department of Transportation 2001). In this study, however, special preventive measures reduced the degree of injury and thus number of injuries considerably. A corresponding degree of injury due to operational noise is not expected for WTs.
An appropriate noise reduction system should be applied during the construction of WTs (e.g. a bubble curtain). In addition it is essential that the impact of impulse like and continuous sound immission on the physiology, behaviour and from a physical perspective, on fish fauna be investigated more thoroughly. This is the only way to consolidate the presently inadequate and largely incoherent understanding, in order to obtain an improved qualitative and quantitative assessment of acoustic impacts on fish.

III-5.2.4 Marine mammals

Marine mammals evolved from land living ancestors and later returned to water. Although they underwent a large number of anatomic and physiological adaptations, their general body features resemble to a large extent those of land mammals.

Whales (Order: Cetacea) are divided into two groups: Baleen Whales (Mysticeti) and Toothed Whales (Odontoceti) (Barnes 2002). Seals (Order: Pinnipedia) are taxonomically classified into True Seals (Phocoidea), Eared Seals (Otarioidea) and Walruses (Odobenidae) (Berta 2002).

A general difference between whales and seals is the degree of adaptation to the marine environment. Whereas whales spend their entire lives in water, seals leave the water to moult and to bear and rear their offspring, amongst other reasons. Thus there is a corresponding difference in their sensory perception. Seals for instance possess an excellent tactile sensitivity whilst at the same time retaining capacity to hear both in the water and air. The tactile sensitivity in whales is not well developed in comparison to seals. However, they do have an extremely sensitive hearing. Added to this, some whale species, including the Harbour porpoise, have developed the ability to echolocate. I.e. they are capable of emitting acoustic signals and receiving acoustic echoes, which provides them with an "acoustic picture" of their surrounds.

Three indigenous marine mammals occur in the German Bight and the German zones of the Baltic Sea: the Harbour porpoise (Phocoena phocoena) as only representative of the toothed whales, the Harbour Seal (Phoca vitulina) and the Grey Seal (Halichoerus grypus), both True Seals. Apart from these other whale or seal species may sporadically occur, however, their appearance is rather seldom.

Harbour porpoise - Phocoena phocoena (Linneaus, 1758)

The harbour porpoise (*Phocoena phocoena*, Linnaeus 1758) (Figure III-38) is a common and only indigenous representative whale species. Up to a few decades ago the harbour porpoise was regularly caught and utilized along the European coast. However, presently their numbers have decreased to the extent that they have received an international protective status (see ASCOBANS, Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas, New York, 1992, which was ratified by Germany in 1993, http://www.ascobans.org/). Harbour porpoises have been placed on the "Red list" where they are classified as being "threatened by extinction" in both the North and Baltic Seas.

The harbour porpoise belongs to the Suborder (Odontoceti) and is one of the smallest representatives of the toothed Whales compared to the largest representative, the Sperm whale (*Physeter macrocephalus*). Harbour Porpoises are born with a body length of 0,80 m an attain a maximum size of 1,80 m (Exceptions up to 2 m). Females are a few centimetres larger, on average, than males. Their maximum weight is approximately 90 kg. Baltic males had an average size of 1,42 m and weight of 48 kg. Females were an average 1,52 m long and weighed 57 kg (Møhl-Hansen 1954).

Figure III-38: Adult harbour Porpoise with calf (sketch).

Stocks and distribution

The distribution of the harbour porpoise ranges from the Pacific Atlantic coastal waters of the Northern Hemisphere as well as bordering Seas. The animals prefer cold and temperate regions. Their southern most limit of distribution is more or less the +25°C surface water Isotherm. In Europe they are found in the Black Sea, the Western Mediterranean, along the North-Atlantic coast as well as the North and Baltic Seas. Their northern limit is probably in the Bering Sea. In the Baltic Sea, the harbour porpoise used to be found up to the Åland-Islands. However, today they are seldom found along the Finnish, (Määttänen 1989), Polish (Skora et al. 1988) and Swedish coasts (Berggren & Petterson 1990). Harbour porpoise frequent the coastal zones but may go into estuaries and rivers.
In 1994 a first attempt was made, within the framework of the SCANS ("Small Cetacean Abundance in the North Sea and adjacent areas") project to obtain quantitative information on the abundance and distribution of small whales, particularly the Harbour Porpoise in the North Sea and bordering seas (Hammond et al. 1995).
The area of investigation (including the division into individual areas) is shown in Figure III-39.

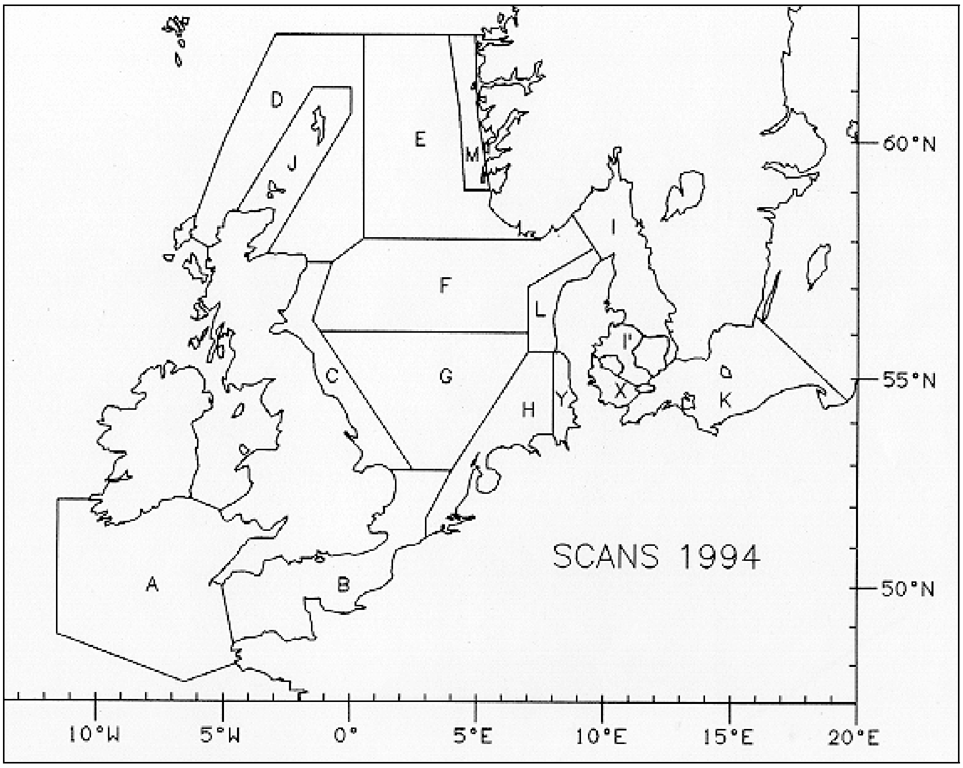

Figure III-39: Areas of investigation including sub divisions during the SCANS-Study (Source: Hammond et al. 1995)

In contrast to previous studies as well as stock assessments of harbour porpoises in the North and Baltic Seas, the SCANS-Data provide absolute animal densities (Animals per km^2), since the correction factor g(0) was applied. This value is a measure of probability of observing a Porpoise under the prevailing conditions. All other studies only provide relative densities (Number of animals per unit distance) and thus only have a limited value for assessments. The SCANS investigation is the only investigation that covers the entire range of distribution.

The calculated density of harbour porpoises for the individual areas is shown in Table III-2.

Table III-2: Abundance, density and average school size of harbour porpoise in selected areas. Values in round brackets are variation coefficients, values in square brackets show the 95% confidence interval (Source: Hammond et al. 1995.)

Block	Abundance	Density [animals / km^2]	School size Ø
A	36.280 (.57)	.180 (.57)	1.64 (.09)
B	0	0	0
C	16.939 (.18)	.387 (.18)	1.65 (.07)
D	37.144 (.25)	.363 (.25)	1.42 (.07)
E	31.419 (.49)	.288 (.49)	1.52 (.24)
F	92.340 (.25)	.776 (.25)	1.46 (.04)
G	38.616 (.34)	.340 (.34)	1.45 (.10)
H	4.211 (.29)	.095 (.29)	1.48 (.14)
I	36.046 (.34)	.725 (.34)	1.46 (.06)
I'	5.262 (.25)	.644 (.25)	1.20 (.03)
J	24.335 (.34)	.783 (.34)	1.13 (.08)
L	11.870 (.47)	.653 (.47)	1.62 (.08)
M	5.666 (.27)	.450 (.27)	1.26 (.08)
X	588 (.48)	.101 (.48)	1.50 (.15)
Y	5.912 (.27)	.812 (.27)	1.45 (.10)
	341.366 (.14) [260.000 – 449.000]		

The waters of Lower Saxony were not well investigated during the SCANS-Study, due to bad weather conditions.

The sightings along the Baltic coast of Schleswig-Holstein in July 1994, during the SCANS-Project, revealed 870 animals with a variation coefficient of 0,48. This represents an average of 0,15 animals per km^2. The estimate for the northern Belt Sea was 8.060 animals (Variation coefficient: 0,25), at a density of 0,987 animals per km^2. In the Kattegatt and Skagerrak there were 36.046 animals (coefficient of variation: 0,34) and corresponding to a density of 0,725 harbour porpoises per km^2.

Additional surveys were carried out in the area of the North Sea coastline of Schleswig Holstein as well as in the German zone of the Baltic during 1995 and 1996. These confirmed the higher densities observed during the 1994 survey. In addition there was a large proportion of calves near Sylt and Amrum (Adelung et al. 1997). The Baltic surveys for the Kiel and Mecklenburg bights in 1995 resulted in a count of 910 animals (95% confidence interval: 360-2.520). In 1996 the surveys yielded 1.830 animals (95% confidence interval: 960-3.840).

In the zone, which includes the Darss ridge up to the eastern border of the German Exclusive Economic Zone, there were 522 animals (95% confidence interval: 233-2.684) in 1995. During 1996 no harbour porpoises were sighted in this zone during the aerial surveys.

Strandings of dead animals as well as coincidental sightings of harbour porpoises along the coast of Mecklenburg-Vorpommern (Benke, Deutsches Meeresmuseum Stralsund, pers. comm.) and Poland (Skora & Kuklik, Hel Marine Station, PL, pers. comm.), however, indicate that the animals still occur there. The stock density seems to be decreasing in an easterly direction.
Genetic investigations carried out on beached porpoises in the southern and south-western Baltic as well as the North Sea revealed that there was only a very restricted genetic exchange between the porpoises of those regions which indicates that the Baltic animals are probably a separate population (Tiedemann et al. 1996). These observations correspond to data on different skull features (Kinze 1985) and enzyme polymorphisms (Andersen 1993) between Baltic and North Sea animals. However, it is not clear where the border between the populations is. Kinze (1985, 1990) assumes that migration between the Baltic and North Sea does occur. Telemetric investigations on harbour porpoises (n=17) revealed that logged animals had a limited range (Larsen et al. 2000). However, some porpoises were tracked into the Skagerrak and in one case up to the Norwegian west coast (Teilmann, pers. comm.). It remains unclear to what extent these animals reproduce and thus whether there is a mixing of populations. Morphometric studies on skulls of harbour porpoises from various locations in the Baltic have shown that the western limit of occurrence of the Baltic population is the Darss ridge (between Germany and Denmark) and the Linhamn ridge between Denmark and Sweden (Huggenberger et al. 2000) (Figure III-40).

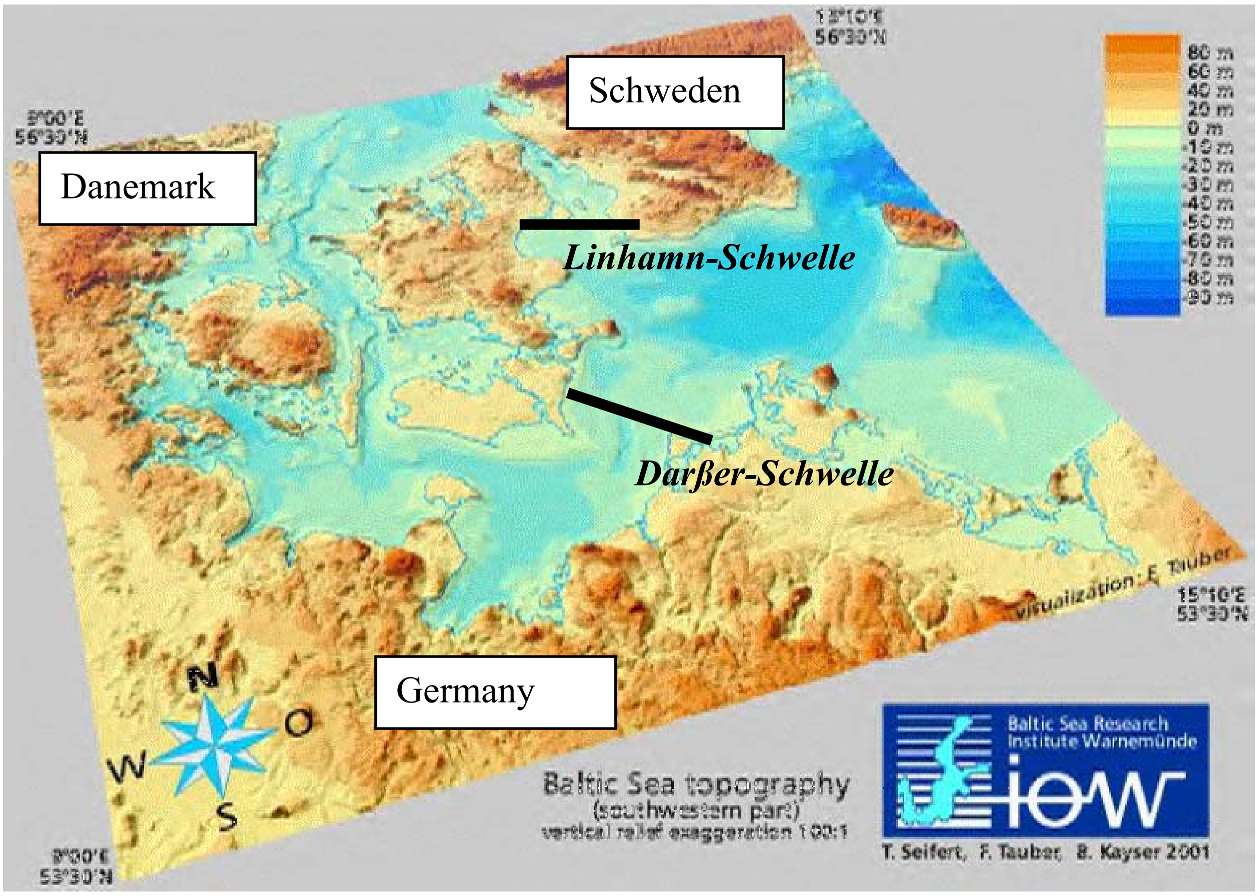

Figure III-40: **Topographic map of the Baltic Sea; Black lines indicate approximate position of the Darss and Linhamn ridges.**

Based on the current available data on standing stocks it is not possible to make reliable statements on the numbers of harbour porpoises in the Baltic populations (for the region east of the Darss ridge) However, it is estimated that the population comprises less than 1000 animals.

Seasonal migration

It is known from observations from the worldwide regions of distribution of the harbour porpoise, that the animals show seasonal migration. Such observations were also made in the Danish region of the Baltic up to the 50s of the last century. The animals migrated through Danish waters into the Baltic during spring and out again in November to January. Due to the decrease in numbers of harbour porpoises in the Baltic and bordering seas (Andersen 1982, Kinze 1995), as well as a lack of data for the North Sea, it is not possible to draw any conclusions on the migration of animals at this stage. Such information may well be obtained from telemetric studies on the harbour porpoises (compare Larsen et al. 2000).

Reproduction

Reproduction of harbour porpoises in the German regions of the North and Baltic Seas appears to be seasonally synchronized. Observations of stranded porpoises and neonatal sightings clearly indicate the birth season to be May to July (Hasselmeier, FTZ west coast, pers. comm.). Mating occurs between June and August as was deducted from the testicle weight as well as follicle maturity in ovaries of sexually mature beached animals (Bandomir et al. 1998, Adelung et al. 1997). Investigations on the reproductive biology of harbour porpoises revealed that females were sexually mature at an age of 4,5 years and males between 3 and 6 years. The fecundity rate of sexually mature females was 0,78 – an indication of an annual reproductive cycle. Analyses of stomach content of beached or bycaught juvenile animals showed that these were nursed for 8 to 9 months. A close connection to their mother is vitally important for the calfs especially during the first months of the nursing period.

Echolocation

The harbour porpoise, like many other Toothed Whales have the ability to echolocate (Busnel et al. 1965, Møhl & Andersen 1973, Kamminga & Wiersma 1981, Akamatsu et al. 1994), i.e. they emit underwater sound and analyse the reflected echoes. Since underwater sound has the least attenuation compared to all other forms of energy, the use of echolocation in combination with passive hearing are ideal for the animals to obtain a “picture” of their surroundings, to navigate, to avoid obstacles and predators, for foraging and probably for communication (Kamminga & Wiersma 1981).

The echolocation signals (Clicks) of harbour porpoises are directional signals (9° Azimuth; 15° Elevation - see Goodson et al. 1995). The clicks have a duration of between 75 µs (Goodson et al. 1995) and 150 µs (Kamminga & Wiersma 1981) and consist of at least two acoustic components: a low frequency signal component of 1,4 – 2,5 kHz (Verboom & Kastelein 1995), a source sound level of 100 dB re 1 µPa at 1 m (Schevill et al. 1969) and a high frequency component which in adult animals attains its highest intensity at 130 kHz. The highest value in young animals is 145 kHz (Goodson et al. 1995). Most of the energy of the clicks is concentrated in the frequency range from 110 – 150 kHz (Møhl & Andersen 1973, Amundin 1991).

The maximum sound intensity of 166 dB re 1 µPa in 1m (distance) was measured in a captive animal. Comparable studies on other Toothed Whales have shown that animals living in an area where there is little reverberation are capable of increasing the intensity by 10 dB (Au et al. 1974). Such situations occur in the open sea. Whereas the high frequency components of the signal serve primarily for echolocation (location and characterization of objects) the low frequency components of the sounds are supposed to play an important role for the communication.

There is no definite confirmation on the existence of the mid frequencies measured by Verboom & Kastelein (1995) in the range of 30-60 kHz, nor of the 20 kHz components measured by Kamminga & Wiersma (1981) and Kamminga et al. (1996). The same applies to the emission of tonal sounds between 40 – 600 Hz („whistling“) by harbour porpoises (Verboom & Kastelein 1997).

Acoustic sensitivity

Absolute aural sensitivity

Andersen (1970) was the first to determine the acoustic sensitivity in harbour porpoises, a second audiogram was measured by Kastelein et al. (2002). The measured values as well as the resulting audiogram are shown in Table III-3 and Figure III-41.

Directional hearing

Van Heel (1962) found directional hearing (minimum audible angle), the smallest change in the spatial position of a sound source that a listener can detect of 8° and 6 kHz. In a subsequent study Andersen (1970) found a resolution of approximately 3° in a harbour porpoise he investigated.

Table III-3: Acoustic sensitivity of the harbour porpoise

Frequency [kHz]	Aural sensitivity [dB per 1 µPa]	
	Andersen (1970)	Kastelein et al. (2002)
0,25		115
0,5		92
1	84	80
2	64	72
4	54	67
8	48	59
16	51	44
32	48	37
40	54	
50		36
64	57	46
80	60	37
100	65	32
120		33
130	69	35
140	69	36
150	126	60
160		91
180		106

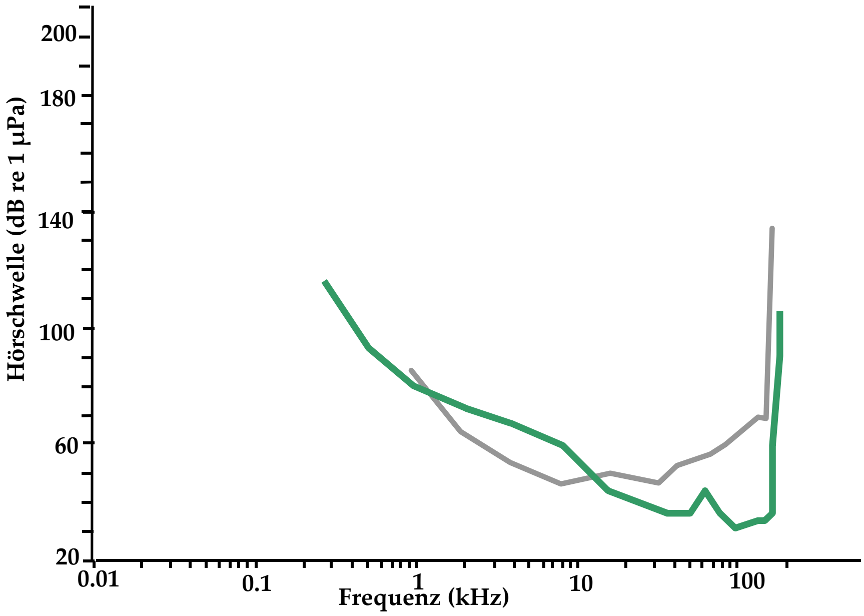

Figure III-41: **Graph showing the audiogram of harbour porpoises (grey: Andersen 1970; green: Kastelein et al. 2002)**

Seals

Seals in general

The body of the harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) is fusiform. As in all true seals they do not have an auricle, but in contrast to the whales they have retained four extremities. In adaptation to the swimming behaviour those have become flattened and flipper shaped. The seal head is slightly flattened and their nasal openings are at the tip of the snout. The body is covered by fur that is moulted once a year after mating and the offspring are weaned.

Harbour seal - *Phoca vitulina* Linneaus, 1758

Adult male harbour seals have a body length of between 150-175 cm and a weight of up to 100 kg. Females attain a maximum size of 130-155 cm and weigh up to 80 kg (Reijnders 1992). Harbour seals are distributed throughout the North Sea from the English Channel to the north coast of Norway including the British Isles, Orkney Islands and parts of the Baltic.

Numbers and distribution in the German North and Baltic Seas

Harbour seals are indigenous throughout the German Wadden Sea. They utilize the sandbanks to rear their young, to rest and moult. In the German North Sea the seals are classified as endangered on the Red List (Benke & Heidemann 1995). Protective measures by the Wadden See neighbouring states are co-ordinated in the framework of the Trilateral Wadden Sea Cooperation (http://www.waddensea-secretariat.org/). Seals are also protected under the Convention on the Conservation of Migratory Species of Wild Animals" (CMS, „Bonn Convention").

The distribution of harbour seals ranges from Skagerrak and Kattegat to the southern Danish Belt Sea [the southern most colony occurs in the area of Rødsand, DK; extensive investigations are being carried out on these animals in view of Danish plans to construct offshore WTs in this area, Dietz et al. 2001]. No colonies exist in the German zone of the Baltic; in this area they are classified as being "threatened by extinction" (Benke et al. 1996). Other colonies exist in South Sweden as well as in the northeastern region of the Baltic (Gulfs of Bothnia and Finland). Whelping of harbour seals occurs from May to July; and nursing takes 4-5 weeks.

The stock of harbour seals in Germany, which was subjected to hunting until 1974, had increased to approx. 8000 in the Wadden Sea by 1988. However the population was drastically reduced (down to 60%) by the distemper virus epidemic in 1988/89. After a recovery in the subsequent 13 years to numbers above those of 1988 (Figure III-42), a new outbreak of the virus occurred in the Kattegatt in 2002 which passed on to animals in the Wadden Sea. It is currently not foreseeable to which magnitude this epidemic will be and what the consequences are for the Wadden Sea population.

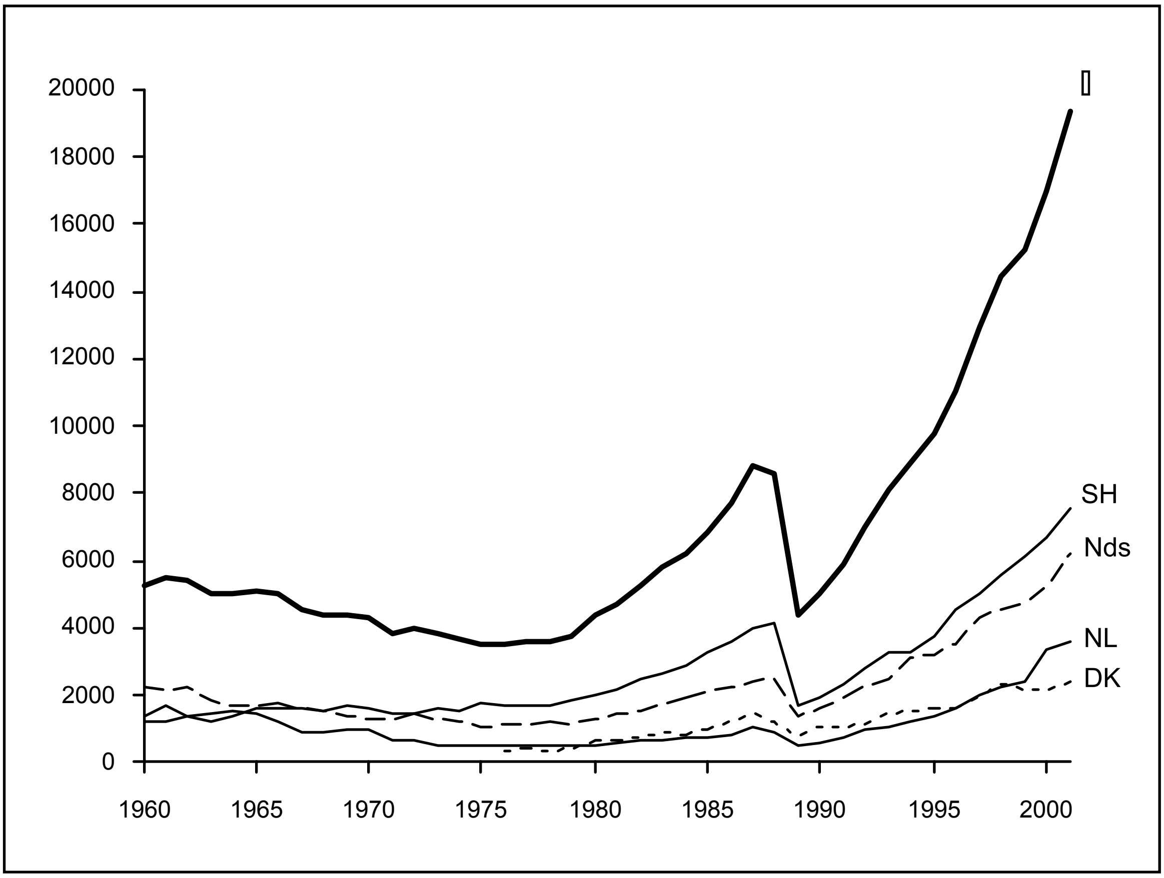

Figure III-42: Development of the harbour seal population in the European Wadden Sea 1960–2001 (Source: Dr. K.F. Abt)

The following numbers of harbour seals were recorded in the Wadden Sea in 2001:

Netherlands:	3.594
Germany:	
Lower Saxony:	6.223
Schleswig-Holstein:	7.534
Denmark:	2.036
Total:	19.387

The distribution or haul out areas of harbour seals in the region of the German Wadden Sea are shown in figure III-43.

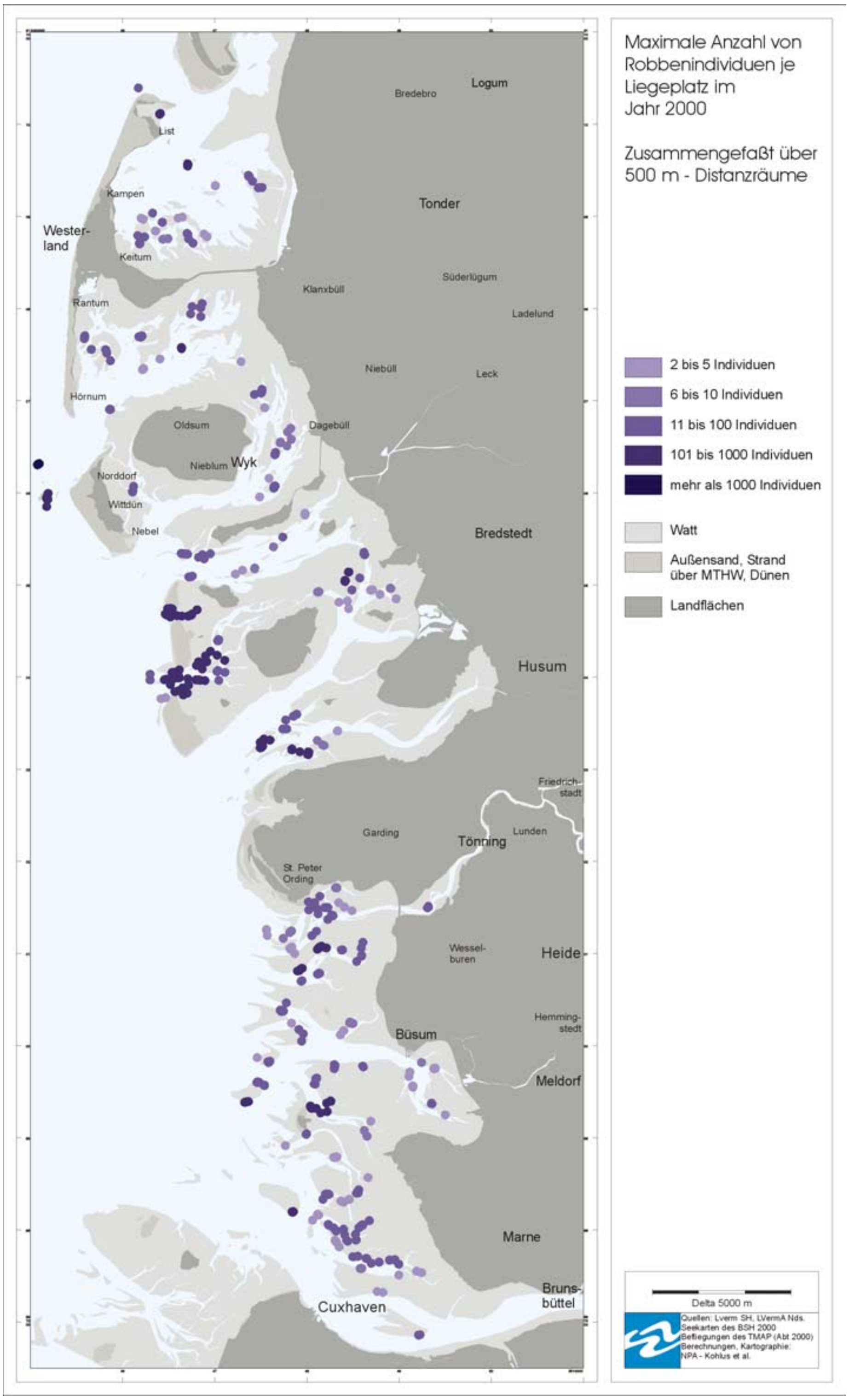

Figure III-43: **Location of harbour seal haul out spots in the Wadden Sea of Schleswig-Holstein as well as size of the observed groups in 2001. (The investigation on the populations of seals were carried out under the Trilateral Monitoring and Assessment Programme (TMAP) on behalf of the Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer).**

Activity range

The activity range of harbour seals can be determined using satellite telemetry. Regular logging of harbour seals in the region of Schleswig Holstein (Lorenzenplate between Süderoogsand and Eiderstedt, see Figure III-44) has been carried out since 1997. A first analysis of the data has been published by Orthmann (2000). It shows that the animals spend up to several days foraging in the open North Sea and traverse distance of up to 100 km from their resting sites on the sandbanks. Detailed studies are, however, still required (see chapter III-8: „research needs").

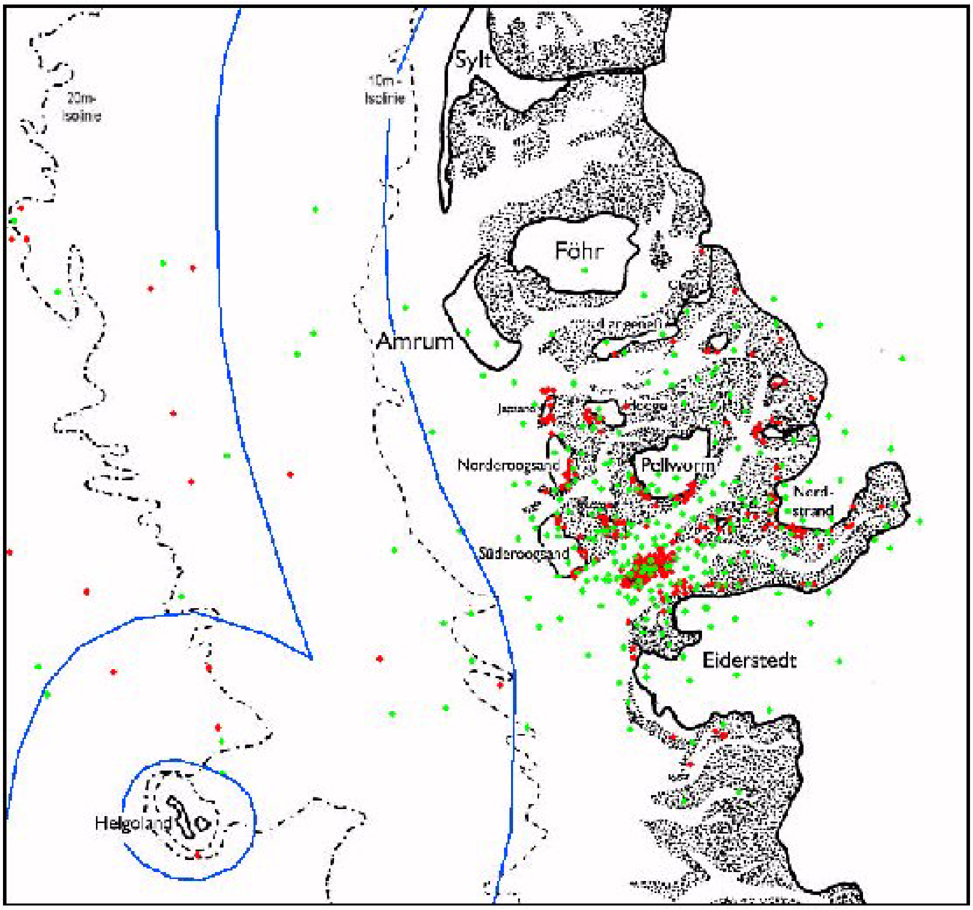

Fig III-44: **Distribution of harbour seal satellite positions of in the "Nationalpark Schleswig-Holsteinisches Wattenmeer" (Orthmann 2000). Accuracy of positioning: red dots, relatively high accuracy, green dots: low accuracy.**

Further investigations on the distribution and habitat utilization are currently being carried out in Denmark (Tougaard, pers. comm.). The investigations are based on telemetric studies and are required for assessments on the effects of offshore wind turbines on seals. Preliminary results indicate that the seals migrate continuously between their resting sites in the Danish Wadden Sea area towards the Northwest and back. The animals appear to have a strong homing instinct with regard to the resting sites as well as the foraging areas.

Acoustic sensitivity

The acoustic sensitivity of harbour seals was studied under water and on land since these semi aquatic animals obviously have – besides other sensory modes – a well developed acoustic perception to enable intra specific communication as well as perception of enemies and prey organisms both in and out of the water.

Møhl (1968) found reactions by seals to acoustic signals between 1 kHz and 180 kHz with the highest sensitivity at 32 kHz. The acoustic sensitivity of the tested animal at 64 kHz was found to be 43-70 dB above the best value. The acoustic perception in air ranged from 1-22,5 kHz, with a sensitivity of 16 dB per 20 µPa at 11,25 kHz. The sensitivity in air recorded for a seal by Terhune (1991) reached an acoustic threshold of 70 dB per 20 µPa at 0,1 kHz. This value dropped to 35 dB per 20 µPa at 4 kHz and increased to 45 dB per 20 µPa at 16 kHz. Kastak & Schusterman (1998) in a similar study found similar values although they used 75 Hz and 6,4 kHz. The sensitivity of this animal in air was between 65,4 dB per 20 µPa at 75 Hz and 19,2 dB per 20 µPa at 6,4 kHz. Under water the sensitivity of the same animal was 101,9 dB re 1 µPa at 75 Hz and 62,8 dB re 1 µPa at 6,4 kHz.

Grey seal - *Halichoerus grypus* (Fabricius, 1791)

In contrast to harbour seals, grey seals have a distinctive sexual dimorphism. Males can attain a length of over 200 cm and a weight of 230 kg, whereas females only grow to 180 cm and up to 154 kg (Anderson 1992). The sexes can also be differentiated by the shape of the head profile. The mail has a dome shaped profile, whereas the female is straight.

Large populations of grey seals are found on the British Isles, Iceland, the Faeroe Islands and the Norwegian coast. They are also found in the North Eastern region of the Baltic Sea. In the German region of the North Sea there are two breeding colonies: One on Helgoland and one on the "Jungnamensand" at Amrum.
These two colonies comprise about 200 adults and probably belong to the British population. There has been no grey seal colony in the Baltic since the intensive hunting in the first half of the 20th century. Thus the grey seal is regarded as "threatened by extinction" (Benke & Heidemann 1995, Benke et al. 1996) and is placed under protection by the „Convention on the Conservation of Migratory Species of Wild Animals“ (CMS, „Bonn Convention“). Grey seals are reared during the winter months (December to February). Juveniles are weaned after an average 4 weeks and leave the resting sites 2 to 3 weeks later or after they have moulted their "lanugo".

Acoustic sensitivity

In contrast to the harbour seal there is little audiometric information on acoustic sensitivity available on grey seals (Bonner 1981). The highest acoustic sensitivity in air was found to be at 4 kHz; above 60 kHz the sensitivity is lower, but could still be detected at 150 kHz.

Acoustic impacts on marine mammals

Potential conflicts

The following impacts on marine mammals are expected to take effect in connection with the immission of sound and vibration during the construction and operation of offshore wind turbines:

- Consequences for the food availability
- Interference with or disruption of important behaviours
- Loss of habitat due to short or long-term displacement
- Acoustic masking (e.g. of communication signals)
- Changes in reproductive success (due to stress and continuous disturbance)
- Impairment by sound immission (e.g. temporal impairment of acoustic sensitivity)
- Injury from sound immission (e.g. permanent impairment of acoustic sensitivity)

Potential effects

The direct effects on marine mammals may be either impairment (physiological i.e. metabolic as well as behavioural effects) or injury (physical i.e. effects on the body). The “masking” of acoustic signals is regarded as an indirect sensory physiological effect.

Physiological Effects

Amongst the likely physiological effects of acoustic signals on marine mammals, are a change in heart rate (partially correlated with increased metabolism and stress), blood pressure, endocrine regulation as well as effects on the reproductive capacity (Richardson 1995). Teilmann et al. (2000) investigated the heart rate of harbour porpoises exposed to sounds produced by an acoustic deterrent („Pinger“). Sounds between 100-140 kHz and a source volume of 153 dB re 1 µPa caused strong Bradycardia (Reduction in heart frequency). However, the animals rapidly habituated. Up to now such effects were only known from investigations on terrestrial mammals and the results are not automatically transferable to marine mammals. However, due to the physiological similarity of marine and terrestrial mammals, qualitative observations on terrestrial animals may also apply to the marine mammals. Possible habituation, sensitisation as well as long-term effects differ considerably between mammals. Thus due to a lack of information, they cannot be assessed in marine mammals.

It is plausible that impulse like immission may produce gas bubbles in the vessels or increase already existing bubbles in affected animals ("rectified diffusion", see Houser et al. 2001). This effect, which may result in an embolism, has up to now not been studied in marine mammals.

Behavioural effects

It is difficult to carry out objective observations on behavioural reactions in marine mammals. The reason being that reactions expected of wild animals cannot be reproduced in captivity. It cannot be excluded, that reactions observed in captivity are not the result of acoustic impulse but that it was induced by an endogenous or exogenous stimulus.

In addition, it is not possible to conclude that an animal is impaired simply because it is capable of perceiving a sound of a particular intensity.

It is, however, possible to document observed temporal and spatial reactions to acoustic signals of free-living animals and to statistically verify significant changes in the behaviour of such animals.

Current observations of behavioural reaction to disturbances by marine mammals have been that animals have disrupted particular behaviour such as feeding, resting and social interaction as well as increased alertness and avoidance. The different reactions may differ considerably in intensity and duration. The sensitivity may be inter as well as intra specific and even be dependant on individual motivation of the animals (e.g. Mother-calf pairs versus vs. hunting individual) (Richardson & Würsig 1997).

Toothed whales

Information on the behavioural response of toothed whales is available for sperm whales (*Physeter macrocephalus*), common dolphins (*Delphinus delphis*), harbour porpoises (*Phocoena phocoena*), pilot whales (*Globicephala spp.*), white-beaked dolphin (*Lagenorhynchus albirostris*), Killer whale (*Orcinus orca*) and Atlantic white-sided dolphin (*Lagenorhynchus acutus*).

These studies deal with the distribution of the species in the area of investigation or with the changes in the active acoustic behaviour in response to seismic surveys. Indirect conclusions regarding the behaviour of whales have been drawn in connection with the (mass-) stranding of whales.
No information is available on the effects of seismic surveys on the distribution within a specific area, of harbour porpoises (Gordon et al. 1998). Goold (1996), however, did observe such effects on the abundance of common dolphins. The studies by Polacheck & Thorpe (1990) did reveal avoidance reactions in harbour porpoises in the presence of shipping noises.

Orcas were displaced from their home range by acoustic deterrents deployed to drive away seals (Morton & Symonds 2002).

In the Gulf of Mexico, sperm whales showed avoidance reactions (leaving the area) to seismic surveys up to 50km away from the source (Mate et al. 1994). Bowles et al. (1994) during a study on sperm whales in the Indian Ocean, found that they reduced their acoustic activity in the presence of audible seismic impulses produced 300 km away. Rankin & Evans (1998), however, did not detect any changes in behaviour of sperm whales in connection with seismic surveys. Swift (1998) made similar observations.
On the other hand seismic surveys did appear to have a negative effect on the distribution of Atlantic white-sided dolphin and white-beaked dolphin. Lower numbers were recorded from the ship, during the survey than during the inactive phases. However, pilot whales displayed the exact opposite behaviour during these investigations. These animals were observed more often during seismic activity than during the inactive phase. (STONE 1998).

A total of 13 Curvier's Beaked Whales (*Ziphius cavirostris*) were stranded in the Gulf of Kyparissiakos, Greece between the 12th and 16th June 1996. Due to the timely coincidence of the strandings with seismic surveys by the vessel NRV Alliance, the strandings were attributed to the surveys (Frantzis 1998). However, a subsequent autopsy on the animals by the SACLANTCEN Undersea Research Centre, La Spezia, Italy, did not reveal a definite cause. A possible panic reaction induced by the acoustic signals (low frequency: 450-700Hz; mid frequency: 2,8-3,3 kHz / Signal duration: 4 sec. / 228dB per 1 µPa) was considered to be a likely consequence of the sound exposure (D'Amico 1998). A similar scenario was (intensive sound signals from a MFAS) considered to be the cause of mass strandings of 17 whales: Curvier's Beaked Whales, Blainville's Beaked whales. Minke whales and a spotted dolphin on the Bahamas (15. /16.03.2000). The cause of the strandings could only be determined for the beaked whales (Cuvier's beaked whales, *Ziphius cavirostris* and Blainville's beaked whales, *Mesoplodon densirostris*). It has to be concluded that an acoustic event resulted in the stranding and subsequent death of the animals. It was attributed to the passing of a ships convoy of the U.S. Navy, which was using mid-frequency sonars whilst other sound sources could be excluded. The sound sources which had a frequency of 2,6 and 3,3 kHz and a source sound pressure of ~235 dB per 1 µPa were therefore considered to be the only likely cause of the strandings (Evans und England, 2001).

Baleen whales

Distinct behavioural response was observed in migrating Grey Whales (*Eschrichtius robustus*) along the Californian coast by Malme et al. (1983, 1984). They found that the Whales reacted to a sound pressure of >160 dB re 1 µPa by increasing breathing frequency, slowing down swimming and avoidance of the sound source. It was interesting to observe, that the sensory threshold of the reaction in the whales increased by ~50 dB relative to other continuous ambient sounds of the same intensity (Richardson 1995) (a similar elevated sensitivity with regard to continuous subjection sound was also observed in humans)

Bowhead Whales (*Balaena mysticetus*) showed behavioural reactions after they were subjected to seismic impulses of 142-157 dB re 1 µPa under controlled conditions; avoidance reactions were documented at impulse intensities of 152-178 dB re 1 µPa (Richardson et al. 1986, Ljungblad et al. 1988). The reactions such as rapid swimming away from the source sometimes continued for as long as an hour. It appears that this whales species generally displays distinct reactions up to a distance of 6 to 8 km or even greater from the survey ship (Richardson 1995). Whereas the is no similar information for Humpback Whales (*Megaptera novaeangliae*) it was shown that Finn whales and Blue Whales apparently do not react acoustically to seismic activity (McDonald et al. 1993). However, no information is available on the sound source or received sound pressure.

The behavioural response of Humpback Whales to a signal of 75 Hz and sound pressure levels of 98-109 dB re 1 µPa was investigated by Frankel and Clark (2000). The animals did not show any reaction, with the exception of the fact that their diving behaviour appeared to have changed. A prolonged acoustic activity was recorded in the animals after subjection to low frequency sonar by the US Navy (Miller et al. 2000). Behavioural responses were also observed in baleen whales in connection with sonar signals (Maybaum 1990, 1993). Watkins (1981b) discovered that Humpbacks Finn and the Right whale often reacted to sonar impulses between 15 Hz und 28 kHz but not above those.

Pinnipedia

Disturbances caused three sea species to leave their resting sites and flee into the water whereas in whales they induced changes in the swimming behaviour and diving parameters (duration, number of breaths, change in direction) (Richardson et al. 1985, 1986; Malme et al. 1988; Richardson & Malme 1993). Long-term effects on marine mammals have, however, not been investigated (Richardson 1995).

The reaction of seals lying on sand banks when a ship approaches is to flee into the water. Physiological as well as behavioural reactions were observed in harbour seals (*Phoca vitulina*) in connection with immission of airgun impulses (Thompson & Evans 1998). The animals displayed avoidance reactions and came out of the water, sometimes immediately after the exposure. A similar reaction was observed by Thompson & Evans (1998) in the grey seal (*Halichoerus grypus*). Avoidance reactions are not always directed away from the sound source. Seals often display evasive actions, which causes them to swim towards the source (e.g. ship) depending on the topographic features (accessibility of the water or deeper water).

Anderson & Hawkins (1978) used various under water sound signals to test the affectivity of deterring harbour and grey seals from approaching fish farms. Apart from testing artificial sounds between 1and 100 Hz, which had no effect, they also used anthropogenic as well as natural noise. The only sounds, which caused a temporary reaction in the harbour seals, were those of the Orcas. A habituation could be observed after a very short time.

Ringed seals (*Phoca hispida*) avoided seismic signals within a radius of 150 m from the source (Harris et al. 2001). However, the seals often approached the ship (112x) to within less than 250 m, the distance prescribed by the Environmental protection agency as minimum distance ships are allowed to approach marine mammals. This meant that the seismic surveys had to be stopped when a seal approached. The sound pressure level received by the animals was in the range of >180 dB re 1 µPa. According to Harris et al. it seems probable that the seals utilize the „Lloyd-Mirror-Effect" (Urick 1983) - a reflection related sound reduction – near the sea surface.

Physical effects

Physical impairment or injury to an organism from sound can occur in different degrees as well as a gradation in severity depending on the strength of the impulse and the sensitivity of the organisms/tissue (resp acoustic organs, see below) (Lehnhardt 1986, Lipscomb 1978, Richardson 1995). The duration of the effects is the critical point in this case (reversible vs. permanent). Mild effects such as pain, dizziness, Tinnitus, injury to the eardrum and a temporary shift in the auditory threshold (see below) are reversible and thus do not have a direct lethal consequence for the affected animals. Major effects are for instance, a permanent shift in the auditory threshold (see below) but need not have immediate lethal consequences. In contrast, strong effects are such as those caused by shock waves e.g. tears in the oval or round window of the inner ear, the breaking or dislocation of ear bones as well as the intrusion of cerebrospinal liquid into the middle ear are permanent and almost inevitably lethal (Ketten 1998a).

With the exception of a shift in the auditory threshold, no other symptoms have been definitely proven in living marine mammals. Severe permanent effects, related to physical injury can only be seen posthumously as long as the condition of the carcass allows clear observations.

Acuesthesia

Hearing is basically defined as the ability to perceive acoustic signals respectively all anatomic structures and physiological processes on which the perception is based. Sound waves are perceived by mammals via the outer ear (consisting of the pinna and the outer ear canal), the middle ear (for air transduction) respectively via vibrations of the skull (bone conduction, especially for high frequencies) to the inner ear (cochlea). The inner ear contains the cochlea. This is the organ that converts sound waves into neural signals. These signals are passed to the brain via the auditory nerve.
Coiling around the inside of the cochlea, the organ of Corti contains the cells responsible for hearing, the hair cells. There are two types of hair cells: inner hair cells and outer hair cells. These cells have stereocilia or "hairs" that stick out. The bottoms of these cells are attached to the basilar membrane, and the stereocilia are in contact with the tectorial membrane. Inside the cochlea, sound waves cause the basilar membrane to vibrate up and down. This creates a shearing force between the basilar membrane and the tectorial membrane, causing the hair cell stereocilia to bend back and forth. This leads to internal changes within the hair cells that create electrical signals. Auditory nerve fibres rest below the hair cells and pass these signals on to the brain. So, the bending of the stereocilia is how hair cells sense sounds. Outer hair cells have a special function within the cochlea. They are shaped cylindrically, like a can, and have stereocilia at the top of the cell, and a nucleus at the bottom. When the stereocilia are bent in response to a sound wave, an electromotile response occurs. This means the cell changes in length. So, with every sound wave, the cell shortens and then elongates. This pushes against the tectoral membrane, selectively amplifying the vibration of the basilar membrane. This allows us to hear very quiet sounds

Toothed whales like all other whales do not possess an auricle. The outer auditory canal is plugged, contrary to the seals, and does not appear to have any specific function. The middle and inner ear have coalesced into a bony complex, the Tympanoperioticum) and are also not situated in the skull, unlike terrestrial mammals. The Tympanoperioticum is contained in the peribular cavity on the side of the skull where it is held by several ligaments. It is embedded in a sponge like mucous. The ears are thus acoustically isolated from the skull and are not excited by the oscillations of the skull bones. The inner ear of seals, however, is embedded in the skull.

The ear bones of marine mammals are relatively large and dense and vary, species specifically, in size shape and the rigidity of their connection to one another. The hammer is connected to the middle ear bone. The moveable stirrup, which is supported by a tense ligament, lies within the oval window of the inner ear. The middle ear, which is probably filled with air (see Ketten 1994), is lined with a thick, strongly fibrous layer (Corpus cavernosum), which is strongly perfused with blood (Wartzok & Ketten 1999). This layer probably serves to regulate the volume during dives.

The cochlea in toothed whales and seals has the same general structure as in terrestrial animals (division into 3 chambers / scalae); however it is much more developed (hypertrophic) and possesses a more intense innervation as well as an exceptionally large basilar membrane The thickness and width of cetacean basilar membranes are closely linked to the unique hearing capacities of adult animals (Wartzok & Ketten 1999). The thickness and width of cetacean basilar membranes are critical for the stiffness and thus oscillatory properties. The stiffer the basilar membrane, the more tuned an ear will be for higher frequency hearing.

Sound transmission

Norris (1968, 1980) found that the lower jaw of toothed whales possessed two extraordinary features. The bones are filled with fat and have an oval region near the back, which is very thin, the so-called panbone. Norris speculated that this mandibular canal channels the sound from the water via the tissue to the auditory bulla since the impedance between the different media is at its lowest here. Investigations of the fat in the jaw bone (wax esters) had an impedance very close to that of seawater (Varanasi & Malins 1971). Electro-physiological and behavioural studies on dolphins revealed a high acoustic sensitivity near the back of the jaw (Brill et al. 1988). A comparable sensitivity was also detected near the auditory canal (not functional) when animals where subjected to sound (Bullock et al. 1968, Popov & Supin 1990). CT- and MRI-observations have served to clarify that in addition to the fat filled mandibulary canals, there are funnel shaped structures in the tissue near the outer auditory canal (Ketten 1994). This tissue is made up of the same fat and also leads to the ears of the toothed whales (Figure III-45, „lateral channel“).

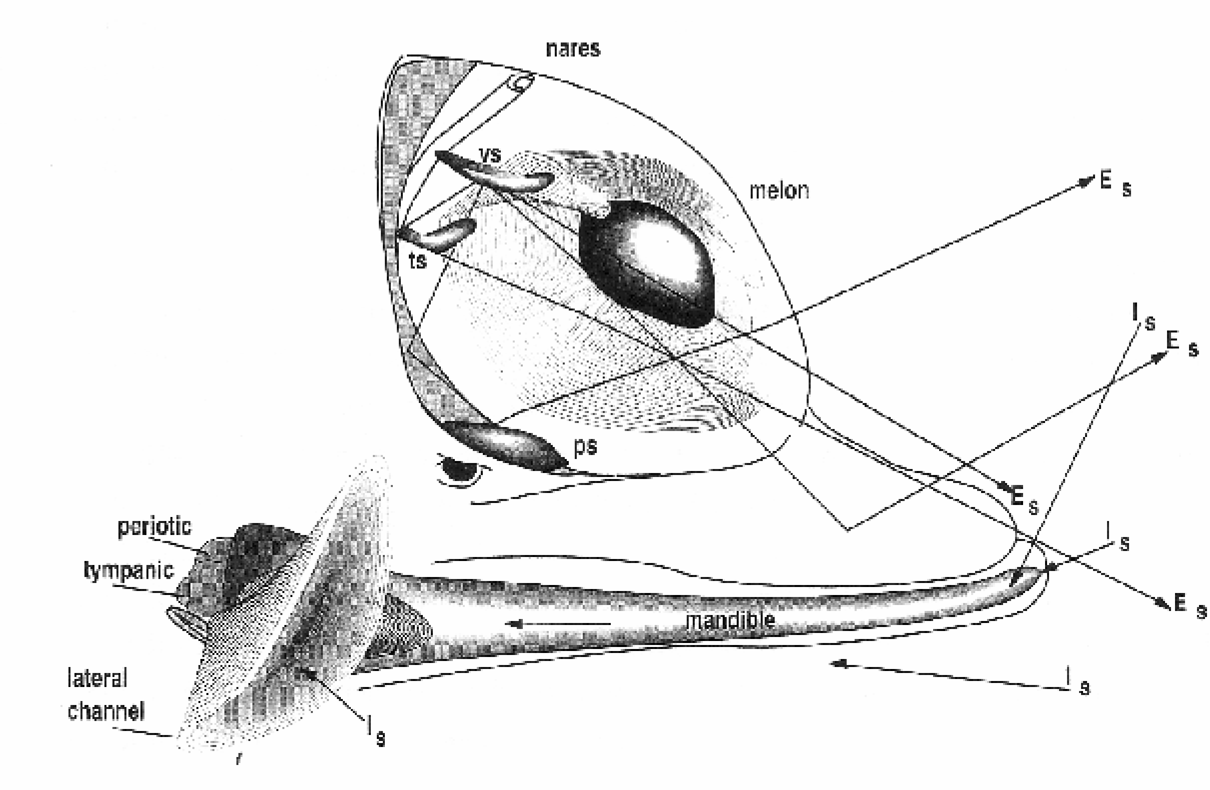

Figure III-45: **Schematic of a dolphin head showing the components involved in the sound production and transmission (transmission and reception) Fat bodies (Melon, lower jaw and lateral channel) (→E: emitted signals, →I: received signals**

In seals the outer auditory canal is functional in air and enables a good auditory capacity. The auditory canal is, however, shut under water. The transmission of sound probably also occurs via fatty tissue near the auditory canal, so that a high acoustic sensitivity under water is guaranteed.

Hearing and temporary threshold shift (TTS)

Fundamental for the assessment of potential dangers of acoustic immission to animals, is the understanding of the acoustic sensitivity and specific features.

The structural auditory elements, acoustic sensitivity as well as physical and physiological effects of excess acoustic pressure have been mainly studied on terrestrial animals (usually small mammals) and humans (see Gisiner 1998). The "functional" auditory range in animals is the frequency range in which sound levels are perceived which do not lie more than 60 dB (re 20 µPa) above the maximum acoustic sensitivity of the animal. Acoustic signals, which lie within the functional auditory range and have a high acoustic intensity, primarily cause a shift in the auditory threshold. The threshold level for this effect lies 80 dB above the auditory threshold in the most sensitive frequency hearing range. Higher intensity acoustic signals generally result in discomfort. It is only when the immission sound level is about 120 dB (for most frequencies) that injury may occur. Acoustic signal frequencies, which lie outside the functional auditory range, require being near the state of discomfort in order to be detected. When frequencies lie outside the range of hearing the signals are only detectable non-auditory means e.g. transmission through bones (Ketten 1998b).

The detection of acoustic signals is further dependant on the duration of the signals. Studies on terrestrial mammals revealed an increase in the auditory threshold when signals had a duration of less than 0,1 to 1 s (Fay 1988). Longer signals did not have the same effect on the auditory threshold.

The knowledge on the auditory system of marine mammals, particularly seal and whales, is still rudimentary. Available data indicate that toothed whales have a functional auditory range of >10

Octaves (compared to 8 Octaves in most other mammals). The highest acoustic sensitivity is 12 kHz in the Orca (*Orcinus orca*) and above 100 kHz in the Boto (*Inia geoffrensis*) or the harbour porpoise (*Phocoena phocoena*). Whereas toothed whales appear to generally have an acute sense of detection in the ultrasound range, the investigated species only have a reduced sensitivity below 200 Hz (Ketten 1998b). Directional hearing has been observed in some small toothed whales (Au & Moore 1984, Andersen 1970), which means that their acoustic perception was not uniform in all directions. Since the intensity of the received ambient noise is inversely proportional to the degree of directional sensitivity, they are capable of filtering signals out of very noisy surrounding (Au 1993). The detailed studies by Au & Moore (1984) bottlenose dolphins (Tursiops truncatus) have shown the degree of directionality increases with increasing frequency (20+ dB at >100 kHz).

(Noise-Induced Hearing Loss, NIHL)

The Threshold Shift (TS) is the increase in the auditory threshold as a result of intensive subjection to sound (Richardson 1995). This effect can only be investigated if the normal acoustic sensitivity is known. If the effect is reversible (within 30 days), the shift in the auditory threshold is temporary (Temporary Threshold Shift, TTS). The recovery of the hearing is continuous ("monotonous"). If the TTS persists beyond 30 days then the shift is considered to be permanent and irreversible (e.g. asymptotic) and not continuous (Permanent Threshold Shift, PTS).
Measurements of auditory thresholds can be carried out with the aid of electrophysiological dissipation of nerve impulses in reaction to different acoustic test signals or by training an animal to react to different acoustic test signals. The latter requires that the test animal cooperate during the tests, whereas the former can be carried out on non-cooperative animals

Both the TTS and PTS have been internationally recognised as clinical criteria of auditory damage. The definition of international danger criteria in industry (Damage Risk Criteria, DRC) is amongst others based on the TS values, which have been obtained from laboratory studies on small mammals under acoustic exposure (e.g. Lehnhardt 1986). It is currently accepted that both the intensity of sound as well as the duration are determining factors in the threshold shift. Thus, TS can be induced by persistent low intensity sound exposure or short-term high intensity exposure (whereby the health of the ears as well as the consequences of previous exposure need to be taken into account). The critical threshold for acoustic exposure in an industrial working environment 80-90 dB per 20 µPa increases by 3-5 dB during a concurrent halving (continuous) acoustic exposure (Lehnhardt 1986).

The degree of a temporary or permanent threshold shift is directly dependant on the extent of damage to sensory cells of the inner ear. The mechanical energy of the pressure impulses is converted to electrical neural impulses by the inner and outer hair cells on the basilar membrane. This process can be interrupted by the metabolic overloading of the sensory cells, the mechanical straining of the connection between the hair cell stereocilia due to a disruption of the synaptic contact in the cells. The relationships, however, have not yet been finally clarified. The degree of a threshold shift is directly correlated to the injury of the inner and outer sensory cells (Liberman 1987).

The transition from a temporary to a permanent shift in the threshold (TTS → PTS) appears to be approx. 15-20 dB above the threshold of a beginning shift on the threshold (TS) (Ahroon et al. 1996). The study by Ahroon et al. (1996) also showed that the impact of an acoustic signal on the auditive system is noticeably enhanced by repetitive exposure. A threshold shift is furthermore dependant on frequency, since not all frequencies have the same effect on TTS or PTS at the same sound pressure High frequency signals cause a threshold shift to larger frequency range of low frequency signals (Gisiner 1998). A comparable effect is observed with an increasing intensity of sound impulses. From a certain sound pressure onwards the effects of exposure to sound (TTS or PTS) extend over an increasingly larger area of the basilar membranes. The individual characteristics of the acoustic sensitivity become increasingly irrelevant.

A further effect which found during studies on terrestrial animals, was that an extremely rapid pressure increase of shock waves will result in a permanent hearing loss in a broader frequency range at low intensity compared to signals which have a slower increase in pressure during the initial pressure phase (Lipscomb 1978, Lehnhardt 1986, Liberman 1987).

The following general statements can be made with regard to sound induced auditory failure: Injury risk

- The pain threshold is higher than the injury threshold
- The degree of damage is correlated to the energy of the sound signal
- Signal impulses are less damaging than continuous signals
- High frequency signals are more dangerous than low frequency signals
- Narrow band signals are more dangerous than broad band signals
- There is a high variability in the sensitivity to sound

Origin, recovery and pattern of impairment

- Auditory loss increases asymptotically with under continuous exposure to sound; it increases rapidly above a critical intensity level
- The acoustic sensitivity may recover (by definition within 1 month after exposure)
- Hearing impairment is dependant on the frequency range of the sound signals: sound signals of low frequency band width will generally result in hearing loss in that frequency range
- Tone signals result in a positive shift by half an octave
- Broad band signals cause impairment of the mid frequency range
- Increasing sound intensity will affect adjacent frequency ranges negatively

Injury to the eardrum due to a temporary or permanent shift in the auditory threshold

- The eardrum is the most sensitive organ to sound
- Destruction of receptor cells (Hair cells)) results in the loss of hearing in specific frequencies
- Impairment of neural cells increases the auditory threshold
- Secondary loss of neural cells

Masking

The expansion of the masking zone is very variable and depends on the parameters, which affect the intensity of the ambient noise and signals. A noise can generally only be detected if the intensity is above the ambient noise level. Acoustic signals of low intensity will easily be masked by a slight elevation in the ambient noise level whereas sound intensive signals will only be masked close to other intensive sound sources.

The difference in intensity between a barely audible signal in relation to sound pressure of the ambient noise is termed the „critical ratio" (CR). An acoustic signal can only mask another signal when both fall within the same frequency range. However, it is possible for an intensive signal in a low frequency range to be masked by a less intensive ambient noise if the integrated sound energy of the ambient noise has a higher energy over a specific frequency range, than the signal. The threshold for this relationship of the frequency bandwidths is termed the critical bandwidth (CB). CR and CB are important acoustic parameters with regard to masking.

An increase in the sound level of ambient noise reduces the distance over which the signal is detected. Changes in the general sound level by 10-20 dB can lead to strong limitations of the range, for instance of marine mammal communication signals (Richardson 1995). Species, which communicate over large distances e.g. Baleen whales, will be severely affected by these factors, since their long distance signals differ only marginally from ambient sound levels.

Some marine mammals, however, have mechanisms to reduce masking effects. Au et al. (1974) documented elevated sound levels in the echolocation signals of Bottlenose dolphins (*Tursiops truncatus*) in correlation with higher ambient noise levels (see also Au 1993). Another mechanism appears to be a change in frequencies. Directional hearing (see below: Hearing and shift in auditory threshold), which has only been shown for a few species so far, is another property of the auditory system, which reduces masking.

As mentioned previously, the direct consequences of masking for animals are the reduced perception of biologically relevant acoustic signals. Of particular significance is the masking of communication signals. If signals which have a social relevance cannot be heard by conspecifics or are only audible within a close range, this could in the long term have a negative effect on reproductive behaviour. If the detection of prey animals is restricted by masking, this will have possible consequences on the productivity and distribution, which may result in animals leaving the area. The most dramatic consequence of acoustic masking would be that the animals are no longer able to detect the signals of predators.

Marine mammal sounds

Marine mammals produce multiple acoustic signals which all have different physical properties. Their sounds often have a particular behavioural context such as orientation, foraging and communication (Watkins 1981a, Clark 1983, Hoelzel & Osborne 1986). Many species have a large sound repertoire, which may vary individually or seasonally. The characteristics of the sound production are species and sex specific.

Sound expression has an important function in both whales and seals where it used for spatial and temporal co-ordination of reproduction. Sounds are also important in marine mammals for communication between mother and offspring, both under water and in air. Young seals keep in contact with parents by calling; the sounds have a frequency of ~350 Hz and are produced both on land and under water (Ralls et al. 1995).

Harbour porpoises do not produce songs or whistling sounds like other whale species do. It is assumed, however, that the echolocation signals emitted by the animals are used for communication, perhaps only for passive location of conspecifics (e.g. amongst small groups or between mother and calf).

If the emission of acoustic signals has a social relevance, the efficacy of perception is dependant on the other members of the social group (school/mother-calf pair). The same applies to all other passively utilized sounds (e.g. Signals of other species, enemies). In the case of signals emitted by the animals to obtain information on their surroundings, the efficacy will depend on the intensity of received signals (i.e. reflection).

The acoustic characteristics of harbour porpoises, harbour seals and grey seals are listed in Tables III-4 and III-5.

Table III-4: Characteristics of under water sounds by Harbour Porpoises (Wartzok & Ketten 1999)

Species	Signal type	Frequency range (kHz)	Dominant frequency (kHz	Sound pressure level (dB re 1 µPa in 1 m)	Source (Citations not in reference list)
Harbour porpoise	Clicks	2	-	100	Busnel & Dziedzic 1966a; Schevill et al. 1969
	Impulse	100-160	110-150	-	Møhl & Andersen 1973
	Clicks		110-150	135-177	Busnel et al. 1965; Møhl & Andersen 1973; Kamminga & Wiersma 1981; Akamatsu et al. 1994

Table III-5: Characteristics of under water sounds by Harbour Seals and Grey Seals (Richardson et al. 1995, Wartzok & Ketten 1999)

Species	Signal type	Frequency range (kHz)	Dominant Frequency (kHz)	Sound pressure level (dB re 1 µPa in 1 m)	Source (Citations not in reference list)
Harbour Seal	social sounds	0,5-3,5	-	-	Beier & Wartzok 1979
	clicks	8-150	12-40	-	Schevill et al. 1963, Cummings & Fish 1971, Renouf et al. 1980, Noseworthy et al. 1989
	roaring	0,4-4	0,4-0,8	-	Hanggi and Schusterman 1992, 1994
	growling, grunting, sighing	<0,1-0,4	<0,1-0,25	-	Hanggi and Schusterman 1992, 1994
	squealing	0,7-4	0,7-2	-	Hanggi and Schusterman 1992, 1994
	calling	350 Hz			Ralls et al. 1995
Grey Seal	clicks, fizzling	0-30; 0-40	-	-	Schevill et al. 1963, Oliver 1978
	6 call types	0,1-5	0,1-3	-	Asselin et al. 1993
	knocking	Up to 16	Up to 10	-	Asselin et al. 1993

Acoustic sensitivity of marine mammals

The acoustic sensitivity is conventionally presented as an audiogram, a sensitivity curve that is determined by behavioural as well as electrophysiological measurements. Mammals normally have a U-shaped audiogram (see figure III-46). The sensitivity decreases on both sides of the relatively narrow frequency band of highest sensitivity.

Audiograms are currently available for 11 marine mammals (small toothed whales and seals) (Richardson 1995, Ketten 1998b). They all have the U-Form typical of mammals. There are no data available for Baleen whales.

Most of the toothed whales investigated so far were dolphins. They all have a broad functional auditory range with the highest acoustic sensitivity between 40 and 80 kHz (Au 1993). No data are available for the large, deep diving toothed whales such as the sperm whale or beaked whales.

The acoustic sensitivity of seals, under water is not typical of mammals since the low-frequency part of the audiogram is relatively flat (Fay 1988, Yost 1994). The highest sensitivity of tested earless seals was between 10 and 30 kHz with a functional upper limit of 60 kHz. The audiograms of seals obtained in air, have the typical U-form and the highest sensitivity 3 and 10 kHz.

The functional auditory range of two eared seal species tested under water is also U-shaped up to 35 to 40 kHz and peak sensitivity between 15 and 30 kHz. Their acoustic sensitivity of eared seals in air is shifted to the low frequency range, similarly to the earless seals. They attain the peak values at <10 kHz (upper functional limit: 25 kHz).

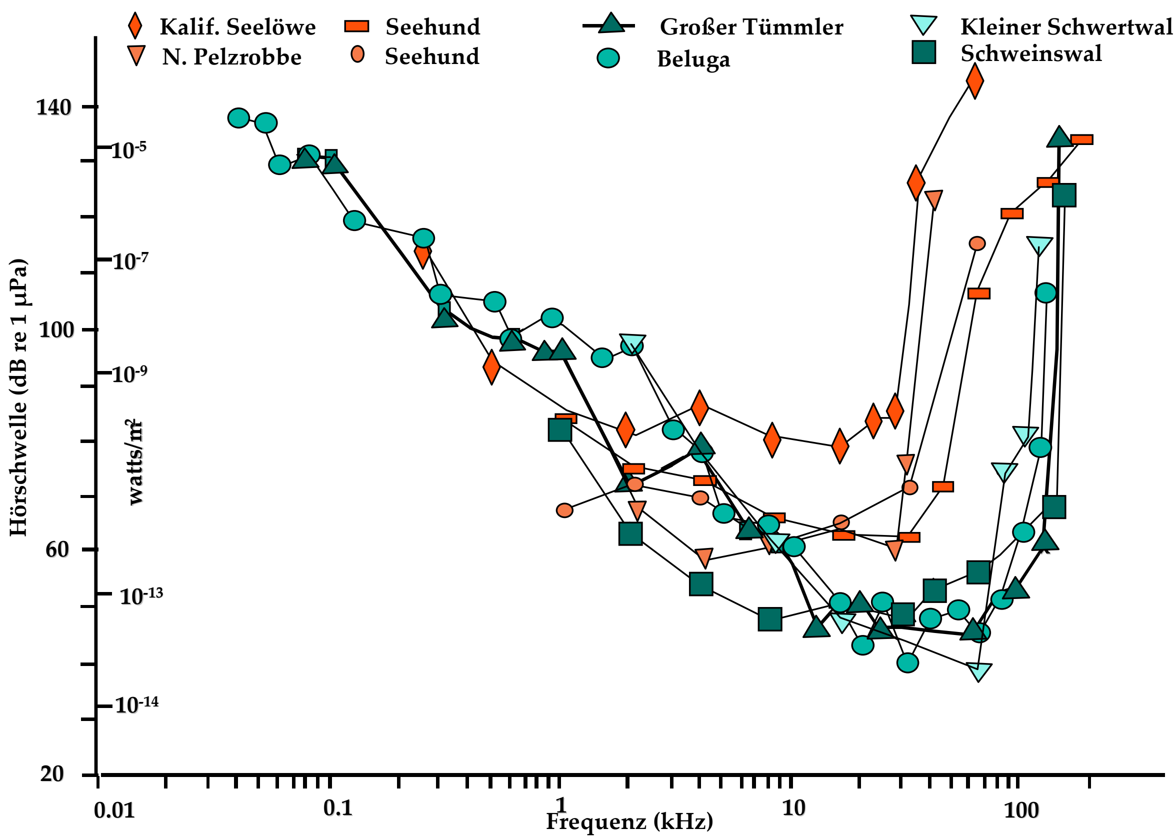

Figure III-46: **Audiograms of different marine mammals. The measured auditory threshold [dB per 1 µPa] is plotted against frequency [kHz]. (Source: Dr. D.R. Ketten)**

TTS-Experiments

Several TTS-experiments have been carried out on different whale and seal species. The results represent the currently available database for the derivation of immission threshold values for marine mammals.

The TTS studies are behavioural investigations on various marine mammal species. The aim of the investigations was to determine the effects of different acoustic signals on the hearing of the animals. The methods applied ensured that the animals were not impaired.

Initially the absolute acoustic sensitivity of the animals was measured. Subsequently the animals were exposed to a selected acoustic signal (S1) of which the sound pressure level was gradually increased during the course of the study. After each exposure the animals were subjected to a test tone (S2) and the (temporary) elevation of their acoustic sensitivity tested (TTS).

The TTS measurements were only carried out at specific frequencies, depending on the applied S1 signal. The behavioural reaction of the animals was also documented.

Since the measurements were carried out in the presence of an ambient sound level of 90 dB re 1 µPa, the resulting shift of the auditory threshold are masked effects (MTTS).

Whales

1.) Ridgway* et al. *(1997)

This TTS-Study was the first to investigate the effects of acoustic signals on the acoustic sensitivity of small whales. The authors found that belugas (*Delphinapterus leucas*) and bottlenose dolphins (*Tursiops truncatus*) showed a temporary increase of the acoustic threshold by 6 dB for three tested tonal frequencies (Signal duration 250ms) and the following sound levels:

- 194 - 201 dB $_{rms}$ re 1 µPa at 3 kHz
- 193 - 196 dB $_{rms}$ re 1 µPa at 20 kHz
- 192 - 194 dB dB $_{rms}$ re 1 µPa at 75 kHz

The masking ambient sound level during the experiment was ~90 dB per dB_{p-p} re 1 µPa. In this case it was also a “masked TTS” (MTTS).

2.) Schlundt* et al. *(2000)

This study was a continuation of the Ridgway et al. (1997) study. The number of tested frequencies was increased. The stimuli selected were again tones of 1 s duration and animals tested, bottlenose dolphins and belugas. The tested frequencies are listed below:

Test stimuli [primary stimulus (figures in brackets denote additional acoustic sensitivity measurements since a shift in TTS by an octave was expected)]:

- 0.4 (0.6) kHz
- 3 (4.5 and 6) kHz
- 10 (15 and 20) kHz
- 20 (30 and 40) kHz
- 75 (85 and 100) kHz

The sound pressure level of the S1-signals was between 141 and 201 dB re 1 µPa, and the masking noise level at ~90 dB per dB_{p-p} re 1 µPa. The results of this experiment are shown in Table III-6.

Table III-6: Stimulus frequencies, during which MTTS was initiated; also shown are the animals involved (T tru = Bottlenose dolphin, D leu = Beluga), the sound pressure level (SPL), the degree of MTTS as well as the frequency at which MTTS was measured.

#	Stimulus-frequency	Species	SPL	MTTS	MTTS-Frequency
	kHz		dB	dB	kHz
1	20	T tru	193	8	40
2	75	T tru	182	8	100
3	3	T tru	194	7	3
4	3	T tru	194	16	4.5
5	3	T tru	194	17	6
6	3	D leu	195	12	4.5
7	10	T tru	192	7	15
8	10	D leu	192	7	20
9	20	D leu	197	8	40
10	20	D leu	200	6	40
11	20	D leu	201	10	30
12	20	D leu	200	12	20
13	20	T tru	196	6	30

Aversive behavioural responses of the dolphins were observed for a sound pressure level above178 dB per 1 µPa, and the belugas above 180 dB per 1 µPa.

3.) Au et al. *(1999)*

In this experiment bottlenose dolphins (*Tursiops truncatus*) were subjected to a continuous 5 to 10 kHz test stimulus for 30 minutes within an experimental period of 50 minutes. The measured TTS frequency was about 7,5 kHz. Whereas no TTS was induced at 171 dB per 1 µPa (= 205 dB per 1 μPa^2*s total energy flux), a TTS did appear at 179 dB per 1 µPa (= 213 dB per 1 μPa^2*s total energy flux or 1330 J/m^2).

4.) Finneran et al. *2000*

These authors continued with the studies of Ridgway et al. (1997) and Schlundt et al. (2000). They tested the effects of simulated explosions on the acoustic sensitivity of bottlenose dolphins and a beluga. In contrast to the previous studies, the S1 stimulus was much shorter than the previously used 1s tones.

The sound level source to which the animals were exposed varied between 170 and 221 dB per 1 µPa. The transferred energy of the impulses lay between –52 to –3 dB per 1 $\mu Pa^2 \cdot s$, and a duration of 5,1 to 13 ms. The sound generator reached its limit at 221 dB per 1 µPa with the result that no higher intensities could be tested with this source.

None of the impulse levels caused a shift in the threshold. The deviation in acoustic sensitivity values after exposure in 95% of the cases, lay below 4 dB and was thus below the previously determined TTS criterion of 6 dB. Only 3,2 % of the auditory threshold values was between 4 and 5,6 dB after exposure.

However, the animals did react aversively in many cases, which have to be taken into account in further assessments on the effects of sound immission on marine mammals. Similar reactions have been documented for comparable studies. The reactions occurred at 196 dB per 1 µPa as well as at 209 dB per 1 µPa in dolphins and at 220 dB per 1 µPa in a Beluga.

5.) Finneran **et al.** *2002*

More intensive S1 sound pressure levels as those used by Finneran et al. (2000) were obtained in this investigation by using a „Water gun" (Seismic instrument). The acoustic effect was tested on a Bottlenose dolphin and a Beluga. The acoustic characteristics of the tested stimuli are listed in tables III-7 and III-8.

Table III-7: Acoustic characteristics of (water gun) sound signals for the Beluga. Values in brackets denote standard deviation for linear units (e.g. kPa) or the maximum ± deviation of dB-values. [p_p = peak pressure, $SPL_{p\text{-}p}$ = sound pressure level ("peak to peak"), E_T = total energy flux, τ = duration]

Level	$SPL_{p\text{-}p}$ [dB re 1 µPa]	E_T [dB re 1 µPa^2*s]	τ [ms]
M1	202	171	37 (2,8)
M2	208	174	24 (4,0)
M3	211	176	15 (0,5)
M4	215	178	15 (1,8)
M5	217	181	15 (0,6)
M6	221	182	14 (1,9)
M7	221	183	14 (1,2)
M8	224	184	13 (1,9)
M9	224	184	13 (1,4)
M10	225	185	11 (1,3)
M11	226	186	6,3 (2,1)
M12	223	183	13 (2,1)
M13	228	187	11 (3,8)

Table III-8: Acoustic characteristics of (water gun) sound signals for the Bottlenose dolphin. Values in brackets denote standard deviation for linear units (e.g. kPa) or the maximum ± deviation of dB-values

Level	$SPL_{p\text{-}p}$ [dB re 1 µPa]	E_T [dB re 1 µPa^2*s]	τ [ms]
B1	215	177	14 (0,9)
B2	225	185	11 (1,5)
B3	229	187	10 (1,4)
B4	228	188	13 (1,7)

The MTTS values determined for the Belugas after exposure as well as the controls (no exposure to sound) varied mainly around ± 4 dB. A degradation of the acoustic sensitivity (MTTS) at 0,4 and 30 kHz around 7 dB was measured immediately after subjection to a sound pressure level of 226 $dB_{p\text{-}p}$ re 1 µPa / 186 dB re 1 µPa^2*s total energy flux and a signal duration of 6,3 ms (Level M11). No aversive reactions of the animals were observed.

In the subsequent experiment (M12) the sound intensity was reduced to ensure that the measured values would not include a behavioural artefact (behavioural method) i.e. a false or no "answer" from the test animal. The resulting MTTS values were still within the normal variation of ±4 dB. The sound exposure at level M13 was meant to be a repetition of M11. However, since the emission of this source cannot be accurately selected, the actual test stimulus had a maximum sound pressure level of 228 dB_{p-p} re 1 µPa in / 187 dB re 1 μPa^2*s total energy flux and a duration of 11 ms. The MTTS value measured shortly afterwards was 5 dB.

The intensive exposure of the bottlenose dolphin was done at a source sound level of 228 dB_{p-p} re 1 µPa at / 188 dB re 1 μPa^2*s absolute energy flux and a duration of 13 ms. No MTTS was observed in this animal

Seals

6.) Kastak & Schusterman (1996)

During an audiometric study on a seal in air, the animal was inadvertently repeatedly exposed to an uncontrolled broadband sound source (at least 20 Hz – 20 kHz) for 6 to 7 hours on 6 consecutive days. The sounds had a sound pressure level of 90-105 dB per 20 µPa. They resulted in a temporary shift in the auditory threshold of 8 dB at 100 Hz. After 1 week the animal had retained its normal aural sensitivity.

7.) Kastak* et al. *(1999)

In a TTS study, the authors exposed several seals to an varying broadband sound (spectrum bandwidth of 1 octave) under water for 20 minutes. The sound pressure level was 60 dB above the threshold of mid frequency of the sound. The exposure resulted in a temporary threshold shift of an average 4,8 dB; after 24 hours the sensitivity had returned to the normal initial values.

Individual variability of aural sensitivity

Experience has shown that the individual acoustic sensitivity of the animals may vary considerably. A possible cause are age related changes (presbyacusis), sex specific differences and existing acoustic impairment. The audiograms of investigated animals do not reveal any abnormal values, however, a projection of the measured acoustic sensitivity data onto other individuals of the same species is questionable on the grounds of the high variability encountered and the low number of investigated animals. A projection of the audiograms onto other species is not justifiable.

MTTS vs. TTS

It is plausible that an elevated ambient noise level i.e. masking sounds (Ridgway, Schlundt, Finneran: 90 dB re 1 µPa) may reduce the degree of TTS since the hearing has been preloaded by these sounds. This would mean that hearing is less sensitive and that TTS would only be attained at higher sound pressure levels of the test stimulus. A similar effect was observed in MTTS studies on humans (Parker et al. 1976, Humes 1980) and Chinchillas (Ades et al. 1974). A recently carried out TTS study by Finneran et al. using a very low ambient sound level, showed that a elevated ambient noise level has no influence on the TTS measurements (Finneran, pers. comm.).

Conclusions

The available audiometric data are inadequate to assess possible impacts on marine mammals due to sound emission by offshore WTs, or to define immission limits.

The most important aspects in this context are:

- The measured effects are stimulus specific
- The measured effects are species specific. A comparable TTS study has not yet been carried out for harbour porpoises or grey seals.
- There are no comprehensive audiometric data (audiogram) available for grey seals.

Since the projection of acoustic data on to other stimuli or species is not possible, the available data can only be used qualitatively on the harbour and grey seals as well as the harbour porpoise, with regard to the expected impacts. However, even such a projection is conditional.

Sound immission during the construction of offshore WTs are expected be of high intensity (up to >220 dB re 1 µPa in 1 m), and continue over a longer period (> 1 h) should foundations be rammed. Broadband sounds will be involved of which the high frequency component (>10 kHz) is expected to be audible above the ambient noise, up to >20 km away. The low frequency noise components (e.g. 0,3 kHz = maximum sound pressure level of noise) are expected to be heard even further (50+ km) and above the "loud" ambient noise level of the North Sea, because of the lower attenuation.

The TTS studies on seals only involved the measurement of the effects of continuous noise on the hearing of the animals. No information is available on the effects of impulse like noise. Should seals occur near the construction work it is expected that, particularly due to the high sound pressure levels of ramming, the animals will suffer from at least a temporary shift in the auditory threshold if not a permanent shift and perhaps damage to other tissue. It is not clear what the consequences of hearing impairment would be for seals, since the tactile sense is probably the most important sensory modality in these animals. However, reduced communication ability in an affected animal could result in decrease of reproductive success. In the light of the currently occurring virus epidemic in seals, any additional interference with the animals constitutes a health risk, which could have lethal consequences for the animals.

The likelihood that seals occur near construction activities is increased by the fact that prey may be attracted to the construction platform. This would increase the damage threshold and the curiosity of the animals. There is no effective method of deterring the animals.

The masking of seal sounds appears to be likely, however, it is not possible to quantify this since no data are available on the sound pressure levels and the duration of the sounds. Particularly the likelihood of masking sounds essential for the communication between mother and pup should be taken account of in this context, since the bonding between them is crucial for survival. The masking of such sounds and other seal sound by ramming noise appears likely both within and above water.

It is very likely that construction noise will elicit behavioural responses in harbour seals. However, it is also not possible here to lay down immission threshold values since the reaction threshold is highly context specific and on top of that varies individually.

The triggering of physiological reactions in seals, by construction noise is also possible. However, since here too there is almost no information available, it is impossible to determine threshold values. With regard to physiological long-term consequences of exposure to sound, there too no information is available making a quantitative assessment impossible.

Generally speaking, the harbour seal in the German area of the North and Baltic Seas is particularly threatened because of the increased danger risk due to the seal distemper virus. Any additional strain would have a negative effect on the immune system of the animals and contribute to the weakening of healthy ore already infected animals. Any acute interference with the animals should be avoided at this stage.

Since there are no comprehensive audiometric data (audiogram) on grey seals, it is also not possible to make any reliable statements on the possible consequences of WT sound immission for this species. It is also not possible to use the information on morphological aspects, gathered for harbour seals since relevant data on the hearing of grey seals are nonexistent.

With regard to the masking, behavioural responses and physiological effects, there is a similar a dearth of information on grey seals as there is for harbour seals. This means that as for harbour seals, no concluding statement can be made with regard to the grey seals. Grey seals do not appear to be endangered by the distemper virus which has affected the harbour seal.

A comparison of the available data on TTS studies of toothed whales (figure III-47) reveals a large variability in the peak pressure values, which result in TTS. This means that no single peak value can be used without considering the signal duration as TTS threshold value. The line in the graph, with a slope of 3 dB ("3 dB-exchange rate", NIOSH 1998) is equivalent to an energy equality criterion which is used to depict the relationship between sound pressure level and allowable exposure to sound and its duration. Thus a doubling of the duration of a signal would require a reduction of the sound pressure level of a single or continuous signal by 3 dB to keep the energy constant.

Since very short signals have extremely high sound pressure levels without having a high energy, an additional maximum peak pressure value needs to be introduced in addition to the 3 db- exchange rate (see also Glorig 1988). Total energy flux and pressure should be applied as a combined criterion.

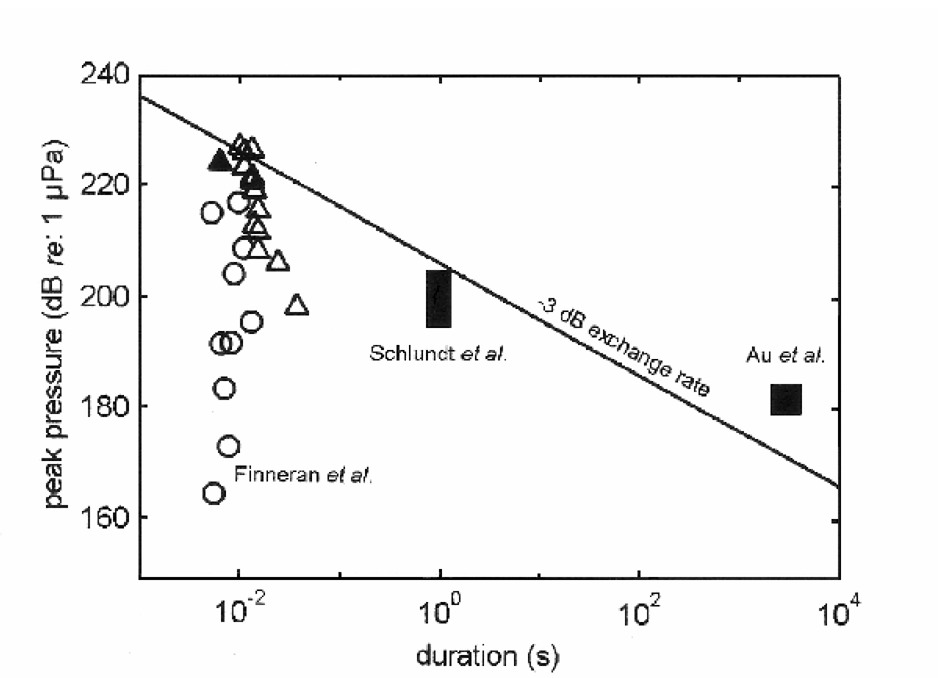

Figure III-47: **Available (M)TTS data for marine mammals (Bottlenose dolphins and Belugas): maximum (SPL) as a function of test impulse duration. Black rectangle: Schlundt et al. (2000) (6-dB or higher MTTS, 1-s test tones, toothed whales); black square: Au et al., (1999) (4.6–4.9 dB TTS, limit frequency range, Pinnipedia); open circles: TTS-study using explosion simulator (Finneran et al. 2000); open triangles: TTS study with water gun– without MTTS, black triangles – with MTTS; line: 3-dB exchange rate.**

Finneran et al. state that a direct projection of these results on other sound stimuli is not possible. Since the TTS threshold is not independent of the frequency and the other acoustic characteristics of the sound stimuli, it is necessary to carry out comparative studies with the appropriate sound immission and animal species, to confirm the general validity of the interactions.

It is expected, that within the immediate proximity of ramming work, sound pressure levels will be so high as to cause a temporary or perhaps permanent shift in the auditory threshold of harbour porpoises. Should the harbour porpoises remain in the vicinity of ramming activities and be exposed to a continuous sound immission, there is a high probability that hearing will be impaired and other tissue damage may occur. The danger zone for a single exposure is probably <100 m. In the case of multiple or repeated exposure, the distance my increase depending on the frequency of immission.

Masking of the harbour porpoise echolocation signals is only expected for the 2 kHz-component of the Harbour porpoise clicks, since the ramming sounds are of low frequency. Should this part of the signals be used for communication, then it can be expected, that construction activities may mask the communication repeatedly for short periods.

It cannot be ruled out that harbour porpoises will seek out the area close to the construction platform during construction work. Anecdotal observations have shown that that these animals are both very inquisitive and timid. The only systematic investigation of the behaviour of harbour porpoises (Thompson et al. 2000) did not reveal any distinct reaction by the animals. As with the seals, it is expected that the behavioural reaction by harbour porpoises varies for the individual and is context specific. Because of the strong bond between mother and calf, such groups may be particularly susceptible to interference during the first months of rearing. Ramming work could result in the panic like escape and thus lead to a possible separation of the calf from its mother and end up fatally.
Physiological reactions are already expected at low sound pressure levels (e.g. >153 dB re 1 μPa) although the projection of the pinger experiments needs to be treated with caution (Teilmann et al. 2000). The long-term consequences of exposure to sound in harbour seals, however, are unknown.

It is currently not possible to determine the effects of infrasound signals produced by ramming, on marine mammals due to a lack of information.

During the **operational phase** the wind turbines will emit continuous noise of relatively low intensity. The broadband noises will be of an increasingly lower frequency with the increasing size of the wind energy turbines (<1 kHz). The emitted frequency spectrum is probably strongly dependant on the type of foundation. The noise will probably be 20-40 dB higher than the ambient noise and will therefore be masked to a large extent within less than100 m, and entirely in <500 m by the ambient noise.

Both harbour Seals and harbour porpoises will be able to detect these low frequency sounds. Due to a better acoustic sensitivity, the Harbour Seals (and possibly Grey Seals) will be able to detect the sounds for a longer distance than harbour porpoises. Reliable quantities conclusions of the range of detection can currently not be drawn since no measurements are available for the type of wind turbine planned for offshore operation.

Based on the available sound pressure data for small turbine types, as well as from a simulation of a 2-MW wind turbine it appears that injury of the marine mammal auditory system by the operational noise can be excluded. Added to this is the fact that the frequency range in larger wind turbines is expected to be in the even lower range where the animals are less sensitive.

The masking of social sounds of the harbour seal (perhaps also in the grey seal) by the operation noise is likely both above and in water. In this context the sounds produced by the pup, which are important for the communication with the mother, need to be taken account of, since they are crucial for the survival of the pups.

Should the noise of operation incite behavioural reactions in seals and harbour porpoises, it could theoretically mean, that they may be attracted to or be frightened off by the wind turbines. However, it is not possible to make any concrete statements neither to this regard nor to the whether the animals may become habituated or sensitised to the sounds due to a lack of information. An increase in the surrounding sound level results in stress symptoms in terrestrial animals. It is likely that a similar effect may occur in marine mammals, but this has not yet been verified.

Working hypothesis

Since the available information does not suffice to determine the impact of acoustic emission by WTs on marine fauna it is essential to formulate a working hypothesis with regard to immission limits. This is particularly crucial since it is intended to commence with the construction of the first wind turbines in the near future. It should be emphasised that this value only reflects the current state of knowledge and that it could change in the light of new information. Nevertheless it seems to be worthwhile to currently formulate an immission limit in order to provide persons responsible with the planning and construction of the wind turbines with a benchmark value. The value reflects a conservative estimate.

Ridgway et al. (1997) and Schlundt et al. (2000) determined the TTS limit for Belugas and Bottlenose dolphins to be 192 dB per 1 µPa. In contrast to Finneran et al. (2000, 2002) the authors used a tone of 1-second duration as a S1 stimulus. This appears to be the more appropriate signal in view of the fact that ramming signals have an average duration of 1 second. The TTS value corresponds to the lowest sound pressure level tested, after which a single exposure resulted in an increase in the TTS at one of the tested frequencies.

Since multiple exposures result in a shift in the auditory threshold at low sound pressure levels and because of the difference in weight dependant damage potential between the heavier Belugas and Bottlenose Dolphins on the one hand and the smaller harbour Porpoises on the other, it is probably recommendable of introduce a safety margin of at least 10 dB.

The working hypothesis describing the limits of the permissible acoustic exposure in the marine environment due to the construction of WTs should therefore be set at 182 dB re 1 µPa The application of such a hypothetical limit can only take place by considering all possible measures to avoid and/or reduce acoustic consequences (see below) The same value was used as a permissible limit in an environmental impact assessment study on the exposure of whales during military experiments by the US Navy (Department of the Navy 2001). The value was accepted by the responsible authorizing agencies in conjunction with the extensive precautionary measures.

Non-auditory effects

In the event, that the introduction of new hard substrata, by way of piles, should have a positive effect on fish stocks and diversity in the proximity to the WTs, this could have positive effects on the food supply for marine mammals.

Apart from the release of continuous and impulse like noise during the construction and operational phases, the WT pile foundations will result in changes of the current regime. Eddy drags in the current direction will result up to several hundred meters behind the piles, depending on the current speed. Since harbour seals depend primarily on their tactile sense (bristles) when searching for food, such a change could have negative effects on the hunting success of the seals and perhaps on that of grey seals too (Dehnhardt et al. 1998, 2001)

III-6 Results of the physical and biological investigations

In this section, the data and conclusions of the physical and biological investigations are combined to enable first concrete statements on the degree of exposure and danger of marine mammals subjected to the installation and operation of future large offshore projects in the North Sea. The construction and operation of the wind turbines will be treated separately.

A differentiation needs to occur between perception, impairment and injury, with regard to the effects of noise interference by offshore WTs on marine fauna. Limits of impairment are not likely to be reached during the regular operation of the wind turbines. However, the limits may be exceeded during the construction phase.

III-6.1 Effects during operation of wind turbines

The acoustic noise emitted by a WT during normal operation can be detected by some animals or may even affect their behaviour, depending on the distance from the wind turbines. The following evaluation is based on the hearing threshold by the animals. Thus the impact radii described in the following are based are therefore equivalent to detection radii (that is, not the “disturbance radii”, since the levels where “disturbance” and behavioral changes occur are not yet known).

Impact radii of selected offshore WTs

Figure III-48 shows under water sound spectra for two different WTs. The data are based on measurements of the 500 kW class and were extrapolated to a rated output of 2 MW (Degn 2000). Also shown are the measured ambient levels. These values together with the calculations from chapterIII-3 yield the approximate impact radii of an offshore WT as shown in Table III-9.

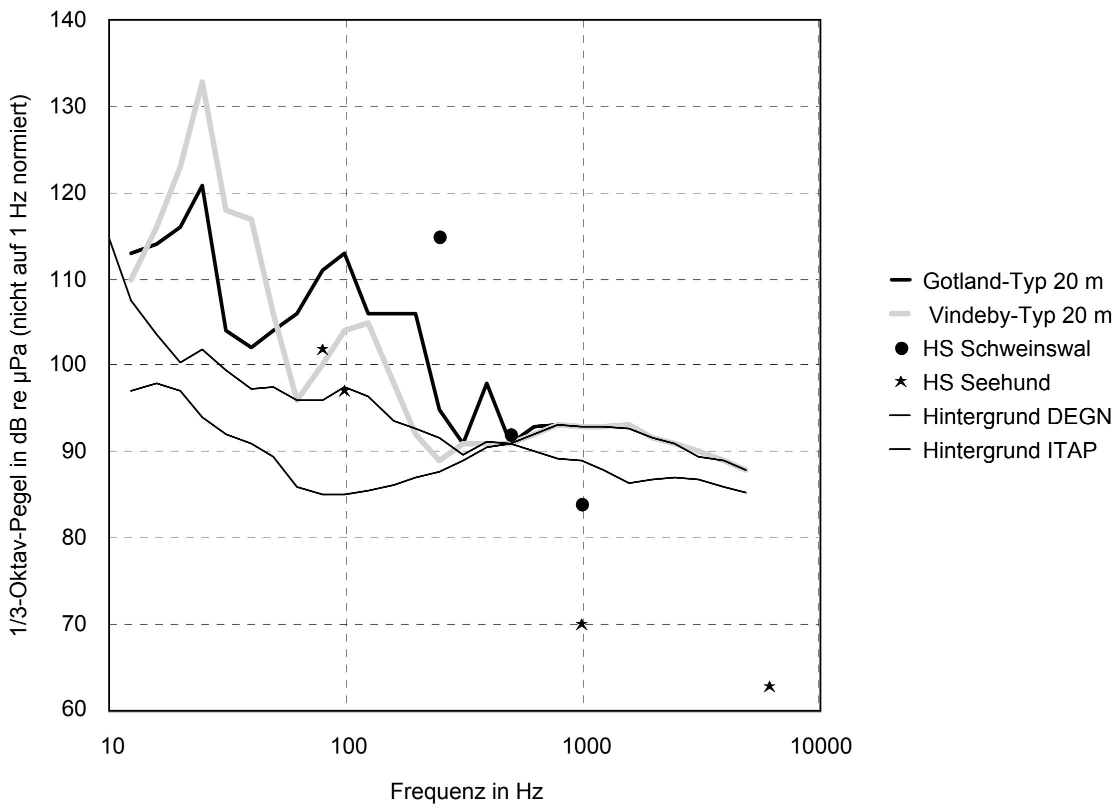

Figure III-48: **Spectra from 2MW –offshore wind turbines (Degn 2000, 2002) compared to measured ambient levels and to acoustic threshold levels of the Harbour Porpoise and Harbour Seals. To facilitate this comparison, the wind turbine as well as ambient spectra are not shown as density levels, but as absolute levels.**

Table III-9: Estimated impact radii of operating WTs, for different criteria, based on current information. The calculation is based on the assumption that the level changes by 4.5 dB per doubling of the distance.

Criterion	Radius	Comments
Wind turbine noise level exceeds ambient level (at 100 Hz)	1000 m	1
Wind turbine noise level exceeds ambient level (at 25 Hz)	4000 m	1
Estimated wind turbine noise level according to chapter III-4 exceeds ambient	700 – 1500 m	2
Hearing threshold of Harbour Seals	150 – 700 m	1, 3
Hearing threshold of Harbour Porpoises	(< 20 m)	1
Hearing threshold of fish	> 2000 m possible	4

Comments:
1) Wind turbine and ambient noise levels after Degn, Figure 2.3.5-1.
2) Small radius of measured ambient levels out of chapter 2.3.2.3, larger radius of ambient levels after Degn, Figure 2.3.5-1
3) 700 m for 10 dB reduction in the auditory levels mentioned in chapter III-5
4) Hearing threshold of “auditory specialists” species lies below the measured ambient levels

The currently known auditory thresholds of Harbour Porpoises, within the relevant frequency range (below 1000 Hz), lie above the ambient noise levels of the wind turbines. For this reason it is not possible to provide an impact radius. Harbour Seals, however, have considerably lower thresholds in this frequency range and will thus be able to detect the wind turbine noise up to a certain distance. Some fish species have even lower thresholds and can therefore theoretically detect the wind turbine noises over even greater distances.

The aural acuity of marine mammals has only been investigated on a few individuals with the result that the published data do not necessarily reflect the average auditory thresholds of the species investigated. Furthermore, studies on humans have shown that the individual thresholds are symmetrically distributed about the mean with a standard deviation of 4 to 6 dB (Betke 1991). This means that half of all individuals have a more sensitive hearing than the average and that the threshold of 2/3 of all individuals lies within a range of ±5 dB around the average auditory threshold. Assuming that the same applies to marine mammals, it is justified to say that a reduction in 10 dB can be applied to the estimate of aural acuity in these animals. This results in the increase in the radius of perception of WTs by Harbour Seals from 150 to 700 m as shown in Table III-9. It is currently not clear though to what extent the reaction zone has changed within this audible zone.

The limit of the impact zone is given by the distance that the wind turbine noise is equal to the ambient noise. The values in Table III-9 are for the 1/3-octave bandwidth. However, this limit is also not absolute: since the turbine noise has several single tones, these are detectable over greater distances when filtered by narrow band. This means they can still be detected over and above the ambient level. See figures III-34 to III-36.

III-6.2 Impacts during the construction of offshore wind turbines

During the construction of a WT it is only the laying of the foundation, which is important from an acoustic point of view. The remaining construction work, in comparison, is negligible and is not considered any further. Currently there is no single concept for the construction of foundations and three possibilities are discussed:

- Gravity foundation,
- Monopile or
- Tripod, Jacket construction.

Although the laying of a gravity foundation involves large amounts of material, the acoustic noise emission is low, according to current knowledge. However, strong noise emission accompanies the ramming of monopiles or the anchor piles of a jacket construction.

Spectra and time functions of pile driving noise (Ødegaars & Danneskiold-Samsøe A/S 2000) were shown in Chapter III-3.2. Accordingly a peak sound pressure level of about 205 dB was registered 30 m away from the pile driver. This value can be used to assess potential damage. To assess the audibility it is necessary to know the spectrum. This is once again shown in figure III-49. The approximate theoretical impact radii during the construction of an offshore WT are shown in Table III-10.

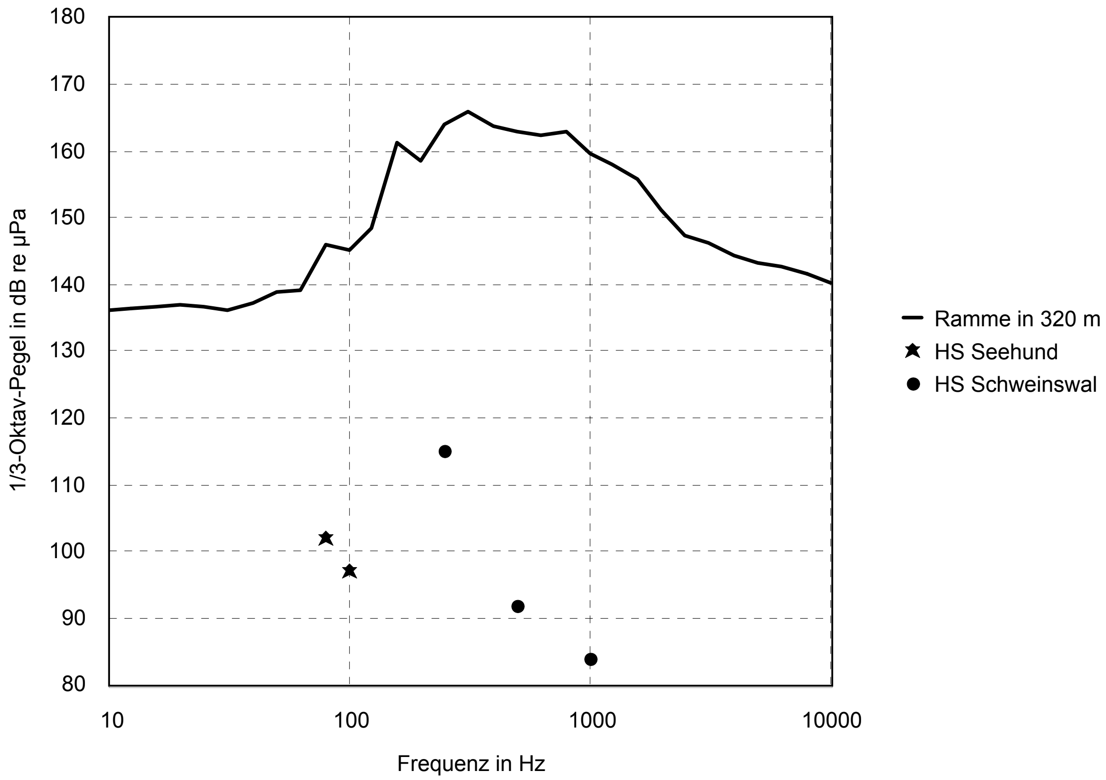

Figure III-49: **Pile driving spectrum at 320 m distance (Ødegaars & Danneskiold-Samsøe A/S 2000) as well as values of the auditory threshold of Harbour Seals and Harbour Porpoises The spectrum shows the sound exposure level (SEL); To assess the aural acuity it is necessary to set a 6 to 10 dB increase in the spectrum.**

Table III-10: Approximate impact radius during the construction phase (pile driving) for different criteria. The calculation is based on the assumption that the level changes by 4.5 dB per doubling of the distance.

Criterion	Radius	Comments
TTS in Harbour Porpoise (Damage begin)	1000 m	TTS = Temporary threshold shift; Assumption: L_{TTS} = 182 dB
Audible by Harbour Seals	> 1000 km	
Audible by Harbour Porpoises	> 1000 km	

To assess the radius of audibility, the following needs to be considered. The spectrum in figure III-49 shows the sound exposure level SEL, a measure to characterize short noise events. The SEL of a discrete noise event is defined as the constant level which, maintained for a period of 1 second, would deliver the same noise energy to the receiver as the actual event itself. Basically, this is the well-known equivalent continuous noise level, which is normalized to a duration of 1 second.

In the human auditory system, loudness is fully established within 100 ms (shorter noise events are perceived as being less loud) (Zwicker & Fastl 1990). The duration of ramming event is of the same magnitude. It is therefore recommended that in order to assess the audibility to use values 6 to 10 dB higher than the SEL values. In addition, the distribution of individual hearing thresholds also applies here, as mentioned above. A simple calculation for both the Harbour Seal and Harbour Porpoise therefore yields audibility radii over 10000 km. This result, however, is not plausible since complex laws of sound propagation apply at such distances. On the other hand, audibility up to 1000 km can be expected.

III-6.3 Assessment of the result from a biological standpoint

The marine fauna of the North and Baltic Seas is comprised of invertebrates, fish and marine mammals. Very little information is available on the acoustic and tactile perception of invertebrates as well as the expected effects of acoustic noise on these animals: Squid will possibly be able to detect the low frequency signals during construction and operation of WTs; behavioural reactions are expected. Acoustic noise may have effects on the settling, growth and survival of other invertebrate species.

In fish, one needs to distinguish between hearing generalists with a relatively low acoustic perception and hearing specialists with a high acoustic sensitivity. Some fish belonging to the latter group even react to infra or ultra sound signals. The effects caused by acoustic noise, range from rapid habituation through large-scale avoidance of the exposed areas to physical injury of the auditory organs, depending on the acoustic noise level. Some fish are capable of regenerating injured auditory sensory cells.

The harbour porpoise, harbour and grey seals represent marine mammals in the North and Baltic Seas. The auditory sense is crucial for the survival of the harbour porpoise. Any interference or injury potentially endangers the animals. The effects caused by acoustic noise immission during construction include stress reactions, averse behavioural reactions, masking of communication signals as well as temporal interference of the acoustic sensitivity. It is not possible to exclude damage to the hearing due ramming noises nor the likelihood of habituation or toleration of the operating noises. No information is available on the duration of the effects or on the long-term effects.

The harbour porpoises in the central Baltic require special attention since they may constitute a separate threatened population. Due to the current existence of the distemper virus in harbour seals they also need to be especially protected against any type of disturbance to avoid additional weakening of their immunological defence.

The use of well-focussed measures to avoid and minimize acoustic noise emission by offshore WTs should considerably reduce their potential impact.

III-7 Measures to avoid immission

The law of minimization of acoustic noise emission by wind turbines should also be applied in the offshore area. Such measures are applied on land-based wind turbines. Of particular importance is the uncoupling of structure-borne noise. In contrast to wind turbines based on land, airborne noise minimization in offshore wind turbines is less important. However, the avoidance of tonal noise immission should be a constructional requirement, particularly for the development of gearboxes, generators and ventilators.
Every effort should also be made to minimize noise during the construction. Quiet methods such as drilling should be considered as alternatives.

Based on the currently available knowledge and data it is possible to recommend the following measures to avoid and minimize negative effects of noise on marine fauna From a biological perspective it is necessary to introduce a series of measures to avoid and minimize acoustic immission by offshore wind turbines:

- Evaluate the significance of the area to marine life (organisms), reduce acoustic immission to a minimum

During the *construction* of the wind turbines, account for the following:

- Maintenance of closed seasons
- Measures to diminish noise (Bubble curtain, Fabric curtain)
- Gradual increase of acoustic noise emission to maximum levels during ramming
- Acoustic deterrent measures
- Acoustic surveillance
- Visual surveillance

The cautionary measures during construction apply more specifically to marine mammals.

The reproductive period of the Harbour Porpoises and Harbour Seals is a particularly sensitive time. Injury or interference should in all cases be avoided and it should be refrained from carrying out acoustic noise intensive activities during this period (May-August).
In the event that WT foundations need to be rammed, care should be taken to gradually increase the sound pressure level over a period of 15 minutes prior to ramming so that animals occurring in the proximity have the opportunity to leave the area (see also JNCC - Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys, http://www.jncc.gov.uk/marine/-seismic_survey/acousticdisturbance.htm).

The sound pressure level of the first signals needs to be so low as to exclude the likelihood of any acoustic injury to the marine mammals. This prior application could involve signals such as the original noise of ramming equipment or a simulated appropriate noise.

Sound pressure measurements recorded during ramming work near the San Francisco-Oakland Bay Bridge (Illingworth & Rodkin 2001, cited in California Department of Transportation 2001) revealed that the air bubble curtain did not reduce the maximum sound pressure level but did effectively dampen the sound components above 800 Hz (see also Würsig et al. 2000).

The fabric curtain containing an aerating system did reduce the sound pressure level by about 10-25 dB as well as effectively dampen the sound components above 800 Hz.

By using of acoustic deterrents ("Pinger") it is possible to drive away harbour porpoises out of a particular area. These instruments are deployed under water where they emit changing signals at intermittent intervals, which cause averse reactions in the animals. The effectivity of such instruments has been investigated on captive harbour porpoises as well as in the field during a EU research project. The intensity of the emitted signals is ~150 dB re 1 µPa, so that during a short-term implementation animals are not likely to be injured. Such pingers should be deployed in sufficient numbers around the construction area. There is no effective measure to deter Harbour Seals.

It is possible to monitor the occurrence of harbour porpoises in an ocean area by using specially developed click detectors. The instruments, which consist of hydrophones, are able to record and identify the echolocation signals of harbour porpoises. Since the range of detection is restricted to a few hundred meters, depending on the ambient noise levels, it is necessary to install several hydrophones with click detectors in order to ensure that the entire construction site is covered. The distance of the hydrophones has to be chosen in such a manner that the harbour porpoise is detected before it swims into the harmful radius (needs to be defined). The signals of the click detectors must be immediately transmitted to a person involved in the construction to ensure that construction is immediately halted.

An additional visual observation of the construction zone before and during construction of the wind turbines will reduce the probability that a marine mammal occurs within the danger zone or is about to swim into it. A description of visual observation methods is provided in the section „Minimum requirements“. If porpoises or seals are observed or detected acoustically, construction has to be interrupted immediately. It should only continue after 30 minutes during which no animal was sighted or detected acoustically.

Similar methods of surveillance are being used as protective measures during the construction of offshore WTs in Danish waters as well as during the deployment of intensive sound sources in the U.S.A. (Gisiner 1998).

III-8 Requirements for research

The results obtained during this study are to be regarded as an introduction to the problem. They are based on the current state of knowledge. The assumed conditions and limitations are discussed. The statements concerning impact radii are to be regarded as preliminary since they are based on very few data, extrapolation, conversion and estimates. The need for further research entails both physical and biological aspects.

From a biological perspective, the major need for research is in the field of audiometric data on marine mammals. The following provides an outline of research requirements for the separate animal groups as well as other aspects concluded from this study.

1.) Effect of acoustic noise on marine mammals. Evaluation of immission limits by:

- obtaining audiograms of grey seals, harbour seals and harbour porpoises
- (increase the number of audiograms or recorded for the first time in grey seals).
- Recording of the actual acoustic noise immission by the planned turbines during different climatic conditions
- Recording of the actual acoustic noise immission of the different foundations
- Determining of TTS values for harbour seals and harbour porpoise in the acoustic noise immission range concerned (corresponding to the mentioned TTS studies)
- Determination of the action radius of seals and harbour porpoises (using satellite telemetry)
- Investigations on the effect of WT acoustic noise immission on habitat utilization by seals and harbour porpoises (fundamental investigations)
- Stress research (short and long term consequences)

2.) Influence of acoustic noise on fish

- Determining the acoustic sensitivity in endemic fish species by recording audiograms
- Investigation of behavioural response to acoustic noise in captivity
- Investigation of behavioural response to acoustic noise in the field
- Investigations on the effect of acoustic noise on catch success
- Investigation on the effect of acoustic noise on survival of fish eggs and growth rate of fish larvae.
- Determining stress caused by acoustic noise in fish as well as the short and long term consequences for the animals

3.) Effect of acoustic noise on invertebrates:

- Determining the effects of exposure to acoustic noise on the colonization of hard substrata by invertebrate animals
- Investigations of short and long term effects of exposure to acoustic noise in invertebrates
- Determining the reaction of invertebrate animals (e.g. squid) to acoustic noise immission by WTs (avoidance or attraction)

4.) Measures to avoid or minimise acoustic impact

- Development/consideration of alternative, less noise intensive methods during the construction of WT foundations
- Development of muffled technology
- Development of acoustically effective deterrents for harbour and grey Seals

5.) General effects

- Effects of acoustic noise on faunal species composition

From a physical perspective, there is research requirement to develop a usable base for the derivation of appropriate criteria to determine limits of acoustic noise immission by offshore wind turbines. The following separate points are applicable:

- the systematic investigation of ambient noise
- Measurement of source volume and immission by different types of real large WTs as well as foundation types
- Long term measurements
- Derivation of transient parameters for the construction of foundations
- specification of the impact zone of offshore WTs
- the establishment of standards and methods for acoustic investigations on offshore WTs
- the establishment of standards and methods to determine ambient noise
- the establishment of recommendations for technical and biological limit values for acoustic noise immission by offshore wind farms.

Relevant current research projects in the context of future investment program of the Federal Environment Ministry are conceived with this objective in mind.

The combination of technical aspects with results from the biological investigations is of great importance. E.g. the evaluation of the immission by WTs derived under real conditions in relation to the ambient noise and sensitivity of the organisms.

The development of a permission granting practice points to a large requirement for concrete statements on limit values and practical recommendations on the avoidance and reduction of interference in the marine environment due to offshore WTs.

III-9 Summary

The impact of the construction and operation of offshore wind turbines on the marine environment was investigated, based on currently available, albeit sparse information and data. The important species living within the target area were listed and their characteristics pertaining to acoustic perception described.

Measurements of sound pressure levels produced by ramming of piles as well as by operating WTs were referred to. Since there are no data available on large WTs with steel foundations, models based on data obtained for WTs on land, were used to estimate acoustic noise immission. Model computations showed that the currently estimated sound levels would lie below the ambient levels at a distance of 700 to 1500 meters away from the wind turbines

The spectral analyses have revealed, that the noise created by the wind turbines mainly exceeds the ambient noise in the frequency range below 1 kHz. This range typically includes the engine noise of WTs (gearbox, generator). As is the case on land it is necessary to apply a narrow band evaluation and assessment since tonal noise is involved. A parallel can be drawn to the determination of tonality established for onshore immission control. Reduction measures of single tones are extremely cost intensive according to experience and would have to be already included into the first construction plans. With this in mind, the evaluation of the relevance, in particular of tonal immission for marine organisms is of crucial importance.

The evaluation of perception in relation to the auditory threshold yielded relevant auditory radii (in relation to the extension of wind farms) for harbour seals and some fish species. It was not possible to make an equivalent statement for grey seals due to the lack of fundamental data. Harbour porpoises were found not to perceive acoustic noise outside the close range of the wind turbines.

Provisional statements on the effects of sound propagation during the operation of WTs from a biological point of view were only made with regard to harbour porpoises. Thus only one working hypothesis can be made for the construction of WTs since clearly higher levels are expected to be produced than during the operation.
To minimize the effects during construction, it is necessary to apply focussed measures in order to avoid increased stress reactions or temporary auditory impairment of marine mammals. Such measures, ranging from the deterrence to the deployment of effective dampening methods are discussed in this report. The next step would be to test the effectivity of these measures on real WTs.

From a technical point of view it is particularly important that additional noise reduction measures or procedures derived from behavioural observations, be applied during summer, which coincides with the reproductive months of marine mammals. A complete exclusion of the summer months from the construction phase would not be possible in the light of the months available for the construction of WTs.

IV Collision risk of ships with wind-energy plants and the danger of pollution in coastal regions

IV-1 Introduction

Sites are being sought within the exclusive economic zone (EEZ) of the North and Baltic Seas to build offshore wind parks comprising between 80 to 200 wind energy plants (WEPs). No comparable parks exist anywhere in the world, with the result that their impact on shipping is largely unknown. New technology is required, due to the unique environmental conditions and water depths in these regions. The impact of such innovative technology on the marine environment has also not yet been studied. .

IV-2 Tasks and solutions

This report was compiled within the framework of the sub project IV "Collision risk of vessels with wind energy plants and the danger of pollution in coastal regions" The aim of this sub-project was to investigate aspects concerning the collision of vessels with WEPs. Furthermore, the risk of potential collisions between ships and WEPs was to be assessed as well as technical and organisational measures to minimise the risks, to be formulated. The following individual tasks were set:

Presentation of vessel traffic in the German exclusive economic zone (EEZ) of the North and Baltic Seas, as well as the identification of shipping of hazardous cargo.

National and international data sources were consulted for the evaluation to evaluate this aspect. Archived data sources on shipping activity were analysed and compared. This enabled the identification of differences and uncertainties in the data and thus to obtain a detailed scenario of shipping activities in the waters of the German EEZ.

IV-3 Presentation of collision risk between offshore WEPs and ships according to intensity of traffic and other risk factors in the North and Baltic Seas

IV-3.1 Ship traffic in the North and Baltic Seas

As mentioned previously, the first part of this sub-project deals with the analysis of current vessel traffic in the EEZ of the North and Baltic Seas. The intention is to use information on the extent and classification[1] of vessel traffic to assess risks and display these on charts. A point system is being developed, which combines vessel traffic with the specific conditions (wind, swell, currents) of the respective sea areas area in The basic principle of the point system and the assessment of the individual parameters were discussed in the preliminary report of this project (Otto 2001) A similar point system was developed for the project on oil pollution along the British coastline "Identification of Marine Environmental High Risk Areas (MEHRAS's) in the UK", MacDonald (1999).
During the course of this project, it became apparent that although the quantification of the various environmental features was possible, the weighting of the factors needed to be calibrated. It was not possible to carry this out during the project, however. It was refrained from linking the various quantitative factors. Instead Otto (2001) discussed and assessed some of the individual factors themselves.

Ship traffic in the North and Baltic Seas
The most important factor concerning the analysis of potential collision risks between offshore WEPs and ships is the extent of traffic i.e. the amount of shipping in the various sea zones. Due to the important status of this factor, intensive research was carried out to obtain a detailed picture of ship traffic. Various sources of information on ship traffic (numbers) are compared in the following sections.

IV-3.1.1 ISL-Report (ISL 2000)

The Institute of Shipping Economics and Logistics (ISL) in Bremen carried out an analysis of the ship traffic in German coastal waters on behalf of the Federal Ministry of Transport, Building and Housing (BMVBW). The institute consulted data provided by the Directorate for Water and Navigation as well as data from Lloyd's Voyage Records. The Lloyd's data comprised port-pairing, start and goal ports of the vessels, from which traffic numbers for specific sea areas were estimated in conjunction with additional information. Shipping traffic was not only classified into vessel types but also included size categories. Data for the first quarter of year 2000 were analysed. The Lloyds data did not entail any Ferry connections. These were obtained from the timetables of Ferry companies.

Figure IV-1 provides an overview of the traffic numbers from the ISL report (2000). Since the data were only obtained for the first quarter of the year 2000, the numbers were quadrupled to obtain annual ship traffic numbers.

The classification of vessel types is shown in Table IV-1. Vessels with a tonnage below 500 [tdw] were not included in the analysis.

The highest number of vessel movements (>80.000 per year) was recorded in the Fehmarn Belt area whereas the Fehmarn Sound was found to be the area with the least traffic (532 vessel movements per year).
The ISL was only required to investigate the ship traffic in the coastal waters, which only partly lie within the EEZ e.g. the Traffic Separation Schemes "TSS German Bight", "TSS Terschelling German Bight " and "TSS Jade Approach".

[1] classification into ship type, size etc

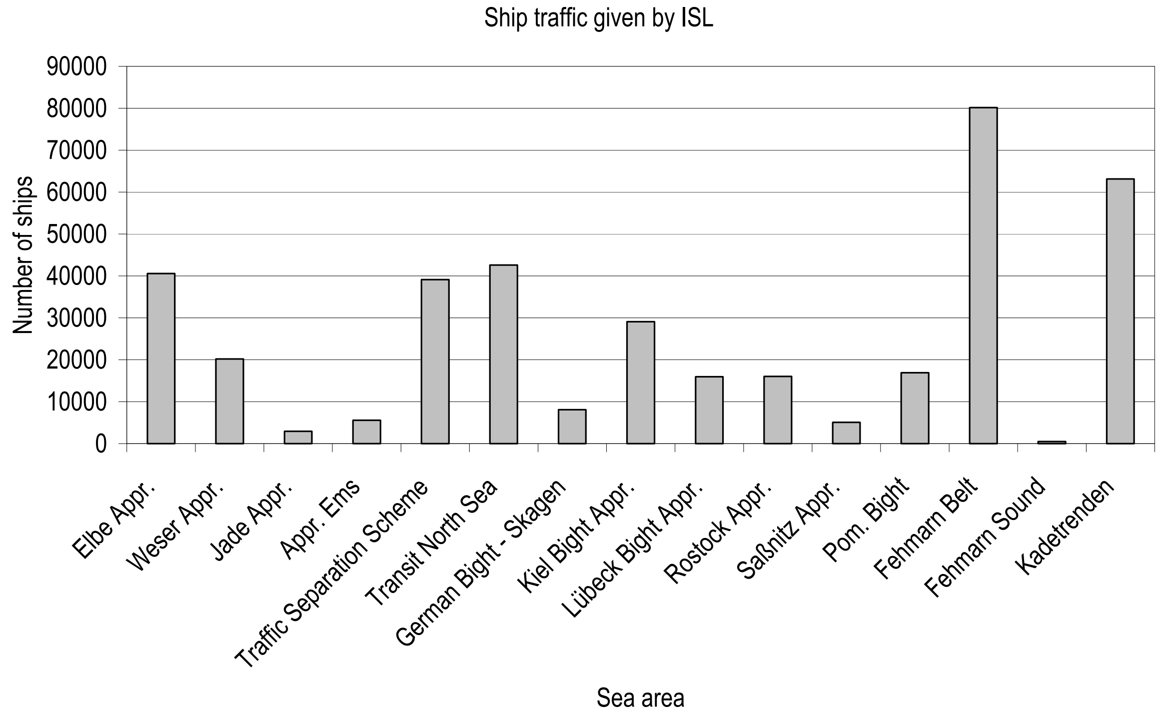

Figure IV-1 : Presentation of ship traffic after ISL (2000)

Table IV-1: Ship traffic in the sea area of the German Bight and Baltic Sea during the year 2000. Vessels above 500 gt, Source ISL (2000)

Area	Tankers	Bulk carriers	Containers	General cargo	Passenger/ RoRo	Other	Ferries	Total
Elbe approach	5 880	1 748	7 584	23 816	356	180	1 032	40 596
Weser approach	1 032	1 072	6 280	11 728	0	104	0	20 216
Jade approach	2 104	256	24	536	0	24	0	2 944
Ems approach	552	312	56	4 536	0	112	0	5 568
Traffic Separation Schemes	5 552	2 360	6 408	23 212	352	228	1 032	39 144
Transit North Sea	7 944	4 016	2 216	24 564	168	548	3 120	42 576
German Bight Skagen	1 396	652	1 564	4 424	4	76	0	8 116
German Bight overall	24 460	10 416	21 132	92 816	220	1 272	5 184	159 160
Kiel Bight approach	2 688	672	2 760	9 624	496	108	3 120	29 092
Lübeck Bight approach	192	88	120	6 120	776	104	8 560	15 960
Rostock approach	936	544	40	3 480	176	72	10 784	16 032
Saßnitz approach	16	8	0	72	0	8	4 984	5 088
Pomeranian Bight approach	728	1 040	136	6 400	0	176	8 456	16 936
Fehmarn Belt	8 348	4 452	3 224	27 244	384	160	36 336	80 148
Fehmarn Sound	28	12	0	480	4	8	0	532
Kadetrenden	8 192	4 180	3 348	31 356	1 268	200	14 592	63 136
Baltic overall	21 128	10 996	9 628	94 400	3 104	836	86 832	226 924
All sea areas	45 588	21 412	33 760	187 216	3 984	2 108	92 016	386 084

IV-3.1.2 Ship traffic numbers from the Directorate for Water and Navigation

As mentioned above, the Directorate for Water and Navigation registers and analyses a part of the ship traffic in the North and Baltic seas. The data were generously made available to the authors of this report.

IV-3.1.2.1 Data of the Directorate for Water and Navigation North

Some of the areas of interest fall under the jurisdiction of the Directorate for Water and Navigation North. These are:

In the North Sea

- The coastal waters from the German/Danish border to the Knechtsand, including the coastal waters around Helgoland
- The high sea within the range of the German continental shelf outside the territorial waters.

In the Baltic

- The coastal waters and the high seas from the German/Danish border to the Border of Poland.

Figure IV-2: **Area of jurisdiction of the Directorate for Water and Navigation North (Source: http://www.wsd-nord.de/framepag.htm)**

The Directorate for Water and Navigation (WSD) North provides vessel traffic data for specific routes in the jurisdictional zone of the North Sea. This source (WSD-N1 1999) covers all vessel classes with the exception of recreational boat traffic and coastal fishing vessels. The Water and navigation department for 1999 collected the data.

Table IV-2: **Number of ship movements in 1999, Source WSD-N1 (1999)**

Route / Destination	Number of ship movements [1/Year]
From and to Skagen	5 000
2 Routes from and to Esbjerg	1 200
From and to List / Havneby	300
From and to Dagebüll / Föhr	280
From and to Husum	1 100

No specifications were provided on the type and size or on the cargo of the ships. .

The Directorate for Water and Navigation North (WSD North) annually delivers a report on the ship traffic and accidents for its area of jurisdiction (WSD-N2 1999). These reports do not include direct references to the shipping activity within the EEZ. However, for the Baltic traffic numbers are provided for the approaches to the harbours of Wismar, Rostock, Stralsund, Wolgast, Saßnitz and

Mukran. These are appropriate for comparisons with the data from other sources. This source includes all ship classes with the exception of recreation vessels

Table IV-3: Number of ship movements in 1999, Source WSD-N1 (1999)

Route	Number of ship movements [1/Year] (total)	Number of Gas-, mineral oil- or chemical tankers [1/Jahr]
Elbe Approach	61 647	9 559
Flensburg Fjord	7 346	0
Kiel Fjord	44 723	3 024
Trave Approach	3 024	452
Wismar Approach	3 358	76
Rostock Approach	31 542	531
Stralsund Approach	9 914	28
Wolgast Approach	4 692	5
Saßnitz Approach	328	24
Mukran Approach	5 968	48

The report does not include data for the EEZ in the Baltic.

IV-3.1.2.2 The Directorate for Water and Navigation (Northwest)

The Directorate also provided data for Water and Navigation (Northwest). The data of the primary source (WSD-NW1 2001), deals with vessel traffic in the Traffic separation schemes "TSS German Bight Western Approach", "TSS Jade Approach" und "TSS Terschelling German-Bight", as well as traffic to the approaches of the harbours located at the rivers Ems, Jade, Weser and Elbe. The data were compiled for the year 2000. Registration of the vessel traffic occurs when vessels pass through an overseen traffic zone where they log in and out.

Table IV-4: Number of ship movements in 2000, Source WSD-NW1 (2001)

Route	Number of ship movements [1/Year] (total)	Number of gas-, mineral oil- or chemical tankers [1/Jahr]
TSS German Bight Western Approach (East course)	1 226	529
TSS German Bight Western Approach (West course)	1 322	692
TSS Terschelling German-Bight (East course)	15 909	1 960
TSS Terschelling German-Bight (West course)	15 622	2 003
TSS Jade Approach (South course)	992	480
TSS Jade Approach (North course)	1 927	587
TSS Elbe Approach (West course)	18 284	2 170
TSS Elbe Approach (East course)	18 786	2 595
Ems Approach	3 491	347
Jade Approach	2 528	1 159
Weser Approach	11 202	724
Elbe Approach	42 354	6 316

Table IV-5: Ship traffic classified according to vessel type, Year 2000, Source WSD-NW1 (2001)

Ship type	TSS German Bight Western Approach	TSS Terschelling German-Bight	TSS Jade Approach	TSS Elbe Approach
Barges	1	10	0	20
Bulker	422	1 446	307	1 012
Containers	59	6 313	304	5 602
General cargo	368	12 169	773	19 407
Chemical tanker	418	1 751	203	2 490
Gas-tanker	132	438	49	586
Oil-tanker	670	1 285	814	2 481
Marine / Authorities	105	330	159	1 255
Passenger vessels / Ferries	2	1 485	49	2 428
RoRo	307	1 873	31	2 158
Special ships	34	504	47	977
Car transporters	8	1 597	111	709
Others	20	260	78	434
Total	2 546	29 461	2 925	39 559

Table IV-6: Ship traffic classified according to vessel type, Year 2000, Source WSD-NW1 (2001))

Size gt/TT	VTG German Bight Western Approach	VTG Terschelling German-Bight	VTG Jade Approach	VTG Elbe Approach
< 500	31	1121	68	3 335
500 to 1 500	101	2813	162	5 036
1500 to 3 000	260	7082	412	12 142
3000 to 10 000	460	7218	741	11 718
10 000 to 20 000	790	3325	457	2 808
20 000 to 40 000	463	4027	338	2 541
40 000 to 60 000	239	3158	514	1 471
> 60 000	202	717	233	508
Total	2 546	2 9461	2 925	39 559

The division into categories (Vessel type and size) was done according to the information on district shipping, pilot obligation, or tidal shipping.

The source WSD-NW2 (2000) from the Directorate for Water and Navigation (Northwest) provides data on ship traffic from the German Bight in the direction of the central and northern Scottish and Icelandic harbours the Shetlands, Orkneys as well as the oil fields and fishing grounds in the north-western North Sea for the year 2000. The data comprises 3 000 data sets which included departure, destination, design, draft, capacity length and width of individual vessels.

IV-3.1.3 Traffic numbers from ANATEC (ANATEC 2001)

After analysing all available sources, it was found that the available data permitted reliable statements on ship traffic in the coastal regions and the monitored Traffic Separation areas, however, did not provide data for large parts of the EEZ. This was particularly the case for a large part of the traffic in the Baltic.

Additional sources, which provided reliable traffic data for all the important areas, were therefore sought.

During their search for similar projects the authors came across the British project "Identification of Marine Environmental High Risk Areas in the UK" (MEHRAS's (MacDonald 1999). This project analyses the impact of shipping on the coastal regions of Great Britain. Amongst others the "COAST data bank was developed in this project. This database combines various data on ship traffic and provides a model for ship traffic in the North Sea. The following information were integrated into the "COAST" data base:

- Harbour registration data (Lloyds Maritime Information System, LMIS)
- Traffic censuses of "Standby" ships at offshore platforms
- Traffic censuses with the aid of land and sea based radar
- Information by operators of oil and gas plants
- Ferry companies
- Ship passage plans
- Deep-water routes

After analysis and coupling of the input data, the following information can be acquired from the database for every shipping route:

- *Ports of departure and arrival:*

Information on the ports of departure and arrival of vessels was obtained from the of Lloyd’s Maritime Information Service (LMIS) database. Information is provided for Western Europe ranging from the Baltic to Greenland and from Iceland to the Mediterranean. Figure IV-3 shows the area, which is covered. It could therefore be guaranteed that all the regions of the German EEZ were covered. This applies particularly to the transit traffic, which passes the German EEZ without calling at German ports or uses the uncontrolled Traffic separation zones and is thus not registered by the Directorates of Water and Navigation.

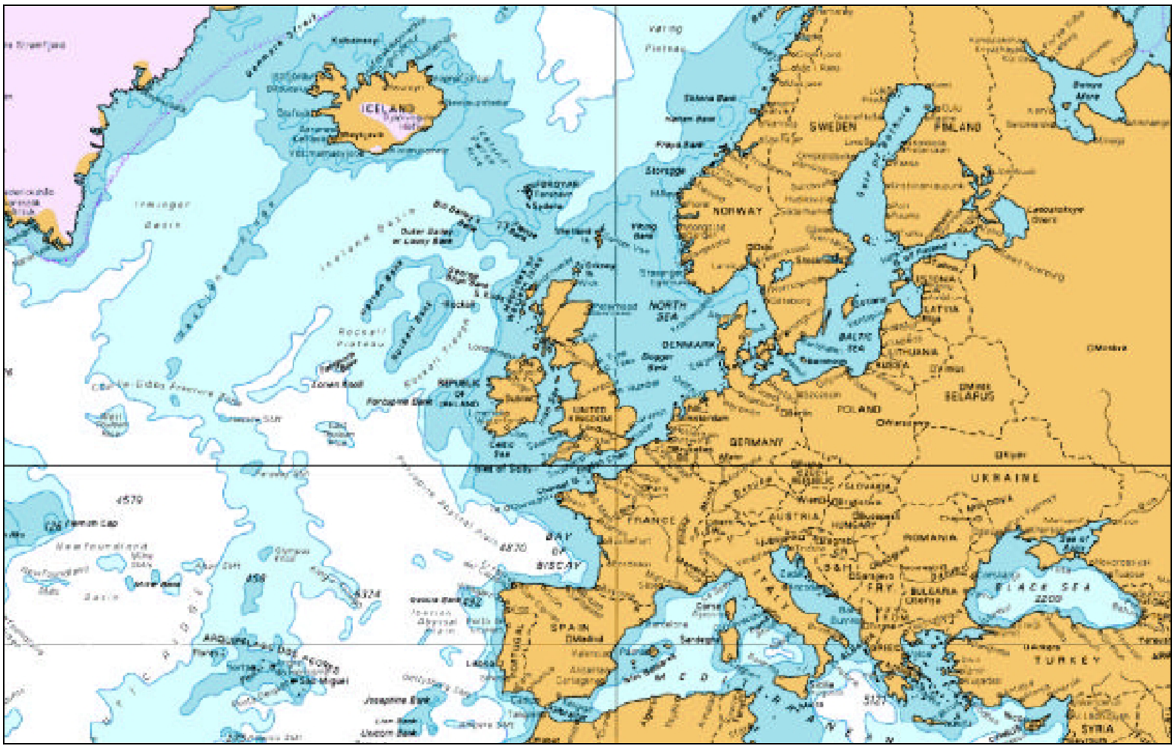

Figure IV-3: Geographical region for which information on ship traffic is saved as "LMIS" waypoints

The routes of the individual vessels were reconstructed from "LMIS" data using waypoints Latitude and Longitude of a position). The properties of the shipping streams and the routes were combined by using attributes (Table IV-7).

The waypoints of the shipping routes were fixed so that ships used the shortest distance between ports of departure and arrival. The draft, block stop zone shallows, traffic separation areas as well as deep-water routes were taken into consideration.

Table IV-7: Attributes for single ship routes in the "COAST" data base

Attribute	Description
Direction	One or two way route
Standard deviation	Width of the ship route
Distribution	Gauss or equal distribution

- *Number of vessels per year*

Ship traffic data for a total of 13 weeks during the year 2000 were analysed. The periods January, April, July and October were selected to account for seasonal fluctuations in ship traffic. The data were then linearly extrapolated to an entire year.

The "LMIS" data are not adequate for the Ferry traffic or the production and oil supply vessels. In order to cover this part of the shipping traffic, the ferry companies and operators of offshore installations were contacted to obtain direct information on their activities.

- *Distribution of ship types*

Ten categories of ships were differentiated in the COAST database, of which some categories have several ship types. Table IV-8 shows an overview of the different ship types

Table IV-8: Ship categories in the COAST data base

Number	Category	Type
1	Bulk Carrier	Bulk Carrier
		Bulk/Container
		Cement Carrier
		Ore Carrier
		Wood-chip Carrier
		Bulk/Oil Carrier
		Ore/Oil Carrier
2	Cargo	General Cargo vessel
		Multipurpose Cargo vessel
		Refrigerated Cargo vessel
		Livestock Carrier
		Container vessel
		Refrigerated Container vessel
3	Ferries	---
4	Gas-tanker	LPG Carrier
		LNG Carrier
		LPG/LNG Carrier
5	Ro-Ro	Ro-Ro vessel
		Ro-Ro Container vessel
		Vehicle Carrier
		Passenger Ro-Ro
6	Standby Ships	---
7	Suppliers of Platforms and Oil rigs	---
8	Chemical tanker	---
9	Oil-tanker	---
10	Shuttle tanker	---

- *Distribution of vessel classes*

All shipping traffic was classified into 5 size categories according to the tonnage.

Table IV-9: classification of ship traffic according to tonnage

Number	Tonnage (tdw)
1	Below 1 500
2	1 500 to 5 000
3	5 000 to 15 000
4	15 000 to 40 000
5	Over 40 000

Additional classification was made in the database, according to flag State, age of the vessel and speed.

As mentioned previously the database "COAST" was initially developed for the analysis of ship traffic in British coastal waters and therefore only included data from the British territorial waters of the North Sea. Comprehensive alterations and additions had to be made regarding ships traffic in the German Bight, in order to use the database for this project. The ship traffic in the Baltic also had to be included since it also was not part of the database.

The "ANATEC UK Limited" company, which services and manages the database, was commissioned to carry out this task.

Figure IV-4 shows some of the reference ports in the German Bight and the Baltic. Those ports from which the vessels use the same shipping routes were collectively assigned to a reference port. An example for such a reference port is the harbour of Hamburg. Figure IV-5 shows all the ports, which are attributed to Hamburg, harbour.

Figure IV-4: **Reference ports for the analysis of ship traffic in the North and Baltic seas**

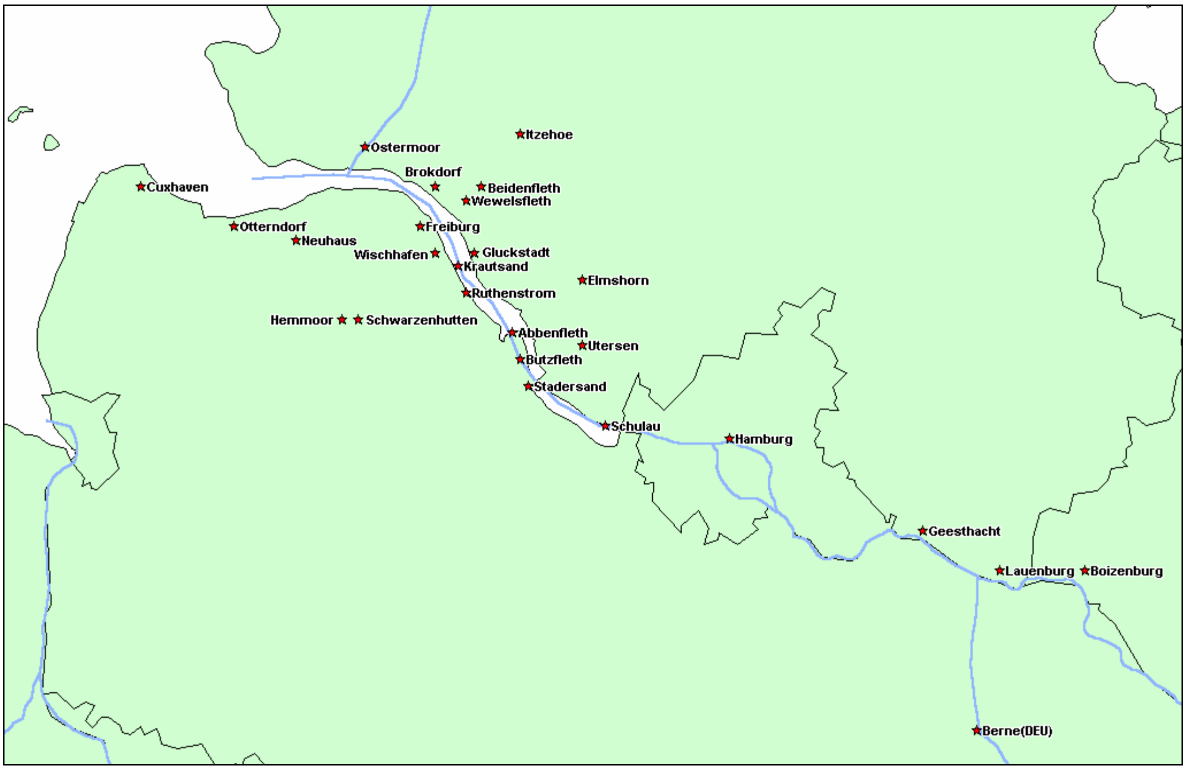

Figure IV-5: **Ports attributed to the reference port of Hamburg**

This means that for the chart presentation, the ship traffic ends at the reference port (see Figure IV-4). Thus the ship traffic along the routes of Bremen and Wilhelmshaven end north of the mouth of the Weser River. This does not have any effect on the display of the ship traffic in the EEZ.

Figure IV-6 shows the ship routes in the revised database. A total of 667 ship routes were identified between the reference ports. The traffic between these was analysed and classified according to the criteria mentioned above. The line widths of the pictured routes denote the intensity of shipping.

The routes shown in figure IV-6 are idealised routes. In reality, the vessels will deviate slightly from these routes. The shipping is thus distributed orthogonal to the shipping route, which is termed lateral distribution. The most exact information on lateral distribution of shipping routes are obtained by traffic censuses. Recent publications (Gluver & Olsen 2001, Randrup-Thomsen et al. 2001) show that restrictions in channels due to obstacles or marking may yield rather complex distribution functions.

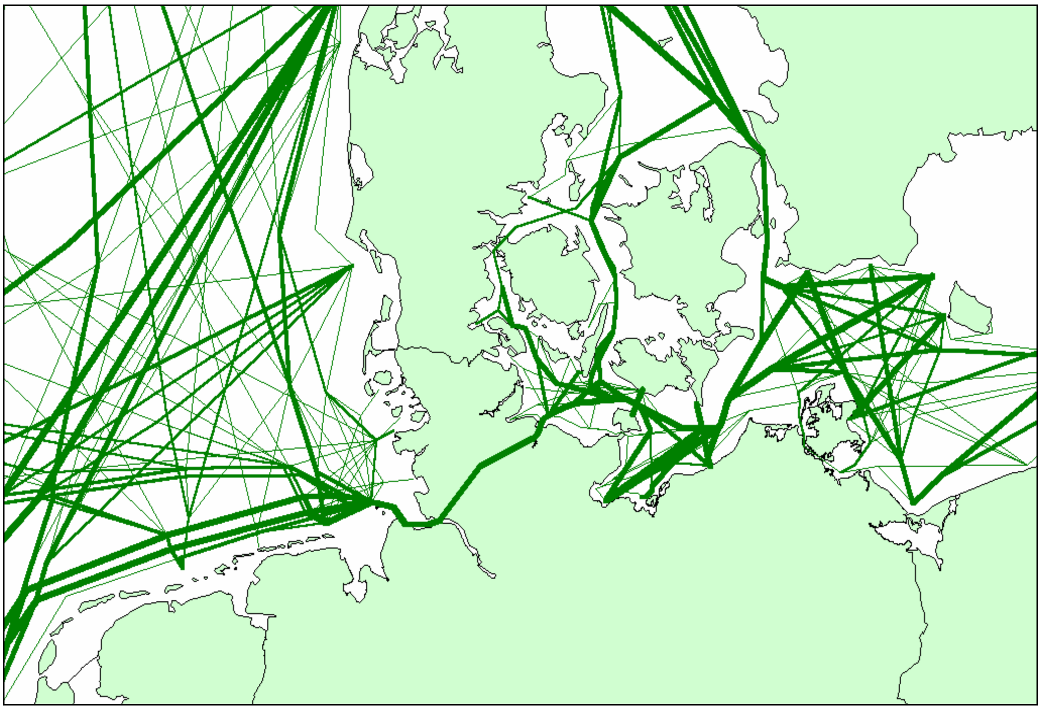

Figure IV-6: shipping routes and significant ports in the North and Baltic Seas

For those routes without navigational limitations, it is accepted that most captains will select the shortest route between ports in order to save time. Thus the maximum lateral distribution lies on the ideal route. Inaccuracies in navigation will lead to deviations from the route. This means that the number of ships decreases with increasing distance from the ideal route. The lateral distribution of ships with unrestricted shipping routes can therefore be regarded as having a Gaussian distribution (Figure IV-7).

Gaussian distribution

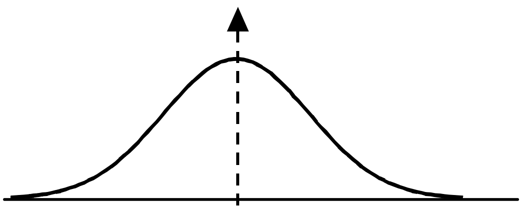

Figure IV-7: Lateral distribution of ship traffic for unrestricted routes

Equal distribution

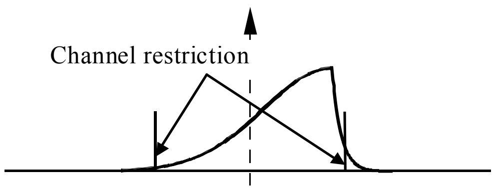

Figure IV-8: Lateral distribution for restricted routes

For navigationally restricted routes such as Traffic Separation Schemes ships are directed to navigate in marked waterways. This means that there is probably an increased awareness during navigation, whereby the lateral distribution is concentrated in the channel. Depending on the type of restriction, a small proportion of ships will always navigate outside the navigation channel. According to the WSD-NW 0.5 [%] of ships, navigating the eastern route VTG "German Bight Western Approach", navigate outside the waterway. On the western route VTG "Terschelling German Bight" it is 1.0 [%].

Traffic densities, which constitute the number of ships navigating in a defined area (cell) per time interval, were plotted. A time interval of one day was chosen so that the plots yield the statistical number of ship movements per day and cell.

Figure IV-9 shows the density of ship traffic in the North Sea section of the German EEZ. The figure shows the greatest traffic densities in the region of the Traffic Separation Schemes. High concentrations also occur due to transit traffic from the English Channel and the Netherlands ports to the Baltic via Skagen. Another highly frequented route is that from Hamburg to and from Skagen. An extremely high traffic concentration is found at the access to the Elbe River. This concentration results from the large number of ships, which are going to Hamburg harbour or passing the Kiel Canal, as well as the relatively narrow access channel in the Elbe River.

Figure IV-10 shows the density of ship traffic in the Baltic section of the German EEZ. In contrast to the North Sea the Baltic has a relatively wide band of zones with a density of over 50 ships per day. This band begins in the area of the Fehmarn belt and stretches through the Kadetrenden in the direction of Bornholm, Russia and Poland.

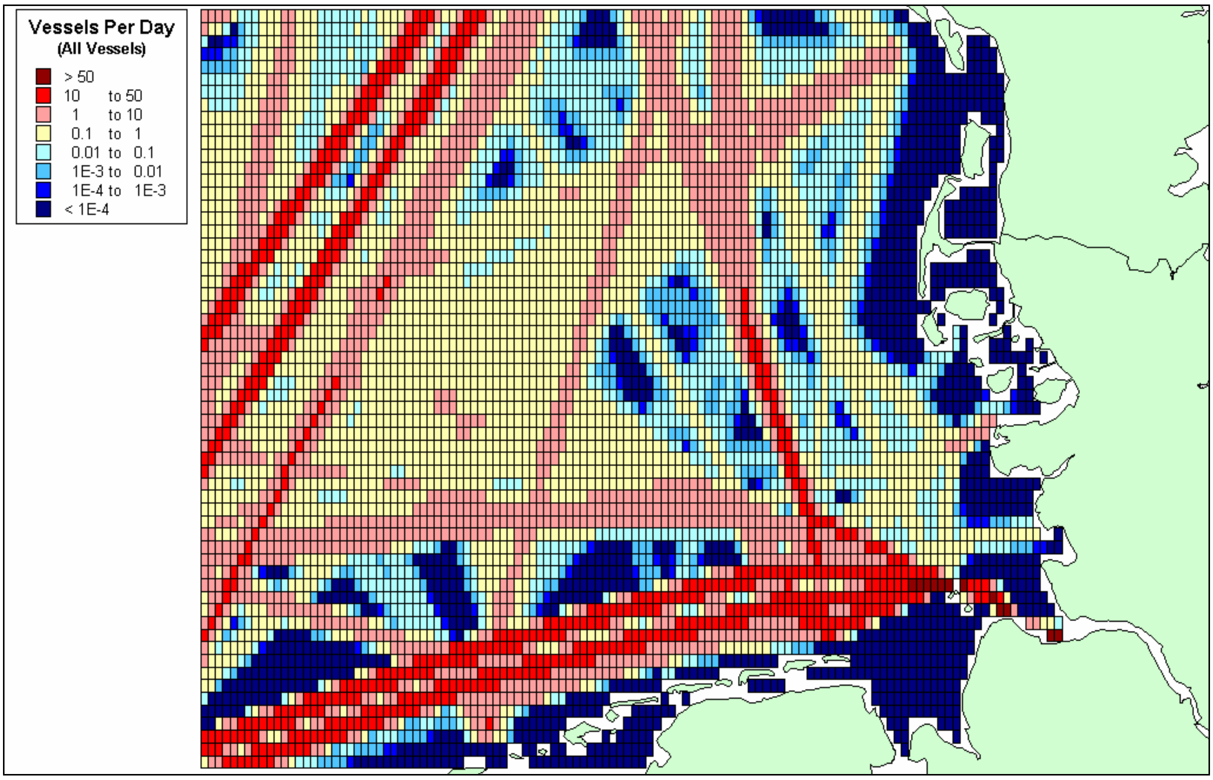

Figure IV-9: Density of ship traffic in the North Sea

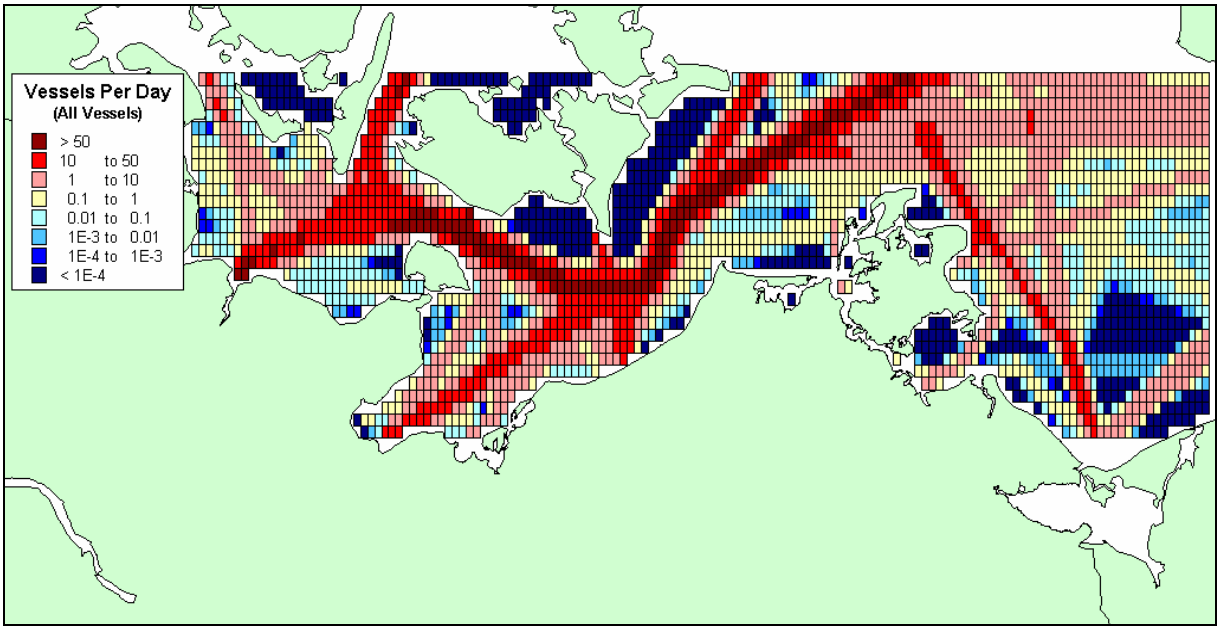

Figure IV-10: Density of ship traffic in the Baltic

The classification of ship traffic according to vessel type and size yields the following statistics:

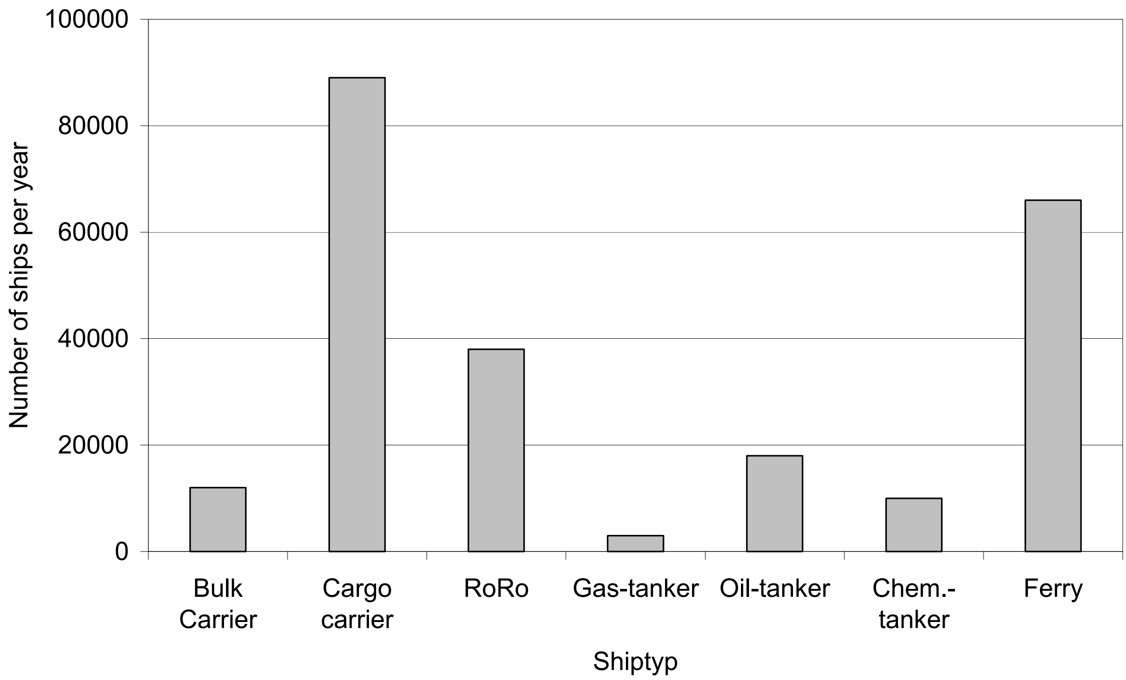

Figure IV-11: Annual number of ship movements in the North and Baltic seas, classified according to vessel type

According to the data by ANATEC, figure IV-11, the general cargo vessels dominate the traffic with ca. 90 000 ship movements annually. A similar intensity of ship movements is brought about by ferry traffic, whereby it is mainly concentrated in the Baltic. Gas and Chemical tankers constitute the smallest proportion.

Classification according to vessel size shows that the most frequent size lies in the categories between 5 000 and 15 000 [tdw] (Figure IV-12).

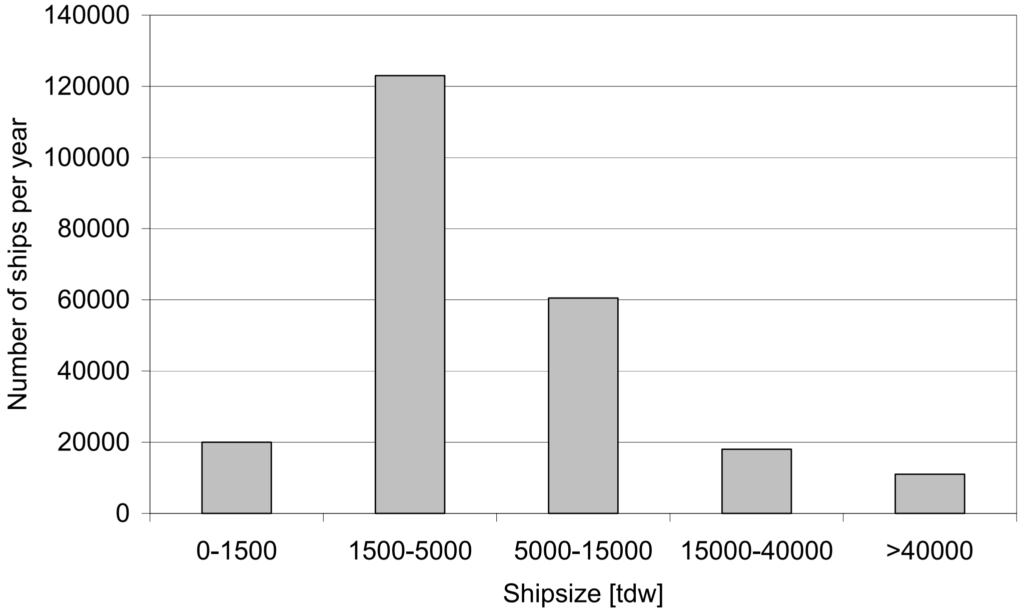

Figure IV-12: Annual number of ship movements in the North and Baltic seas, classified according to vessel size

IV-3.1.4 Comparison of traffic numbers

In order to be able to use sound numbers for the assessment of risk, the different sources were compared with one another. In this context, the data provided by ANATEC were the most extensive and of the greatest detail. They include the shipping traffic in all important areas which is not always the case in the other sources

However, there are differences between the statistics due to the different sources, classification of vessel types and vessel size categories. It is only possible to check if the statistics are plausible by comparing the different data sources by applying the same restrictions.

IV-3.1.4.1 Comparison of ISL with ANATEC data

Only a partial comparison between the ISL and ANATEC is possible. The reason being that the ISL only registers vessels with a capacity above 500 [tdw] whereas the ANATEC data do not have any tonnage restriction regarding the registered ship traffic, but do not include traffic of recreation and fishing vessels.

The method of analysis also differs. The ISL databases uses the data obtained for the first quarter of the year 2000 and extrapolates these for the entire year. ANATEC is also based on the data of "LMIS" for 2000 and 2001, but takes account of seasonal variations.

Figure IV-13 is a graph of all ship movements. To enable this comparison all the ANATEC were combined according to the areas listed in the ISL statistics. Both statistics represent the ship traffic in a similar manner.

The highest traffic was found to be in the "Fehmarn Belt" [76 832 ship movements/year] (ANATEC) and [80 148 ship movements/year] (ISL) and the "Kadetrenden" [ca. 65 700 ship movements/year] (ANATEC) and [63 136 ship movements/year] (ISL). Due to the traffic in the Kiel Canal the area of the Kiel Bight also had strong traffic of 27 354 [ship movements/year] (ANATEC) and 29 092 [ship movements/year] (ISL). The area with the least traffic was the Fehmarn Sound with 64 [ship movements/year] (ANATEC) and 532 [ship movements/year] (ISL).

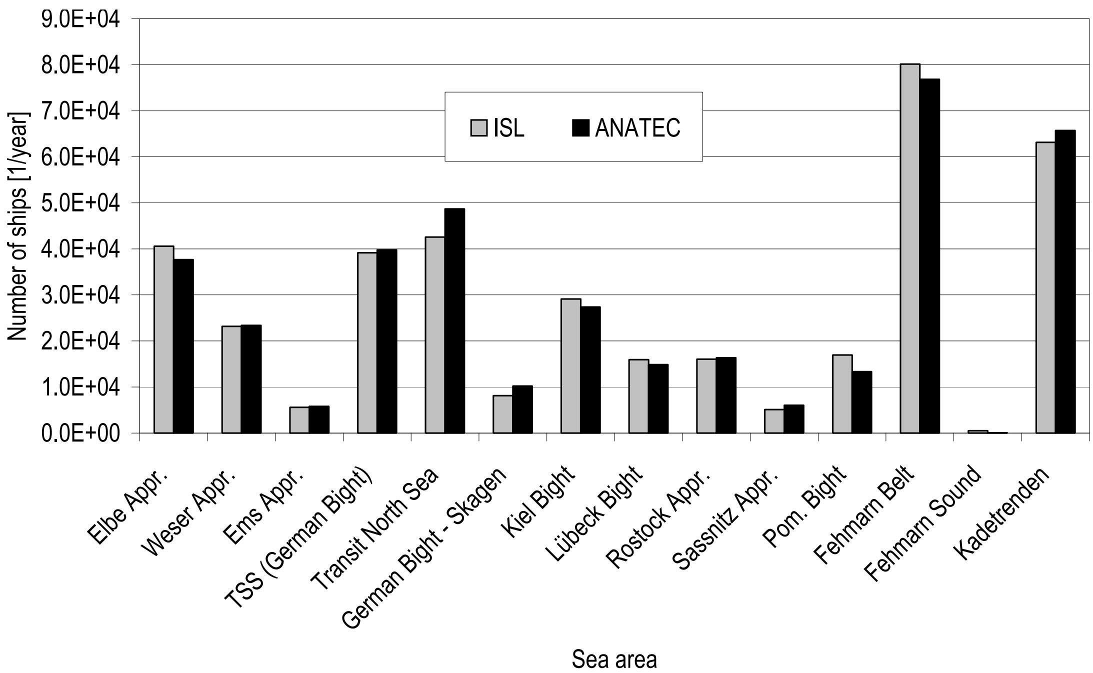

Figure IV-13: Comparison of ISL and ANATEC data on ship traffic

The most frequented routes in the North Sea are the sea area "Elbe Approach" with 37 670 [ship movements/year] (ANATEC) and 40 596 [ship movements/year] (ISL). The ship traffic in this are comprises the ships, which call at ports of the Elbe River as well as those, which pass through Kiel Canal. A comparison of the traffic of the "Transit North Sea", "German Bight - Skagen" and that of the Traffic Separation Scheme are of interest for the zone of the EEZ. A total of 48 672 [ship movements/year] (ANATEC) were registered for the route "Transit North Sea" and 42 576 [ship movements/year] by (ISL). Distinctly less traffic was recorded for the “German Bight – Skagen” ca. 10 188 [ship movements/year] (ANATEC) and 8 116 [ship movements/year] (ISL).

Figure IV-14 shows to what degree the data sources differ from one another. There is a good correlation between the data on ship movements for the zones "Ems Approach", "Weser Approach", "Elbe Approach" as well as for the traffic in the Traffic Separation Scheme "TSS Terschelling German Bight", "TSS German Bight Western Approach" and "TSS Jade Approach".

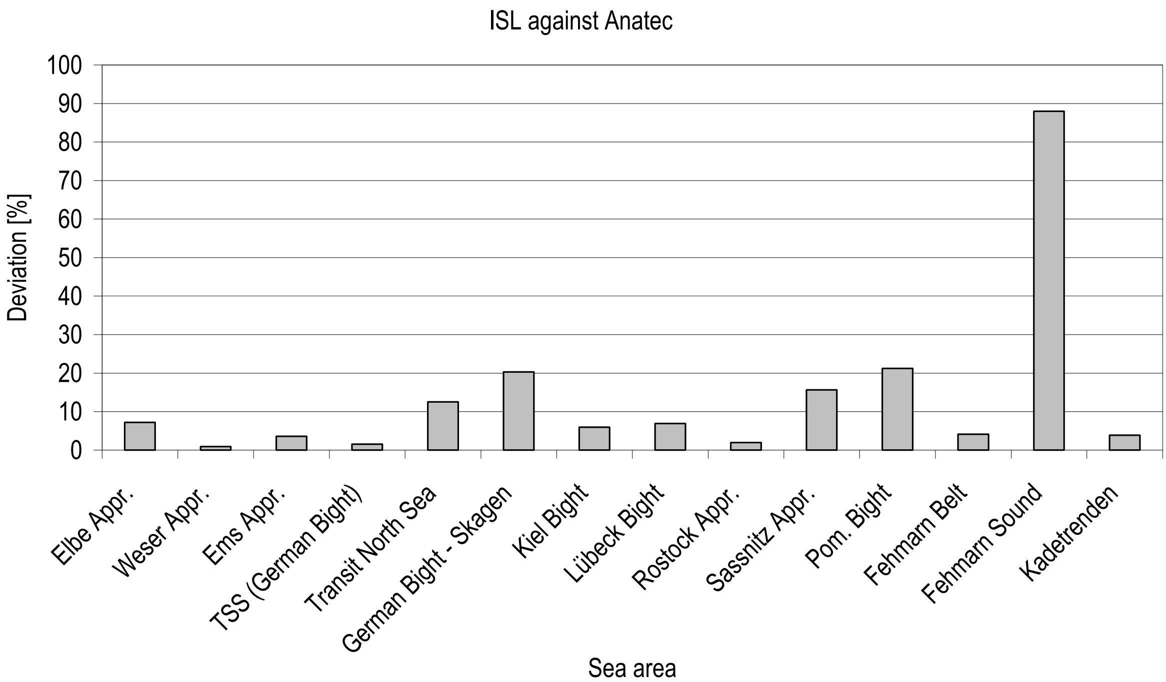

Figure IV-14: Deviation between ISL and ANATEC statistics

The deviation lies below 10% for these sea areas or routes. The differences are probably caused by the difference in origin and processing of the data, as mentioned above. The differences are larger for the sea areas "Transit North Sea" and "German Bight - Skagen" with ca. 13% and 20% respectively. The opposite trend observed for the areas "Elbe Approach" and "Transit North Sea" as well as. "German Bight - Skagen" indicates that the division of traffic from Great Britain, the Netherlands and the English Channel through the Kiel Canal or alternatively over Skagen were evaluated differently. The same applies for the ships, which navigate from the German North Sea ports into the Baltic. The numbers imply that ANATEC attributed more ship movements of transit traffic Baltic/North Sea to the route through the Kiel Canal and the Traffic Separation Schemes than the ISL database did.

The differences in the statistics for the Baltic Sea are less than 10% for the "Kiel Bight", "Lübeck Bight", "Rostock Approach", "Fehmarn Belt" and the "Kadetrenden". For the areas “Saßnitz Approach" and "Pomeranian Bight" the differences are larger. The absolute ship numbers, see figure IV-13, show that allocations of ship movements to sea areas were different. For the sea area "Pomeranian Bight" the ISL shows a higher number of ship movements compared to the ANATEC, whereas for the “Saßnitz Approach" ANATEC has larger numbers.

There is a particularly large difference in traffic numbers (88%) for the area "Fehmarn Sound". The reason for this difference might be the different assessment of the traffic through the Fehmarn Belt, which may also alternatively navigate through the Fehmarn Sound. However, the absolute values for the "Fehmarn Sound" are relatively low 532 [ship movements/year], also for the ISL.

IV-3.1.4.2 Comparison of the WSD-N1 source with data from ANATEC

The data compiled by the Directorate of water and Navigation in Tönning (WSD-N1) do not refer to sea areas but to shipping routes. Thus it is possible to compare these with the ANATEC data, which are also based on routes.

Figure IV-15 shows the traffic numbers of the shipping routes. The highest frequency was recorded on the route "Elbe, Bremen - Skagen" with an estimated 5000 [ship movements/year] (WSD-N1) and 6 992 [ship movements/year] (ANATEC). These were the maximum values obtained from both databases. The traffic to ports along the North Frisian Islands and the west coast of Jütland was much lower. The southwestern ports of Denmark were combined into a single route by ANATEC. Thus the ship traffic from and to Havneby and List were attributed to the Esbjerg route.

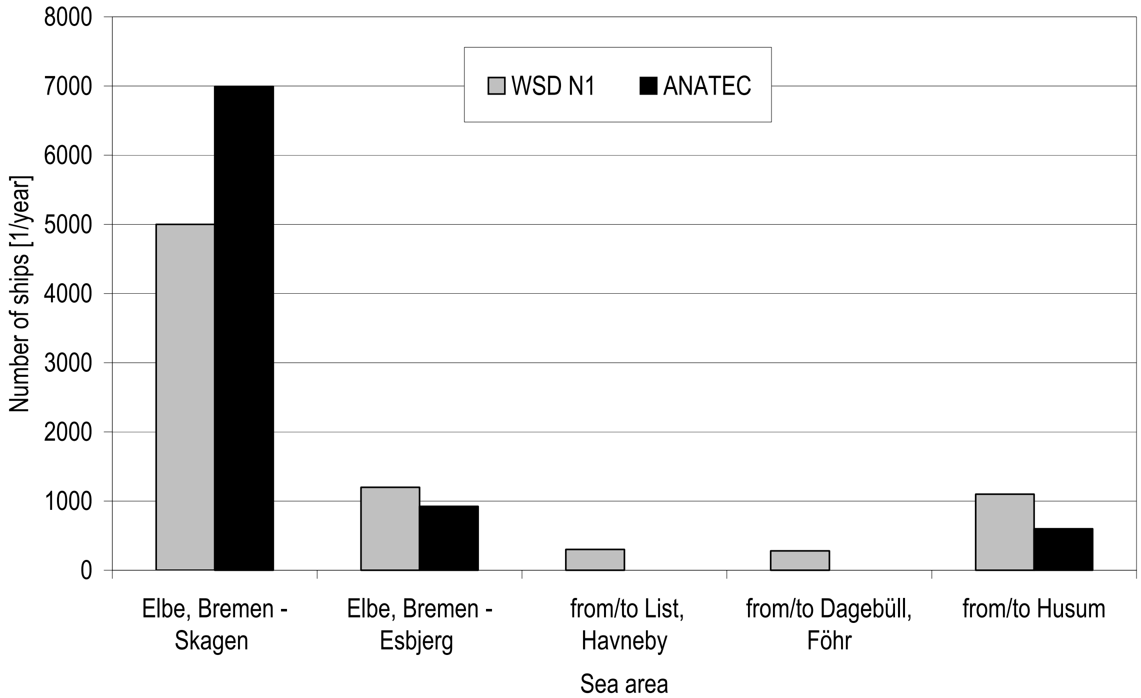

Figure IV-2: Comparison of WSD-N1 and ANATEC data

The quantitative statistical comparison of both data sets revealed distinct differences. There is a difference of 20% between the data of all routes. The largest deviations of 100% were found for the routes; "from/to List, Havneby" and "from/to Dagebüll, Föhr" since these routes were not listed separately by ANATEC. Although ANATEC attributed the latter routes to the "Elbe, Bremen - Esbjerg" route, the WSD-N1 still shows a 23% higher traffic for this region.

The reason for these differences could lie in the different registering periods. The data of the WSD-N1 source were obtained for 1999, whereas the ANATEC evaluated data for 2000. In addition, the data from WSD-N1 also include fishing vessels which is not the case for ANATEC.

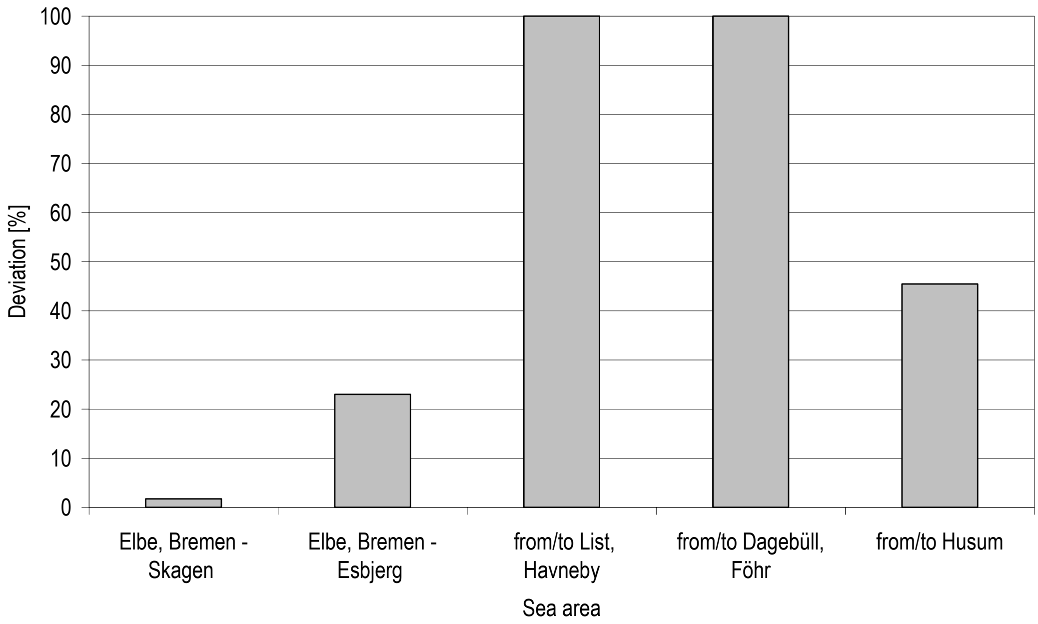

Figure IV-16: Graph of the differences between estimates of ship traffic of the ANATEC and WSD-N1 sources

IV-3.1.4.3 comparison of WSD-N2 and ANATEC data

This comparison also yielded large differences between WSD-N2 ANATEC data. Generally the number provided by WSD-N2 is larger than that of ANATEC. A 90% difference exists for data for the sea areas "Flensburg Fjord" and the approaches of Wolgast and Stralsund.

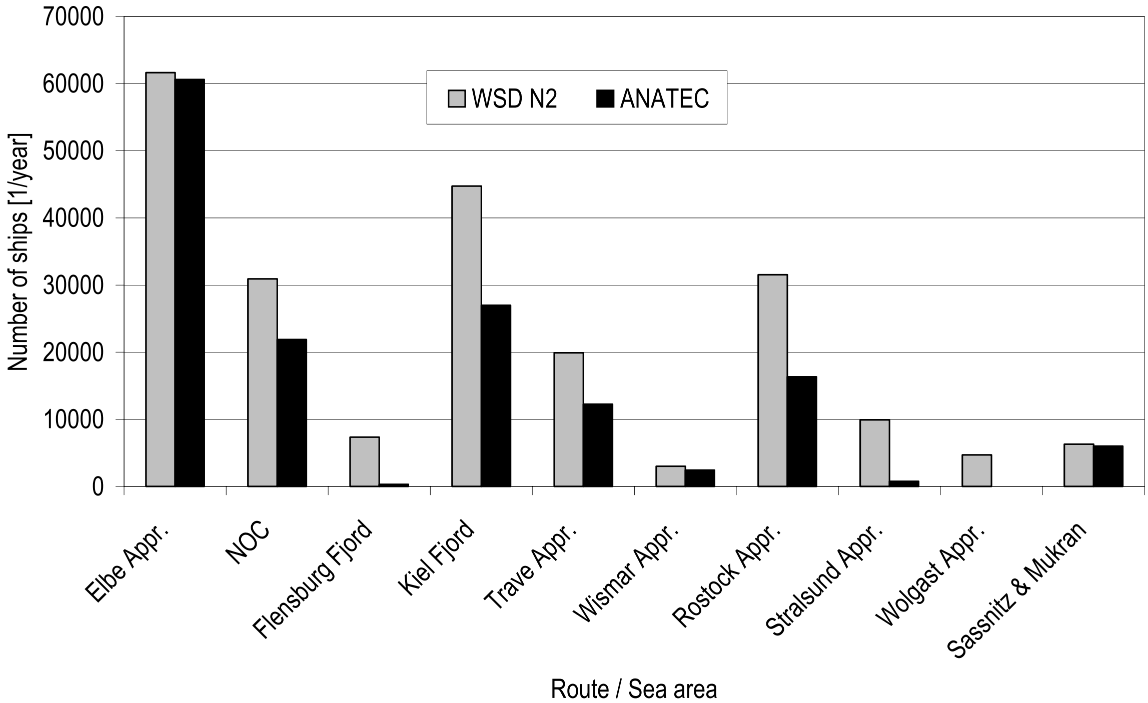

Figure IV-17: Statistics of the sources WSD-N2 (1999) and ANATEC

The differences are probably caused by the directorate of Water and Navigation North Region included fishing vessels, which is not the case for ANATEC. Since the fishing vessels cannot be identified in the WSD-N2 source, it is not possible to deduce the vessel type from the ANATEC data. The ship numbers of both sources are shown in figure IV-17.

IV-3.1.4.4 Comparison of the source WSD-NW1 with data from ANATEC

The first data source from the Directorate of Water and Navigation North West region has detailed information on traffic in the Traffic Separation Schemes of the German Bight and on the approaches and departures from ports along the Jade, Weser, Ems and Elbe.

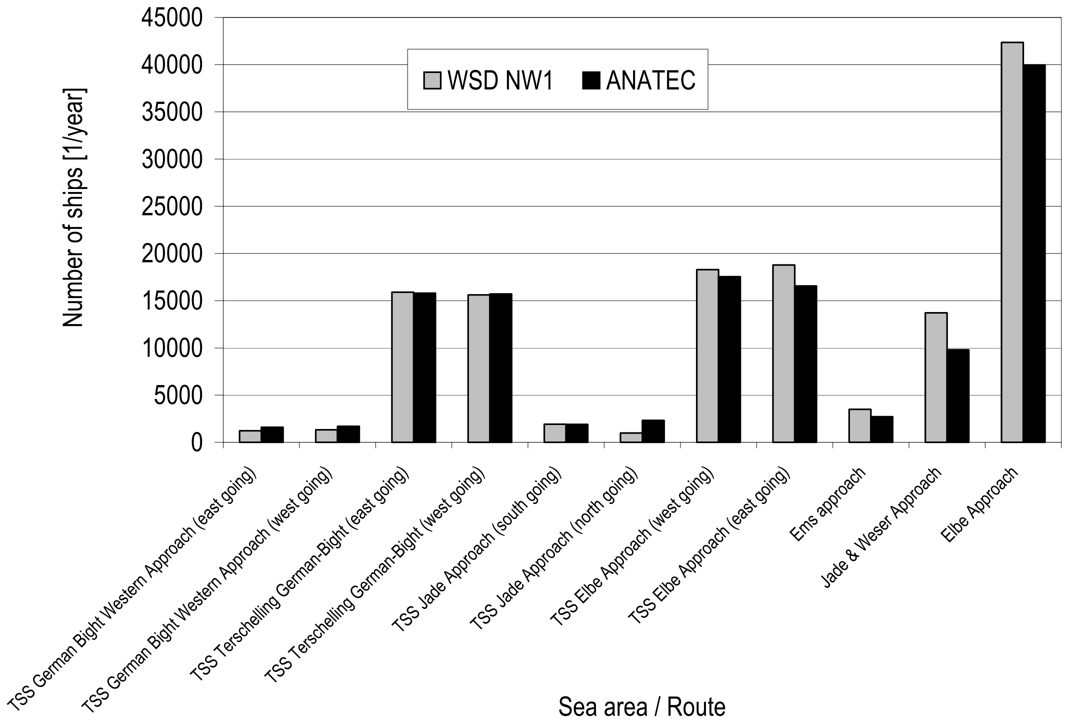

Figure IV-18: Comparison of data sources WSD NW1 and ANATEC

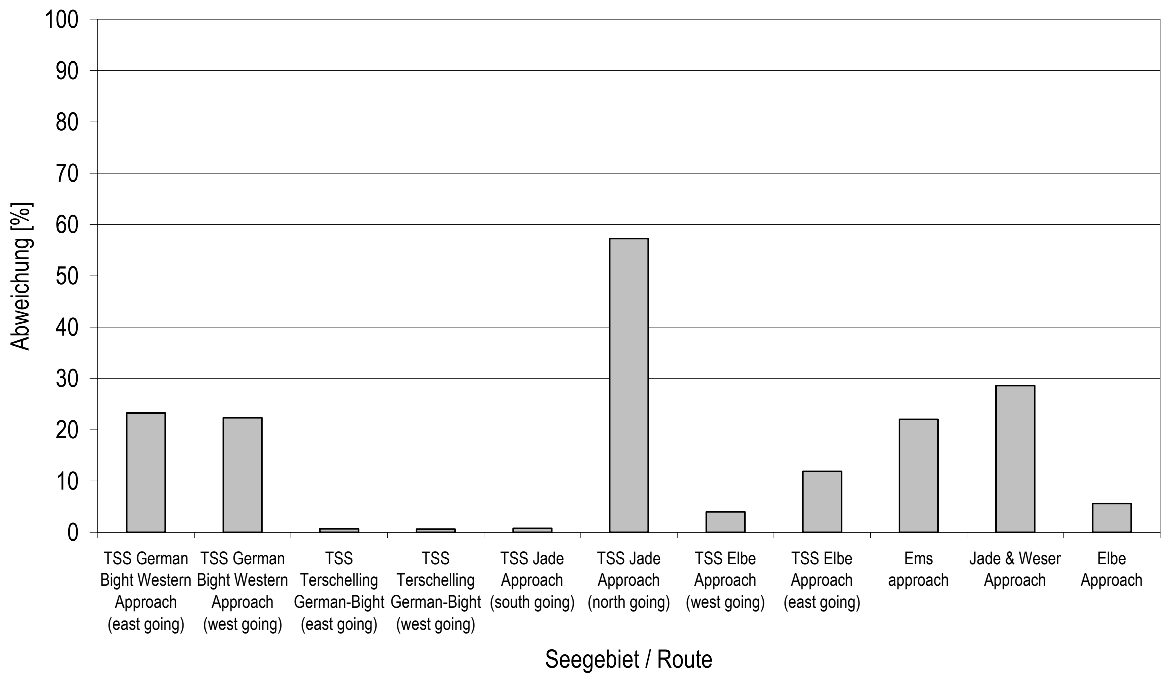

Figure IV-19: Deviation between the data sources WSD-NW1 and ANATEC

The sources attribute maximum numbers of 42354 [ship movements/year] (WSD-NW1) and 39972 [ship movements/year] (ANATEC) to the "Elbe Approach". As mentioned previously the high traffic numbers are comprised from the traffic to and from the ports on the Elbe and the Transit traffic through the Kiel Canal (Figure IV-18). A large portion of the transit traffic is either coming from or leaving in a westerly direction and thus passes the Traffic Separation Schemes "TSS Elbe Approach" and "TSS Terschelling German-Bight".

The percentage deviation of the data sources is shown in figure IV-19. There is a good agreement between the traffic data of the Traffic Separation Schemes "TSS Terschelling German Bight" and "TSS Jade Approach (south course)". The deviations for this route lie below 1%. It is therefore surprising that the route "TSS Jade Approach (north course)" has the largest deviation (57 %. There is no explanation for this deviation.

IV-3.2 Transport of dangerous goods in the North and Baltic Seas

One of the priorities of this research project was to identify routes on which vessels carrying dangerous cargo navigate. This section therefore deals with this aspect in more detail. It is preceded by a short description of the current rules and regulations applicable to the transport of dangerous goods at sea, which is followed by figures on the distribution of oil, gas and chemical carrier traffic.

IV-3.2.1 Rules and regulations for the Transport of dangerous goods

This section provides a short overview of the rules ad regulations concerning the transport of dangerous goods at sea. Bahlke (1998) provides a comprehensive overview on the topic of Transport of Dangerous Goods.

- *Recommendation on the Transport of Dangerous Goods (Orange Book)*

The Economic and Social Commission of the UN 1957 released the Recommendation on the Transport of Dangerous Goods. Aim of this recommendation is the harmonization of regulations on the transport of dangerous goods with different modes of transport. Although not binding, the recommendations were usually included in the regulations of the different means transport and have thus become standard. The committee of experts regularly revises the recommendations. The 9th version is currently valid.

- *International Convention for the Safety of Life at Sea* (SOLAS)

The SOLAS agreement (IMO 2001) regulates the safety aspects of the equipment and running of internationally operating vessels of a size above 500 [gt]. The first version of the SOLAS agreement was accepted by the "International Maritime Organization" (IMO) in 1960.The current version of the agreement became effective in 1980 in Kraft and poses the minimum requirements regarding fire protection, stability, life saving appliances and cargo safety. Chapter VII of the SOLAS agreement deals with the transport of dangerous goods on passenger ships. The SOLAS agreement stipulates the implementation of the ISM Code for shipping. The SOLAS recommendation was recently revised and implemented in 2002. By 1998, a total of 138 States had ratified the agreement and thus converted it to national law.

- *MARPOL - International Convention for the Prevention of Pollution from Ships*

The MARPOL convention (IMO 1997) constitutes the agreement itself as well as a number of protocols and amendments, which have become effective in stages. The MARPOL agreement defines the term; pollution in the sea and has compiled regulations regarding the notification of incidences concerning harmful substances, rules regarding the prevention of oil pollution as well as regulations concerning the monitoring of the transport of dangerous fluid substances classified as bulk cargo. The transport of harmful substances in packaged form as well as the prevention of pollution by ship effluents and garbage is also dealt with. The first version of the MARPOL convention was accepted by the IMO in 1973. The convention has to be ratified by the individual states in order to convert it to national law.

- *IMDG Code - International Maritime Dangerous Goods Code*

On 27th September 1965 the IMDG Code was accepted the by the IMO. It is probably the most import body of rules and regulations on the transport of dangerous goods on the sea. The IMDG Code is a recommendation and therefore has to be ratified by the individual states to become binding law. Approximately 80% of the world trade tonnage is registered in states, which have implemented this recommendation. The code is valid for all ships on which the SOLAS recommendation is applicable and which transport dangerous goods. The legislation provides recommendations how and to what extent dangerous goods are identified and categorized. The regulations also deal with aspects such as the labelling, packaging and the stowage of such goods. In Germany, this regulation has been implemented and is thus a binding law.

- *MoU - Declaration of the transport of dangerous goods on Ro/Ro carriers and ferries (Memorandum of understanding / Baltic)*

The MoU exists since 1974 and is based on the 3rd paragraph of the provision of dangerous goods. It is regularly revised and adapted to the IMGD code. The first part of the MoU deals with the regulation of the Spa traffic between the North and East Frisian Islands. The second part is a directive for the transport of dangerous goods by ships in the Baltic. The MoU differentiates between long and short routes. The strict adherence to the IMGD Codes is prescribed. In addition guidelines are provided for the construction of road and railway tankers. Regulation for the stowage, labelling, packaging, classification and documentation is provided for short routes. The regulation provides the basis for the land-based implementation for the dangerous goods regulation on ships. The specific problems of sea traffic are taken into account.

- *HELCOM – Helsinki Commission - Baltic Marine Environment Protection Commission*

The first agreement on the protection of the Baltic marine environment was signed in 1974 Baltic Sea neighbouring states and later by the European Union. Leading this treaty was the Helsinki Commission (Baltic Marine Environment Protection Commission). Aim of the treaty is the protection of the Baltic Marine Environment against all sources of pollution The HELCOM commission only deals with operative emission of pollutants and is not applicable in conjunction with collision of ships with WEP since these are considered accidents or breakdowns.

IV-3.2.2 Existing ship traffic of dangerous goods

The available sources were analysed with regard to transport of dangerous goods in the EEZ of the North and Baltic Seas. The WSD-N1 source did not include any data on this aspect. However, the data of theWSD-N2 source yield some separate information on the tanker traffic (Figure IV-20). The maximum tanker traffic thus occurs in the “Elbe Approach" with 9 559 [ship movements/year]. Figure IV-20 that a large proportion of this traffic passes through the Kiel Canal. For the number of tankers passing through the Kiel Canal 6 141 [ship movements/year] were registered. The number of ship movements for the Baltic harbours are considerably less. For the Baltic, the highest number (3 024ship movements/year) for tanker traffic was registered in the "Kiel Fjord". The numbers are distinctly lower in other areas. It must be remembered that this statistic only includes the traffic through the Kiel Canal. The routes passing through the Great Belt, the Small belt and the sound were not registered. A further subdivision of the ship traffic into Oil, gas and chemical tankers was not discernable from the data.
The WSD-NW1 source also provides separate data on the tanker traffic. The maximum traffic was found on the "Elbe Approach" with 6 316 [ship movements/year] this value lies 445 below 44 % the comparable value from the WSD-N2 source. In addition, the WSD-NW1 source provides an extensive

compilation of the handling of dangerous goods in ports. However, it is difficult to attribute this information to the individual routes with the result that these data were not included.

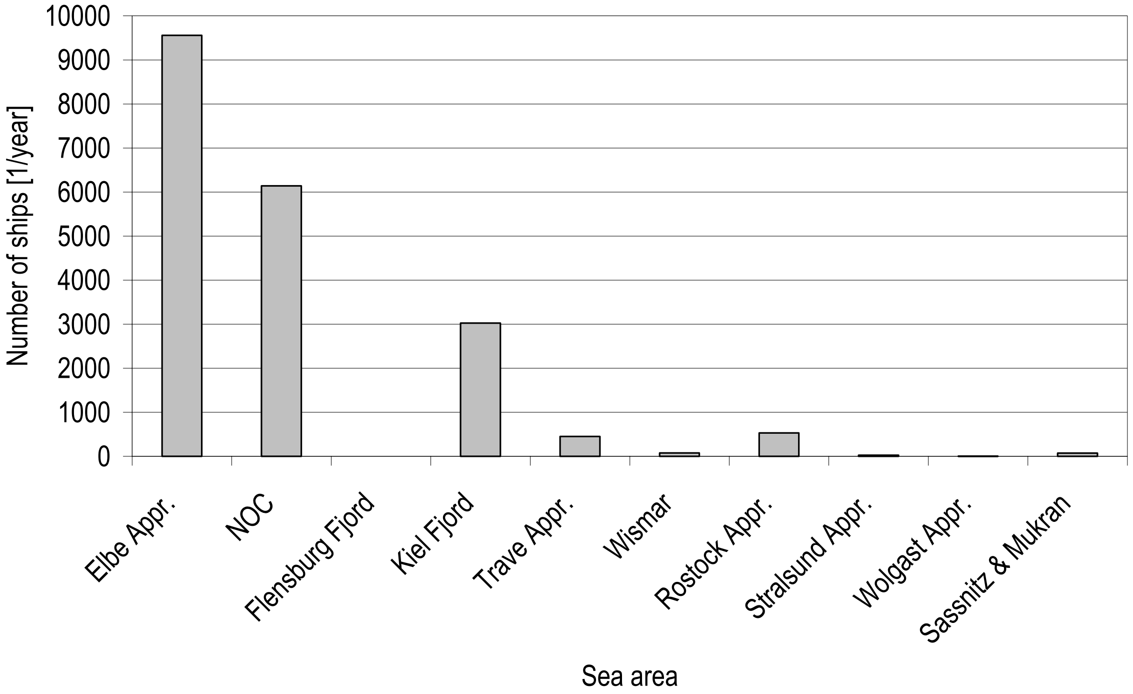

Figure IV-20: Tanker traffic from WSD-N2

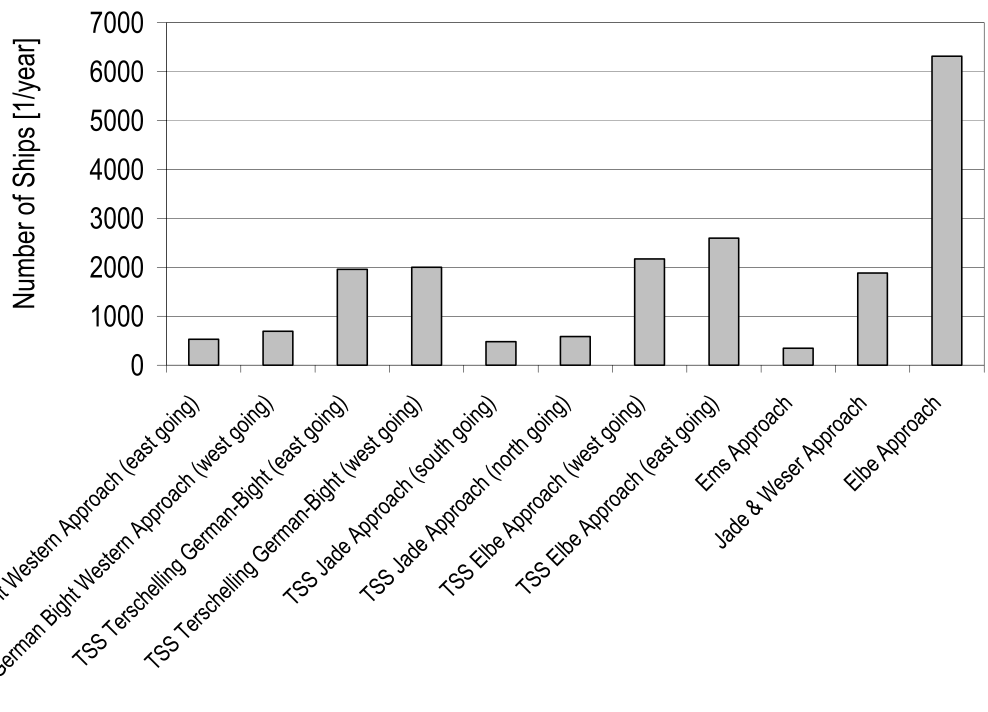

Figure IV-21: Tanker traffic from WSD-NW1

The traffic streams on which dangerous goods are transported were extracted from the ANATEC data. The transport density of oil and other chemicals were separated. The results are shown in the following figures. Oil and chemical tankers use the same routes as all other vessels, with the exception of the Traffic Separation Schemes. Oil tankers over 10 000 [BRZ], Chemical tankers over

10 000 [BRZ] with cargo according to MARPOL appendix II Group C and D as well as chemical tankers over 5 000 [BRZ] with cargo according to MARPOL appendix II Group A or B are forced to navigate the Traffic Separation Scheme "TSS German Bight Western Approach". The following figure shows the traffic densities of oil, gas and chemical tankers in the North and Baltic Seas. In the figures, it is possible to identify areas of increased collision risk. It is to be expected that areas with higher traffic densities will be at a higher risk of collision than areas with less traffic. More concrete information on the collision risk can only be provided when the dimensions, foundations and set up patterns etc of the wind parks are known. Thus, these figures can only serve as a preliminary orientation for the assessment of collision risk.

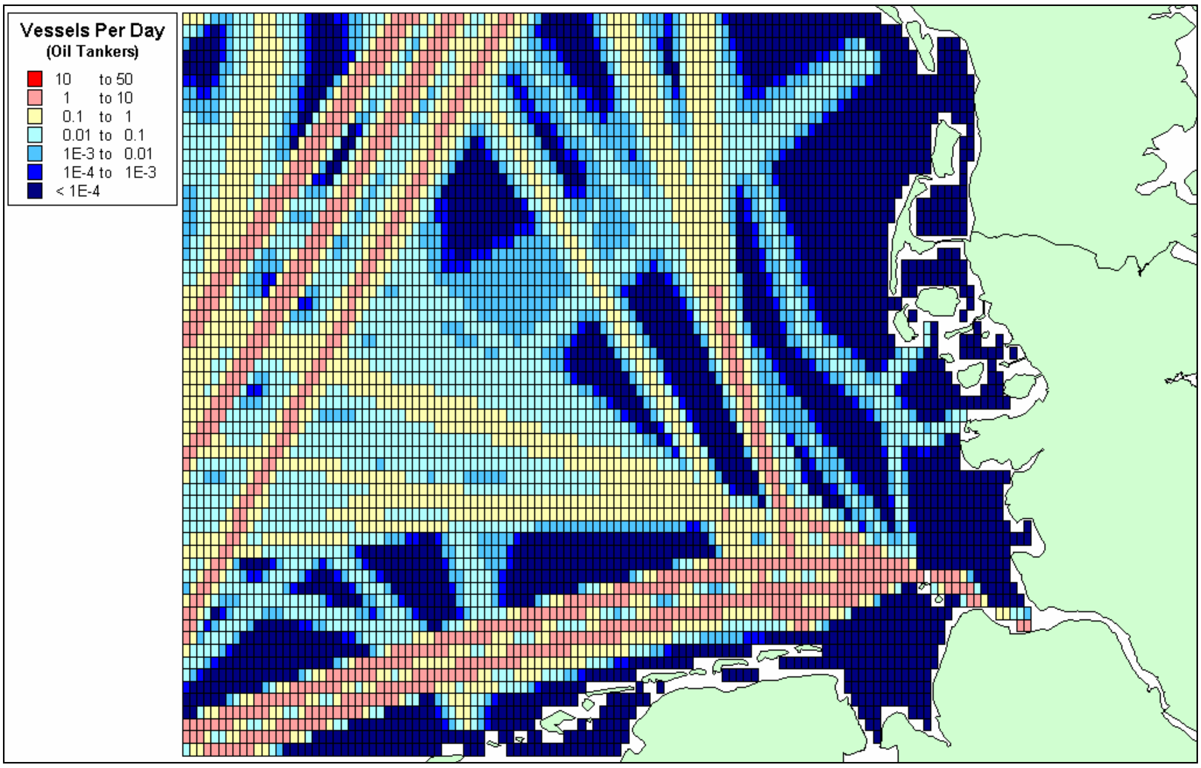

Figure IV-22: Density of oil tanker traffic in the North Sea

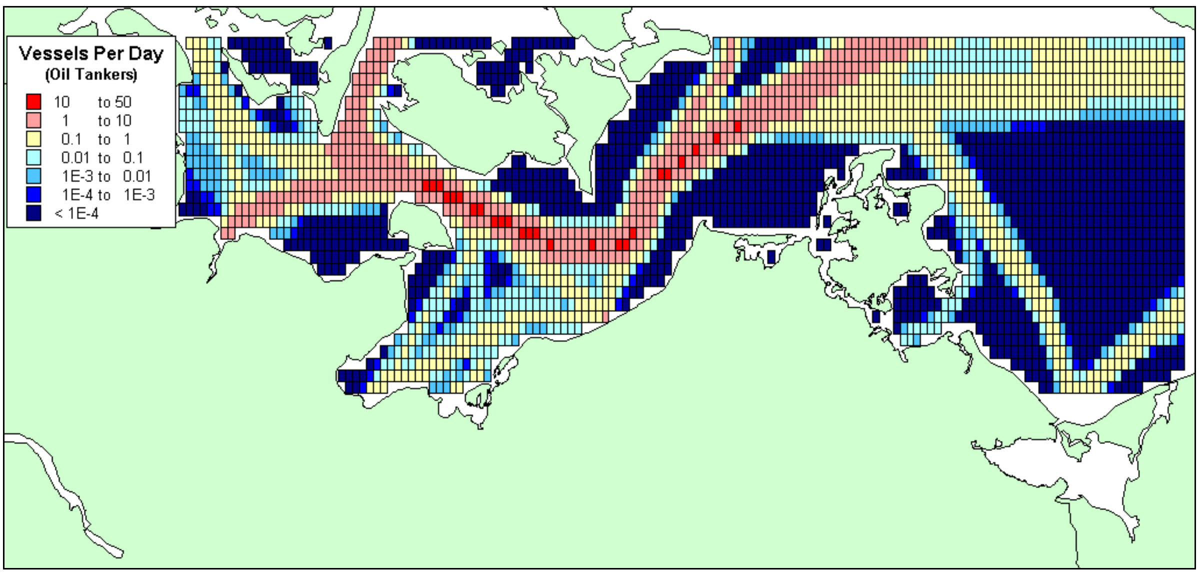

Figure IV-23: Density of oil tanker traffic in the Baltic

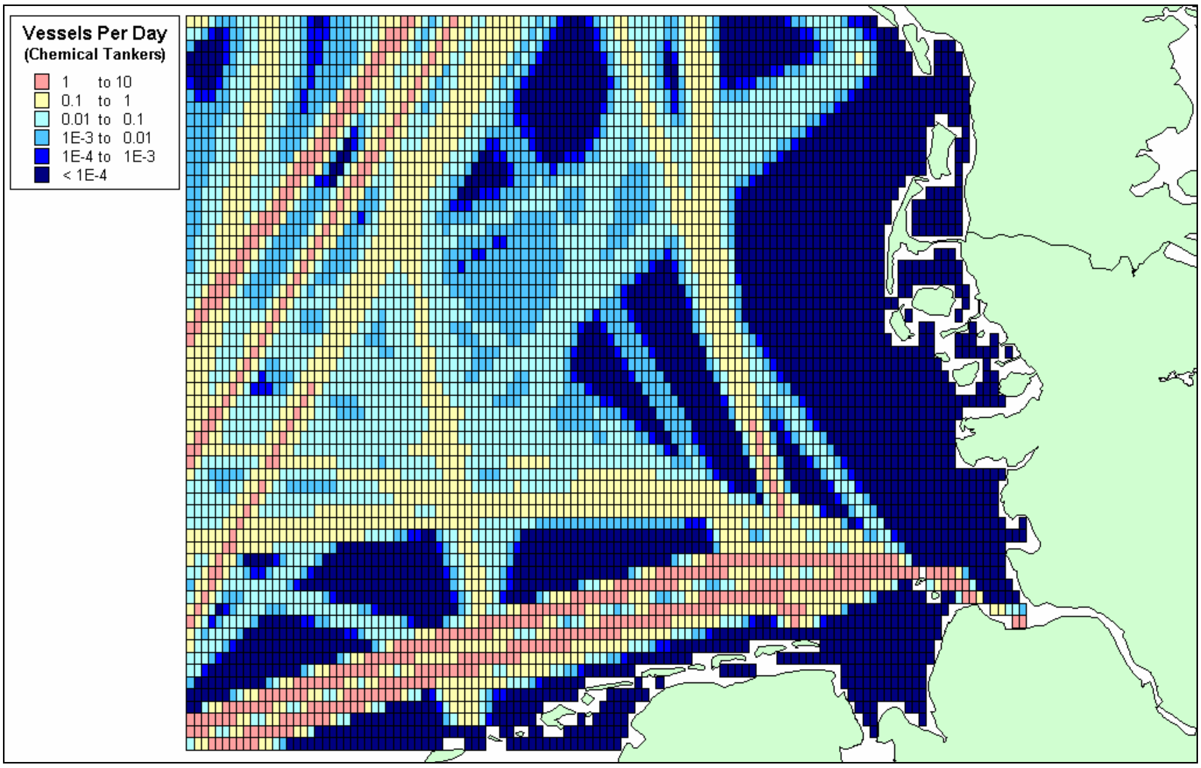

Figure IV-24: Density of chemical tanker traffic in the North Sea

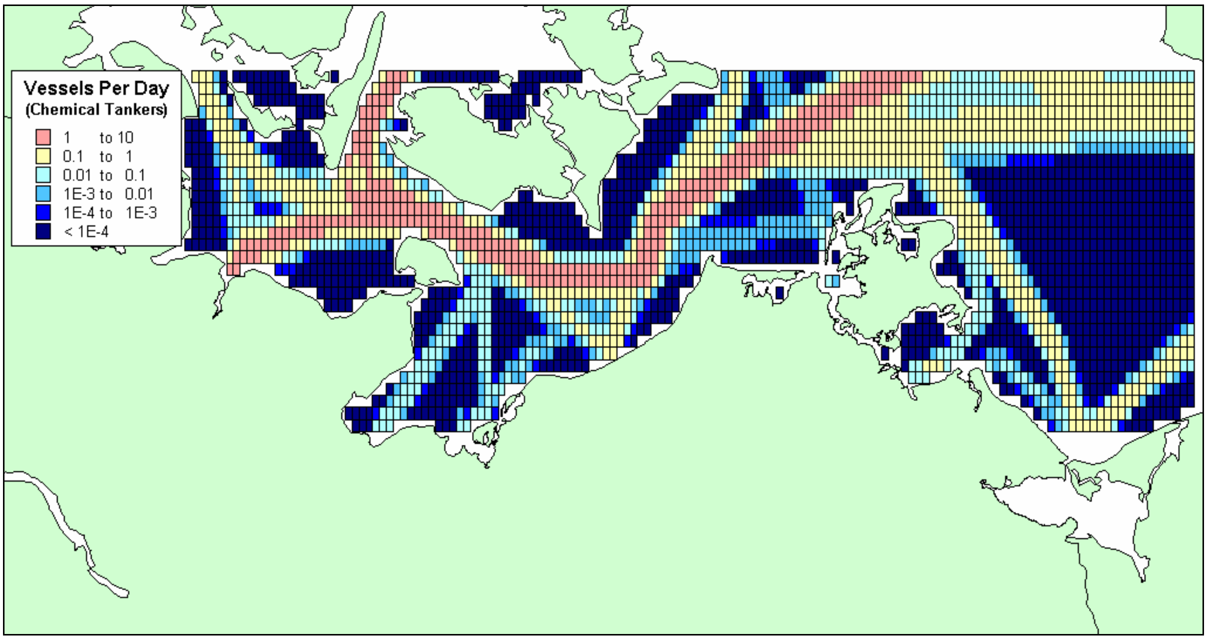

Figure IV-25: Density of chemical tanker traffic in the Baltic

IV-4 Methods to assess collision risk between offshore WEPs and ships

IV-4.1 Historical overview on the use of risk analyses.

Man in every day life intuitively assessed and evaluated risks. Colloquially, risk is regarded as a challenge, danger or possible loss during an unsafe undertaking. (Duden 1990). The roots of the quantification of risks date back to antiquity. First attempts were made by gamblers who sought a way to improve their wins in dice games. Later, insurance companies developed methods to cover the risks of claims. Much progress was made by the development of calculation after the opening of stock markets, so as to estimate gain and loss in the dealing with securities.

The beginnings of the use of analyses to quantify risks in the maritime industry date back about three decades. During the early 70s they concentrated on technical aspects of shipping in order to determine the reliability of engines on ships. These efforts were later expanded to include the offshore oil and gas industry. During the 80s and 90s the application of risk analyses on safety technology in this industrial branch was strongly belaboured. This resulted from a row of accidents in conjunction with offshore oil and gas platforms. Probably the worst accident occurred on the 6th July 1988 on the British Oil Platform Piper Alpha in the North Sea, when 167 people lost their lives. The economic damage was estimated to e 3.5 billion dollars. The reaction of the British authorities on the investigation of this accident (Cullen 1990) led to the establishment of the "Safety Case" Regulation (HSE 1992), which in the meantime is a widely used rulebook for the offshore industry and is based on risk assessment. Up to that point in time risk analyses to estimate the dangers of offshore activities for the environment were only used in Norway.

The risk-based methods of calculation have been used extensively in the offshore industry in recent years. A proactive mentality has developed instead of a reactive mentality regarding the reaction to accidents Operators of offshore platforms, which are subject to "Safety Case" regulations are compelled to provide evidence that their installations conform to today’s state of technology and safety

Intensified efforts are also being made in maritime technology to introduce risk-based methods in the assessment of safety measures. In 1997 the IMO adopted a guideline (IMO 1997) with which risk based instructions could be developed. The instructions are based on the "Formal Safety Assessment" (FSA), which not only focuses on safety aspects but also covers environment relevant risks. Intensive research was carried out in this regard, on the European level (CAFSEA 1999).

IV-4.2 Scientific and technical definition of the risk

In a scientific technical sense a risk is defined as the product of the frequency F of an undesirable event and its consequences C.

$$R = F \cdot C \tag{IV-1}$$

Statistical data from similar systems are mostly used to estimate the relative frequency. For this purpose, the failure of technical systems or their components over a specific period are registered. This method is, however, only applicable if sufficient failures can be registered over a manageable period in order to provide statistically significant values.

Should the events occur so as not to enable their registration in a manageable period, it will not be possible to carry out a statistical analysis. However, in such cases it is often possible to statistically determine the factors, which have caused the incidences. The frequency of an undesirable incidence can then be determined stochastically[2], a process in which a sequence of values is drawn from a corresponding sequence of jointly distributed random variables, which have resulted in the undesirable event. A larger number of statistical methods have been developed in this field. Examples are fault-tree and event-tree analyses, Markov chains or Neural networks.

Should it not be possible to determine the frequency using the above two methods, there is still the possibility of questioning experts who are capable of making intuitive estimates of event frequencies and consequences due to their long term experience.

The results or consequences of undesirable events may differ considerably. They can principally be decided into five groups:

- Consequences for the lives and health of humans,
- Consequences for the environment,
- Economic and material consequences,
- Social consequences
- Ethical, political and legal consequences.

Generally it is not possible, or only with an unacceptable effort, to determine or quantify all the consequences of an undesirable event. However, this is often not the case with regard to risk, since events with heavy consequences do not necessarily entail a high risk, especially if the frequency is very low. Accordingly and befitting the aim of this project, only the consequences for the environment are considered.

IV-4.3 Aim of the risk analysis

Risk analysis is a method by which the risk of an action for man or environment is determined systematically, both quantitatively and qualitatively. The main aims of a risk analysis are:

- The identification of significant dangers as a basis for examination,
- The identification of conditions and sites where undesirable events occur, which can lead to injury to man, environment and assets,
- The identification of measures to reduce risks.

The results of risk analyses thus help to make decisions as to whether a risk associated with the installation or action is acceptable or not. It is also possible to assess whether risk-reducing actions, if quantifiable, can be carried out with an economically acceptable effort.

[2] Stochastics - designating a process in which a sequence of values is drawn from a corresponding sequence of jointly distributed random variables

IV-4.4 The classification of risk analyses in the decision-making process

Two aspects need consideration when making decisions (Figure IV-26) On the one hand the objective risk is determined by risk analysis. For this purpose, the problem to be treated (undesirable event) is systematically split up into less complex scenarios. Frequency and consequences are then determined both quantitatively and qualitatively by using statistical data as well as mathematical algorithms.

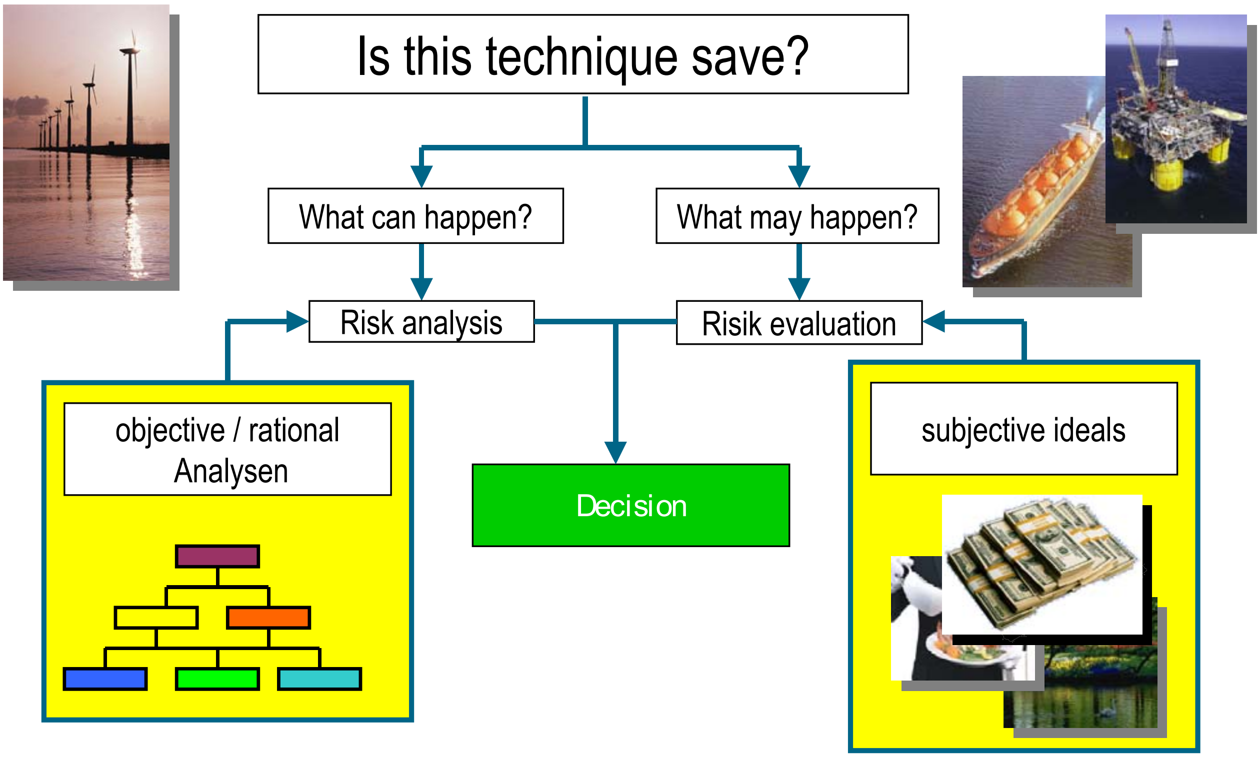

Figure IV-26: classification of results of risk analyses for decision making

The second aspect is the assessment of a risk, whereby the subjective ideals of the affected people need to be considered. These are uncoupled from the objectively existing risks and are thus difficult or impossible to determine rationally. The cause is the risk aversion (NSU 2001; Vrijling & van Gelder 1997), embodied in the subjective ideals of people.

IV-4.5 Methods and guidelines for the analysis of risks

As already mentioned in section IV-4.1 there are several standards for the analysis of risks in the shipping and offshore technology. The following sections describe the essential contents, aims as well as advantages and disadvantages of these guidelines since they also constitute the basis of the guidelines compiled in this report.

IV-4.5.1 Safety analyses

Some formalities dealing with safety aspects i.e. the protection of human life and health are presented in the following sections. They cannot offhand be transferred to risk analyses concerning possible environmental damage. Parts of the regulations and procedures can, however, be used for the current problem. This is particularly the case when the guidelines have a generic character and are thus applicable to other problems.

IV-4.5.1.1 SC - Safety Case Regulation

The main aim of the "Safety Case" regulation is to guarantee an adequate safety standard for technical installations. To achieve this goal, the risks associated with the installation need to be identified and quantified. In addition, procedures or measures need to be developed which maintain the remaining risk of the installation below the generally accepted risks one of the major advantages of the "Safety Case" regulations is that the responsibility of proving safety measures is with the operator of the installation. The "Safety Case" entails a detailed description of the plant, its processes and the environmental conditions. The results of the application of “Safety Case“ regulation are the (Safety Case) document. This provides, on the one hand, a detailed risk analysis and on the other a "Safety Management System" which has to be developed and implemented by the company.

The risk analysis is compiled by applying established methods of analysis such as FMEA and HAZOP methodologies to identify dangers as well as for example - Fault and event tree analyses for the quantitative estimation of existing risks. Acceptable risks are determined and compared to the computed risks using the acceptance criteria following the ALARP principle. The "Safety Management System" is a regulation in which the safety goals of a company are described. Furthermore, the organisation, planning, introduction and control of the effectiveness of risk reducing measures are also documented in the "Safety Management System".

Generally a preliminary "Safety Case" is produced before an installation goes into operation. During operation, the "Safety Case" is regularly revised and supplemented to account for modifications or alterations to the operational procedure. Regular inspections are carried out for this purpose. It is important that the "Safety Case" is developed in close co-operation between the involved parties who are familiar with the plants, the processes and the operational procedures.

The "Safety Case" regulations are primarily applied in the offshore oil and gas industry. An adaptation of the "Safety Case" regulations to wind parks is only possible in as far as it may serve to identify and estimate risks. The reason being that the "Safety Case" regulations were mainly developed for the assessment of safety evaluation (Danger to life and health of man). The assessments of risk for the environment are not included.
Detailed information on this method can be found in HSE (1992). A risk analysis produced in this manner can be seen in Kuo et al. (1997).

IV-4.5.1.2 FSA - Formal Safety Assessment

"Formal Safety Assessment" is applied to describe a systematic approach for the determination of safety relevant risks.
In the maritime industry the term "Formal Safety Assessment" (FSA) is combined with a procedure of the IMO (IMO 1997) in order to develop risk-based recommendations in ship technology. The FSA method of the IMO was developed by two working groups (Maritime Safety Committees, Environmental Protection Committee), on the basis of research in Great Britain. Both committees adopted the recommendations in 1997. FSA is a structured and systematic procedure based on risk analyses and cost benefit analysis. Aim of the FSA procedure is the increase in safety in the maritime industry, i.e. the protection of life and health as well as the protection of the marine environment. FSA was developed as a tool to develop risk based recommendations, which enable the assessment of the increase in safety and the expenses arising for safety measures.

The FSA comprises 5 steps:

1. Identification of the dangers and the assessment of the danger potential
2. Quantitative risk analysis of the dangers identified in the first step
3. Identification of measures so called. "Risk Control Options" (RCO) to check the identified risks
4. Cost benefit analyses of the measures identified in step 3. 5.Recommendations and decision guidance on the basis of information out of steps 1-4.

Generally applied analysis techniques are used to carry out the recommendations. These include qualitative analytical methods as well as structured consultation of groups (Brainstorming), the analysis of accident data or danger analyses and quantitative methods such as fault tree analyses or Monte-Carlo techniques. The technique to be used is actually prescribed.

Cost benefit analyses allow the user to estimate the impact of RCO's, whereby an effective use of resources is achieved with regard to existing risks. .

The FSA method is to be applied on a generic level in order to analyses all the risks in connection with special ship types, for example. FSA is not envisaged to be applied to individual plants or installations.

Extensive information on the methods is obtainable from CAFSEA (1999) and IMO (1997) an example of the application of the FSA method can be found in UK (1997)

IV-4.5.2 Methods to analyse dangers for the environment

IV-4.5.2.1 EA - Environmental Accounting

The idea of "Environmental Accounting" is to obtain information on a plant, a ship or any technical system over an extended period. The data mostly concern amounts of released pollutants. By comparing the collected data it is possible to deduce whether a plant has released more hazardous substances or not over a specific period. One goal of this method is to establish the impact of risk reducing measures (Measures to reduce pollution, $No_{x,}$ SO_x, oil,) The system limit of this method is the plant itself. This means that the effects of the pollution on the environment cannot be calculated nor determined in any other manner. The method takes into account both the emission during normal operation as well as the release of hazardous substances during an accidental breakdown. It is only applied during the operational phase of the plant. The construction and dismantling phase are not considered

IV-4.5.2.2 LCA - Life Cycle Analysis

"Life Cycle Analysis" or "Life Cycle Assessment" was defined in the Norm ISO 14040 (ISO 14040 1997) as a method to estimate the environmental compatibility of a product, a process or an activity during its entire life cycle. An LCA includes the following stages:

- Determination of the environmental burden of a product, process or activity during its entire life by quantifying required resources (Energy, raw materials)
  And the released hazardous substances and waste,
- Determination of the effects of utilized energy, raw materials and waste
- Identification of ways to reduce the use of resources and the arising waste

The LCA method is always appropriate for application when a comparison has to be made between different technologies. Problems often arise with the limitation of the system. I.e. by setting the quantitative limits after which influence and effects on the environment still have to be included in the analysis. More information on this method is provided by Nord (1995).

IV-4.5.2.3 EI - Environmental Indexing"

The method of "Environmental Indexing" is an elaboration of the method described in section 4.5.2.1 "Environmental Accounting". In addition to determining the emission of hazardous substances by a plant, this method also carries out an assessment of the impact of pollution on the environment. The degree of the effect or the consequences of the individual hazardous substances relative to each other are determined and are described by points or indices.

As with the "Environmental Accounting" this method also used the plant as a system limit and only the operational phase of the plant is considered. The release of hazardous substances during both the operation and an accident are used in the analysis. It is often very difficult to estimate the consequences and their significance between the two since usually there is very little information available on the effects of quantities and type of the individual hazardous substance on the environment. To bypass the problem of quantifying, the plants are often compared relatively to one another. An extensive example of the application of this method is provided by MacDonald (1999) and Selmer-Olsen (1996).

IV-4.5.2.4 ERA - Environmental Risk Analysis

The approach with the ERA resembles that of risk analyses, which deal with safety aspects. The analyses are termed ERA when the system limits are defined by geographical regions or habitats. The most important sources of hazardous substances and the sensitivity of the habitat components are identified. Frequency and severity of the pollution in the effected area are determined. Operational as well as accidental emissions are considered in the calculation. Also considered is the influence of risk reduction measures. Additional information on this method can be found in US EPA (1992).

IV-4.6 Risk acceptance, Risk aversion and Risk assessment

The appraisal whether an existing risk is acceptable or not can only be made by the comparison of the calculated or estimated risk using the so-called acceptance criteria. Acceptance criteria define the risk categories, which represent the borderline between acceptable or unacceptable risks.
As mentioned previously, values of comparable risks (other activities or installations) on the one hand as well as the subjective appraisal of persons, groups or society are combined to determine the acceptance criteria. It is therefore difficult to lay down general acceptance criteria. This section therefore concentrates on defining comparable risks. The influence of subjective ideals is neglected, since these have to be realized by decision-making persons.

Environmental risks differ from other risks because the external environment is affected by a variety of human activities. The term external environment in this study includes the surroundings and the coastline, which is potentially affected by an accidental collision of a ship with a WEP. The risk acceptance criteria should therefore take into account that different human activities are based on the same natural resources.
In defining the acceptance criteria with regard to collision of ships with WEPs, criteria for the different material classes need to be established according to their danger for the corresponding area. Fundamental to this is the fact that the environment reacts differently to different substances of the same concentration. It is generally very costly to estimate the sensitivity of the environment to all the various hazardous materials.
Acceptance criteria are, however, available for which it is not necessary to explicitly indicate the sensitivity of the environment. One such criterion is the regeneration time of the environment. I.e. the time required for the environment returns to its original condition. Accordingly the regeneration time of an area must be considerably less than the average time between incidences of pollution. The following example will show how this approach is used to define acceptance criteria.

Firstly, damage categories are determined (specific degree of consequences) Table IV-10. The value, H_t defines the upper limit of the so-called ALARP Zone for established average regeneration times $\overline{T}_r$. Figure IV-27 show the assessment of the calculated risks is obtained with the acceptance criteria. The diagram achses show the risk components, i.e. the collision frequency plotted against the consequences as regeneration time. A specific risk is attributed to a point in the diagram. If the point lies in the region of high risk, the risk is greater than the acceptable risk determined by the acceptance criteria. This requires the application of risk reducing measures. If the calculated risk lies within the ALARP Zone, risk-reducing measures should be investigated and applied under consideration of economical aspects. If the calculated risk is below the ALARP Zone, it is lower than that risk level established by the acceptance criteria.

Table IV-10: Example of defined damage categories

Category	Duration of environmental damage and recovery T_r [Years]
Insignificant	$0 < T_r \leq 7/365$
Considerable	$7/365 < T_r \leq 6/12$
Large	$1/2 < T_r \leq 1.5$
Catastrophic	$1.5 < T_r$

According to the definition the decision making person is required to quantify the term "considerably less". This factor k defines the relationship between the recovery period T_r and the average time between pollution events. In the current example k = 5.0 [%].
The acceptable time between events T_a is obtained from the following equation (IV-2), where $\overline{T}_r$ is the average time span required for the complete regeneration of the environment (Table IV-11).

$$T_a = \frac{\overline{T}_r}{k} \tag{IV-2}$$

The second aspect of the risk assessment in which the subjective ideals of affected persons have to be considered, is independent of the objectively existing risks and are thus very difficult to determine rationally, if at all. The reason for this is the risk aversion of subjective ideals.

Table IV-11: Acceptable incident frequencies for k=5 [%]

Category	Average regeneration period $\overline{T}_r$ [Years]	Acceptable accident frequency H_t [1/Year]	Average time between accidents [Years]
Insignificant	9.59E-03	5.21E+00	1.92E-01
Considerable	2.60E-01	1.93E-01	5.19E+00
Large	1.00E+00	5.00E-02	2.00E+01
Catastrophic	1.00E+01	5.00E-03	2.00E+02

Devooght (1999) describes risk aversion as a behaviour whereby persons not only fear injury but also the uncertainty of its occurrence. Or in other word, risk aversion is the assumption that the reaction by the public to 10 victims is greater than to 10 times one victim. Several sources from the literature have attempted to define risk aversion mathematically. A historical review of assessments of risk aversion is provided by NSU (2001) An explanation of risk aversion due to coincidence is attempted by Vrijling & van Gelder (1997).

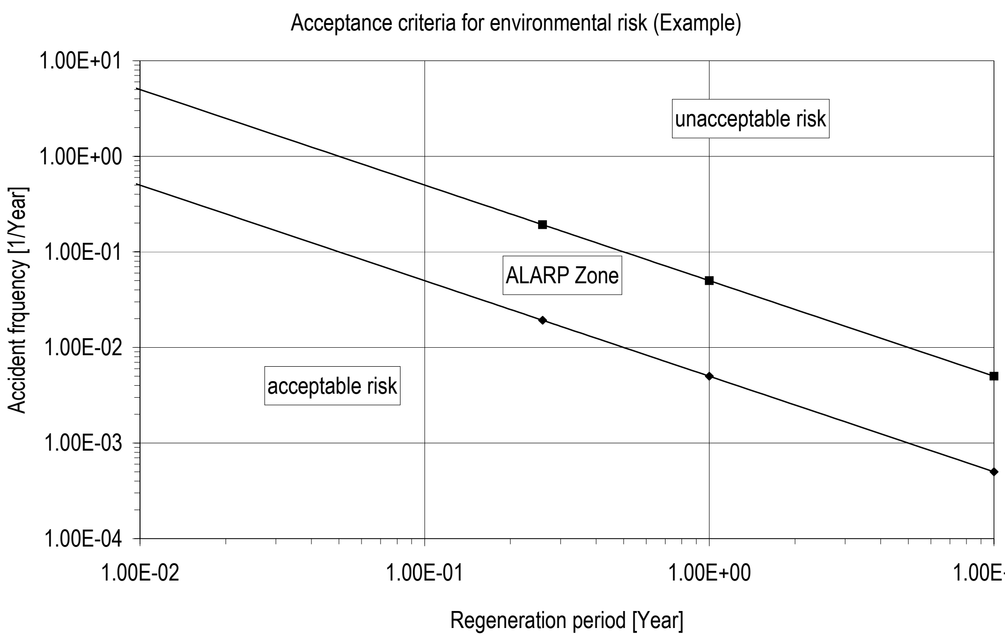

Figure IV-27: Example of a plot of acceptance criteria for environmental risks and the ALARP Zone

IV-4.7 Methods to identify and calculate collision risks

IV-4.71 Identification of collision risks

One aim of a risk analysis is the identification of all possible situations/scenarios where the potential danger of a collision between ships and a WEP exists. In order to include all potential dangerous situations it is necessary to systematically investigate probable failures and their consequences of all systems involved.

The formal danger analysis was developed according to the standardized failure effect analysis (DIN 25488). Aim of the danger analysis is to establish flaws in the system and at the interfaces as well as the establishment of possible single faults or single events, which could lead to a disaster. Danger analyses generally investigate single incidents or failures and not combination of events and failure.

The steps of a danger analysis are:

- Listing of all involved systems,
- Identification of undesirable incidents or failures,
- Establishment of results and consequences,
- Assessment of degree of failure A,
- Estimate of the probability of occurrence E,
- Determination of the risk priority number (RPN) by multiplying of A with E.

The assessment of risk resulting from the scenarios requires the evaluation of the probability of occurrence and the degree of failure or impact and a comparison with acceptance criteria. GLO recommended a Table, which enables the classification of the probability of occurrence and the impact of the scenarios (Table IV-12).

Four failure classes (from insignificant to catastrophic) and four probability classes (qualitative: from frequent to extremely unlikely) were defined. The combination of degree of failure and probability of an event in a column yields the still acceptable risk and thus corresponds to the upper ALARP limit figure IV-27.

Experience with offshore platforms has shown that generally two scenarios prevail. One is the collision with a manoeuvrable ship as a result of errors in navigation or the collision with a disabled drifting vessel. The following section introduces procedures to calculate the frequency and consequences of discussed collision events.

Table **IV-12: Classification of degree of failure and liklyhood of occurrence in the formal danger analysis**

Frequency H (1/year) safety (quantitative)	$H > 10^{-1}$	$10^{-1} \geq H > 10^{-2}$	$10^{-2} \geq H > 10^{-3}$	$H \leq 10^{-3}$
Frequency H (1/year) environment (quantitative)	$H > 2x10^{-1}$	$2x10^{-1} \geq H > 2x10^{-2}$	$2x10^{-2} \geq H > 2x10^{-3}$	$H \leq 2x10^{-3}$
Frequency (qualitative)	probable	improbable		extremely improbable
	frequent	remote	extremely remote	
Failure severity classification	minor	major	severe	catastrophic
Failure effect	• slight reduction of safety margins • small damage to property • slight reduction of stability or strength • small impact to the environment • slight increase in work-load • physical impacts, but no injuries to staff or crew • slight discomfort	• significant reduction of safety margins • medium damage • significant reduction of stability or strength • serious impact to the environment • Reduction of crew's/staff's capability to handle adverse conditions due to an increase of work-load or other conditions • Injuries to staff or crew	• severe reduction of safety margins and/or functionality • severe damage • reaching the limits of stability and structural integrity • big impact to the environment • a physical distress or work-load that does not allow the staff to reliably fulfil their tasks correctly and in a competent manner • serious/severe injuries to staff or crew, small number of deaths	• failure that leads to loss of the ship/ installation • high number of deaths • severe, long-lasting and wide spread environmental pollution

IV-4.7.2 Calculation of collision frequency of manoeuvrable ships

In collisions of manoeuvrable ships with WEPs it is assumed that the propulsion and steering systems of the vessels are functional.

IV-4.7.2.1 Calculation of collision frequency after Pedersen

Pedersen (1995) presents a method of calculation in which the collision frequency of manoeuvrable ships with unmovable objects can be determined. Pedersen acts on the assumption that two conditions need to be fulfilled simultaneously for a collision to take place. The first is that the vessel must be on a course of collision with one or several WEPs of a wind farm. The other is that no collision preventative measures must be in effect e.g. change of course by the crew. The probability of occurrence for both conditions has to be determined.

- *Calculation of the probability* P_{fK} *on course of collision with one or more WEPs*

Considering the ship traffic in the North and Baltic Seas (Section IV-3.1), it becomes clear that there are routes on which the traffic is concentrated. These routes arise inevitably since the ship's command chooses the shortest route between ports. Nautical restrictions such as TSS or shallows are, however, taken into account. Matsui et al. (1985) and Randrup-Thomsen et al. (2001) have shown that so called lateral distribution $h_l = f(z)$ occurs when the deviation of the vessels is seen as being orthogonal to the ideal route. See sectionIV-3.1.3. Such lateral distributions are shown in figure IV-28. . For routes without nautical restrictions, the distribution is normal. A typical lateral distribution is the distribution "a" shown in figure IV-28. It is assumed that the deviations of the passages from the ideal are similar on both sides and thus show a symmetric distribution. On prescribed routes such as TSS or buoyed channels (distribution function "b" in figure IV-28), the maximum of the distribution function (Modal value) shifts to the side of the channel, since the buoys are often used as orientation points and vessels have to navigate on the right according to the collision avoidance regulation KVR (1972).

The probability P_{fK}, that a ship is on collision course with a WEP in a wind farm, is determined by the surface area of the normalised distribution function $h_l = f(z)$, covered by the shadow area of the WEP plus 2 times the vessel width, when the shadow falls on the ideal shipping route. Thus for a WEP with a pylon diameter D of the i-th WEP the following probability is given:

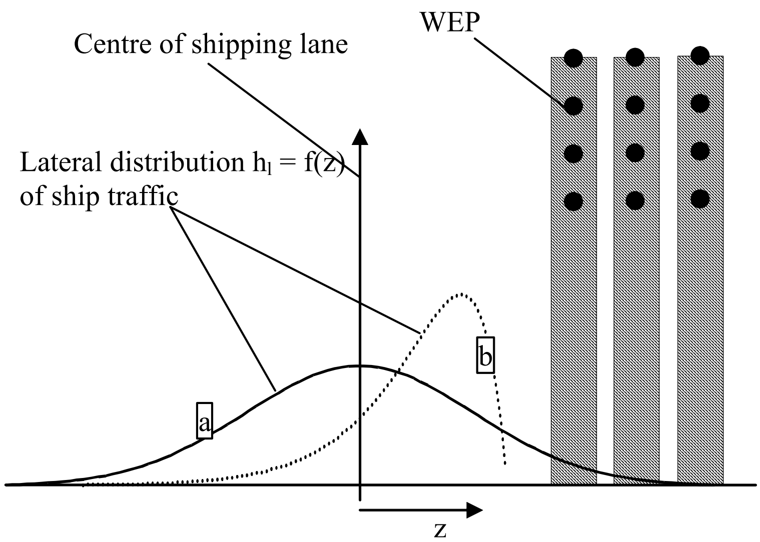

Figure IV-28: Different lateral distributions of ship traffic

$$P_{fK} = \sum_i P_{fk,i} = \sum_i \int_{D_i} f(z)dz \tag{IV-3}$$

This integration has to be carried out for all WEPs, whereby care has to be taken that the shadows do not overlap since components of the normalised distribution function, which are covered by other WEPs, would then be included.

- *Calculation of probability P_{fM} of failure or non-implementation of collision avoidance measures*

This probability P_{fM}, also termed “causation factor", includes all technical and human factors which result in the fact that ships are unable to avoid the plants in a wind park. Pedersen uses the error tree method for this probability (Figure IV-29), to integrate the individual factors into one probability factor P_{fM}. Extensive information on the error tree method which is widely used in safety technology is provided by DIN 25424 (1990), Vesely et al. (1981) or Barlow et al. (1975).

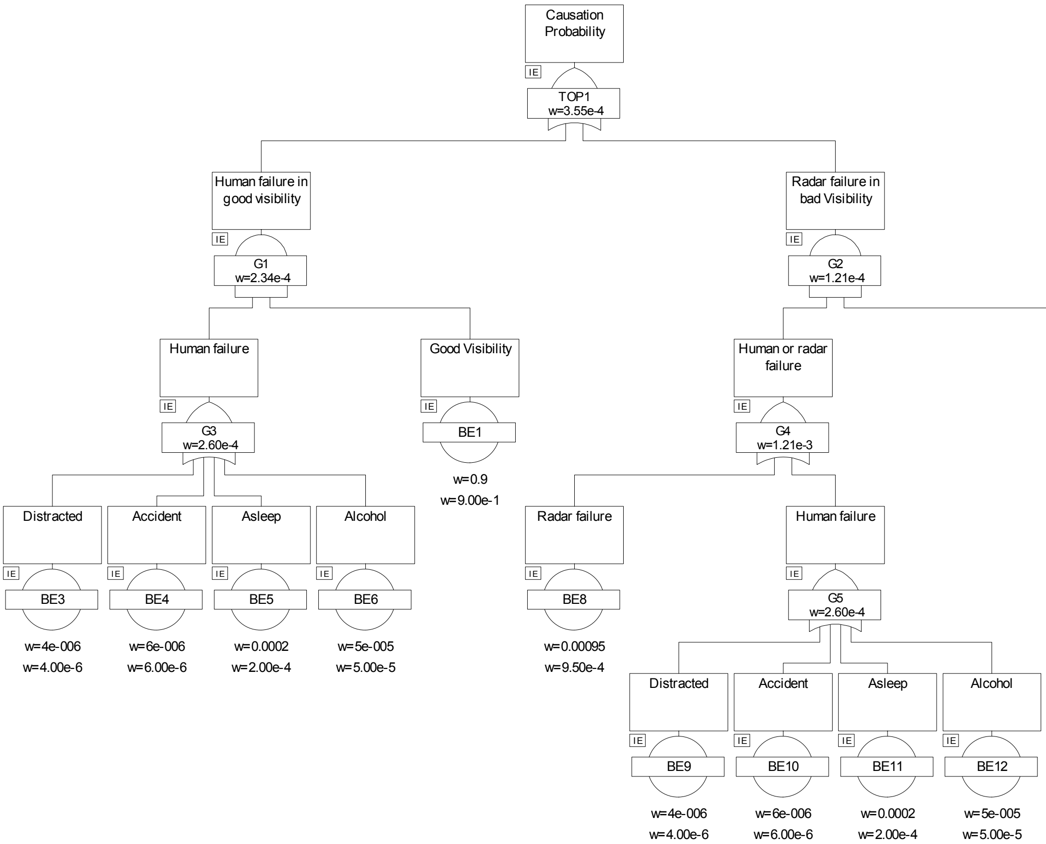

Figure IV-29: Example of an error tree used to calculate probability of failure P_{fM} from Pedersen 1995

- *Calculation of collision frequency*

The product of the probability P_{fM} and P_{fK} yields the probability with which, as ship will collide with a WEP in the wind park. The calculation of the probabilities P_{fM} and P_{fK} can be done for various vessel classes (Ship type, size, draft, equipment, crew training, etc). The expected frequency of collisions $n_{coll,pow}$ of ships with WEPs is derived from the number of vessels in every class $n_{S,k}$ and the corresponding combination of P_{fM} and P_{fK}.

$$n_{coll,pow} = \sum_{K} P_{fM,k} \cdot P_{fK,k} \cdot n_{S,k} \tag{IV-4}$$

- *Advantages and disadvantages of the method*

The method of Pedersen is widely used in the maritime world to calculate collision scenarios with manoeuvrable ships. The method is not only applicable for fixed objects, but can also be used to calculate collisions between ships by using some extensions (s. Otto et al. 2001). An advantage of the method is the simple calculation (Equation IV-4). A disadvantage is the use of the distribution function $h_l = f(z)$. Usually very few statistical data are available to determine the ends of the distribution function, which are required for the integration. An inaccurate fitting of the distribution function and its extrapolation of the ends may result in errors in the calculation of the probability P_{fK}. The calculation of the probability P_{fM} is extendible by fitting the Fault Tree (Figure IV-29) or by applying new methods and thus provide a more precise analysis of human behaviour and the failure of technical systems (Friis-Hansen & Pedersen. 1998).

IV-4.7.2.2 Calculation of collision frequency after

MARIN

The Maritime Research Institute of the Netherlands (MARIN) has developed a method to calculate the collision frequency which des not require the analytical lateral distribution of ship traffic. This method has been used to calculate risks in two projects.

The number of collisions is determined as follows:

$$n_{coll,pow} = NER \cdot \sum_{K} SO_k \tag{IV-5}$$

using NER the so-called "Navigational Error Rate". NER is a statistic value derived from collisions, which took place between ships and offshore platforms in the North Sea from 1978 to 1991. The source of the data is the accident database "Lloyd's Casualty Database". The analysis of the data yielded only one collision between a vessel and fixed platform. Thus, for a total of 193 150 weighted ship passages, this yields an NER ratio of 1/19350. This part of the equation contains the information, which in the Pedersen method is given by the probability P_{fK}. However, in this case it was statistically estimated.

The value SO_k includes the number of ships on a specific route section, which can be regarded as collision partners due to their course and distance from the Wind farm. It is determined with the aid of equation (IV-6)

$$SO_k = \sum_{N} \sum_{N_\psi} \sum_{I} P_n \cdot P_{n\psi} \cdot N_{ik} \cdot \int_{x_1}^{x_2} e^{-a \frac{d_{n\psi}(x)}{L_i}} dx \tag{IV-6}$$

where P_n - is the probability of a specific loading, $P_{n\psi}$ - the probability of a specific course, N_{ik} - the number of passages of the ship class i on the route section k, x_1 and x_2 - the limits of the route section, a - the danger parameter, x - the position on the route section k, $d_{n\psi}(x)$ - the distance of the vessel from the windpark (at position x, on the route section k, and course $n\psi$) and L_i - the length of the i ship class. Figure IV-30 shows some of the variables.

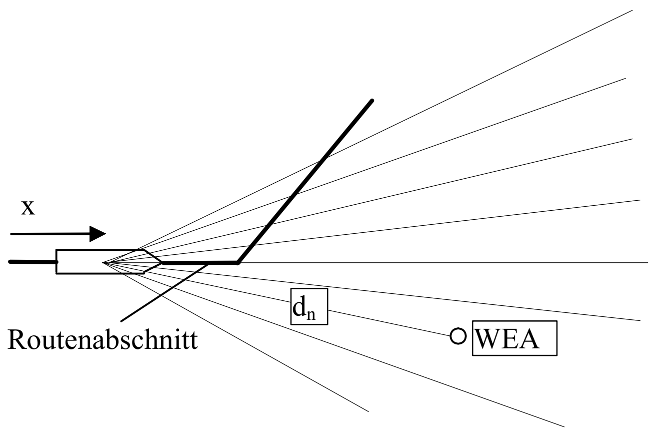

Figure IV-30: Scenario of a ship collision with a WEP (MARIN)

- *Advantages and disadvantages of the method*

The advantage of this method is that no lateral distribution of ship traffic is required for the calculation of collision frequency. All that is required are the number of ship movements and the distance of the route section from the WEP. The method is calibrated with the danger factor and the "Navigational Error Rate" NER. The relationship between collision probability and the distance $d_{n\psi}$ between ship and WEP is given by the exponential function in equation (IV-6), whereby the danger factor only determines the shape of the function. The effect of the danger factor a is shown in figure IV-31 For a distance $d_{n\psi} = 0$, the probability is 1, since the ship is already in contact with the WEP. The probability of collision decreases with increasing distance. An increase in the factor a increases the curvature of the function which results in lesser probability of collision when the distance $d_{n\psi}$ remains constant.

Since the danger factor cannot be determined rationally, but has to be estimated, the question is whether the uncertainties which arise by applying the lateral distribution of Pedersens method are not implicitly contained in the MARIN method through the estimation of the danger factor a.
A further disadvantage of the method is the calculation of NER. The calculation of NER on the basis of a collision event contains an unacceptable statistical uncertainty of 50 [%]. Even when considering that the calculated value NER is really the average of the navigational error, another 193 150 have to occur until another event can verify this value. Thus it is hardly possible to statistically verify the NER.

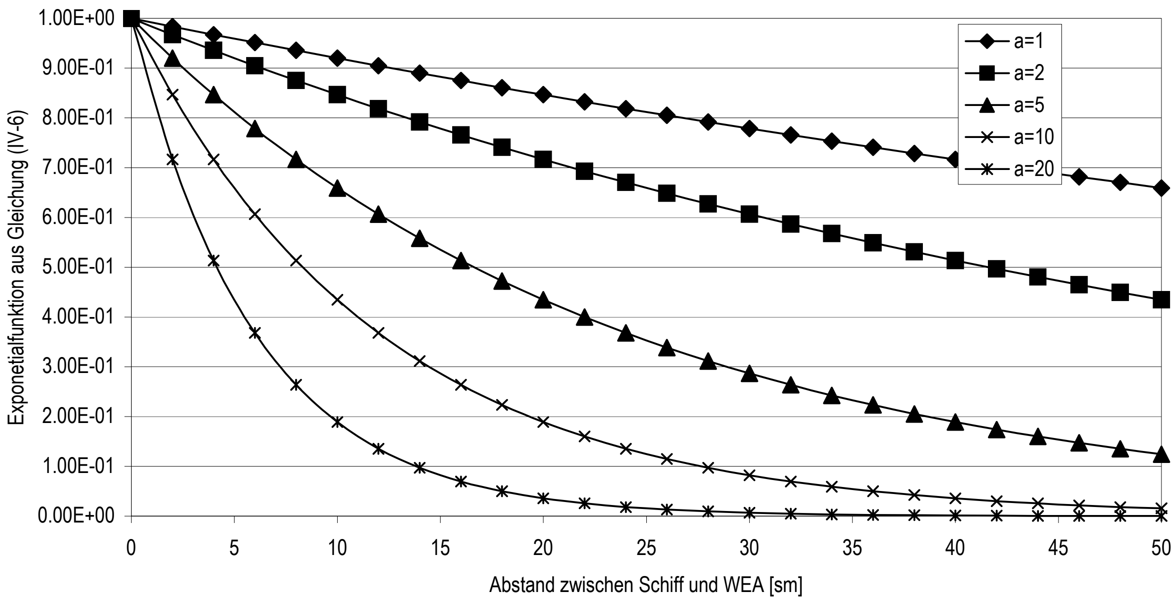

Figure IV-31: effect of the danger factor a on the probability of collision

IV-4.7.2.3 Calculation of collision frequency after GLO

Based on the method of Pedersen (1995), the GLO expanded the method. The idea behind the expansion was that the distance of a ship on collision course with a wind park influences the probability in which the ship's command would become aware of the course. Generally the ship's command carries out routine checks of the position and course of the ship. This means that the error can be detected and corrected during each check. The larger the distance between vessel and wind park, the higher the probability that the error will be detected.
To include this effect in the calculation, the equation of Pedersen (1995) was extended as follows:

$$n_{coll,pow} = \sum_{K} P_{fM,k}^{\frac{d}{t_c \cdot v_S}} \cdot P_{fK,k} \cdot n_{S,k} \cdot P_{aR} \qquad \text{(IV-7)}$$

In the equation (IV-7) d – is the distance from the beginning of the route section, t_c – the period between position checks v_S – the vessel speed. The exponent on its own shows the number of position checks from the beginning of the route section to the point of a possible collision (see figure IV-32).

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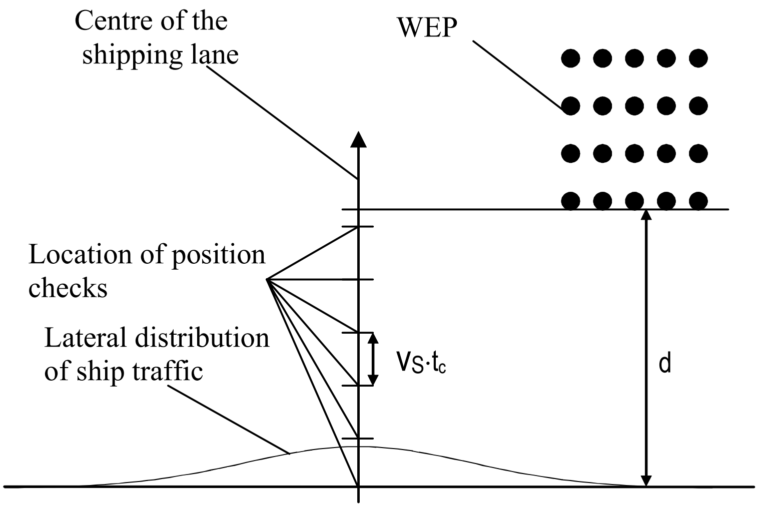


Figure IV-32: Additional variables used in the GL method

The additional factor P_{aR} was included to account for the time the ship has been navigating this route. Because this is the only period during which the danger of collision exists. The probability P_{aR} is derived from the time t_k during which the vessel is navigating the route section k the length l_k based on 1 year (8 760 h):

$$P_{aR} = \frac{t_k}{8760} = \frac{l_k \cdot v_S}{8760} \qquad \text{(IV-8)}$$

IV-4.7.3 Collision frequency of disabled ships

Ships are disabled when they lose their propulsion or steering capabilities. The movement of disabled ships results from the equilibrium between the forces acting on the vessel. These are wind, currents and waves. Measures such as emergency anchoring can stop the drift of the disabled vessel and therefore have to be incorporated in the calculation. The use of, the use of salvage tugs with which the disabled vessel can be stopped and towed out of the danger zone of a WEP, also needs to be considered. The fact that the failure resulting in the disablement may be restored by the vessel crew and thus prevent the collision also needs to be taken into account. The following two sections introduce two methods to calculate collision frequencies of disabled vessels.

IV-4.7.3.1 Calculation of collision frequency after MARIN

The calculation of the collision frequency of ships with WEPs is based on the consideration of a "dangerous" zone or section of a shipping route. If a ship is disabled in such a section and bad weather conditions exist at that time (wind, waves), this will result in a collision.

The calculation factor for the collision frequency $n_{coll,dis}$ is given in equation (IV-9).

$$n_{coll,dis} = \sum_K \sum_B CASRAT_{EF,b} \cdot P_b \cdot DM_{bk} \qquad \text{(IV-9)}$$

where $CASRAT_{EF,b}$ - is the rate of engine failure (which results in disablement), P_b - the probability of wind force (Beaufort class b) and DM_{bk} - the "dangerous " of ships on the route k in wind of Beaufort force b.
The calculation of the distance DM_{bk} is obtained with equation (IV-10).

$$DM_{bk} = P_n \cdot P_{n\psi} \cdot N_{ik} \cdot \int_{x_1}^{x_2} P\left[t_f > \frac{d_{n\psi}(x)}{v_{dbin}} \right] dx \qquad \text{(IV-10)}$$

where P_n - is the probability of a specific loading state, $P_{n\psi}$ - the probability of a specific wind direction and N_{ik} - the number of ship passages in the class i on the shipping route k.

The integrant in the equation (IV-10) is the probability that the time required for repair is longer than the drifting time for a collision to occur. I.e. the vessel is not capable of avoiding a collision on its own. The distance between the accident and point of collision is $d_{n\psi}$. The drifting speed of the vessel v_{dbin} is obtained from equation (IV-11).

$$v_{dbin} = \sqrt{\frac{\rho_{Air}}{\rho_W} \cdot \frac{A_{l,Wiin}}{L_i \cdot T_{in}} \cdot \frac{c_{dwind}}{c_d} \cdot v_b^2 + \frac{\varsigma_b^2 \cdot g}{T_{in}} \cdot \frac{c_{wave}}{c_d}} \qquad \text{(IV-11)}$$

Where ρ_{Air} - the air density, ρ_W – the density of sea water, $A_{l,Win}$ - the lateral surface of the ship above sea level (Surface exposed to wind), L_i - the length of the ship belonging to class i, T_{in} - the draft of the ship i loaded n, c_{dwind} - the lateral drag coefficient of the ship above water, c_d - the lateral drag coefficient of the ship under water, v_b - wind speed in the Beaufort class b, ς_b - the significant wind amplitude resulting from Beaufort b and c_{wave} - the wave drift coefficient.

The tidal currents are not considered in the calculation method recommended by MARIN. The reason given is that the direction of the current varies periodically and the effects are thus averaged out. The impact of the use of salvage tugs as well as the possibility of repair and recovery of manoeuvrability is taken into account by the time dependant probability of success. The effect of emergency anchoring is also covered by probability of success, which depends on the drift speed.

- Advantages and disadvantages of the method of calculation
Equation (IV-9) uses the dependency of engine reliability with the existing wind force (Beaufort b). According to the GLO this relationship is not given. Increased failure usually only occurs during the running of the vessel. E.g. change in engine revolution or switch from oil to diesel operation.

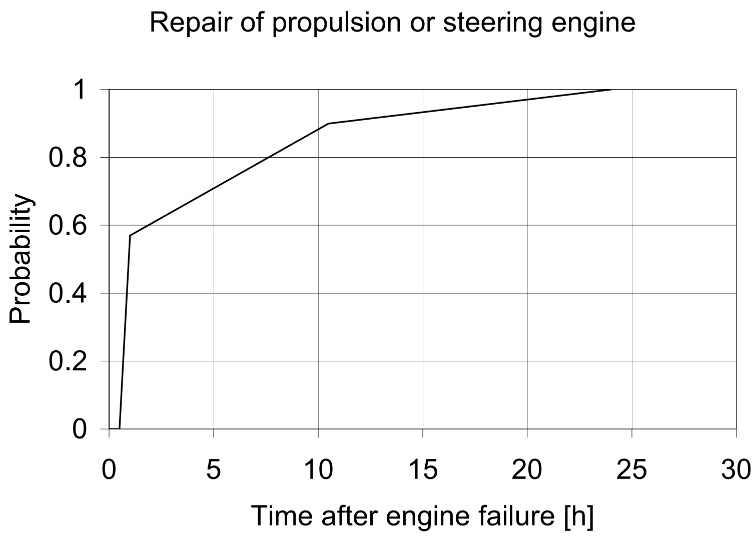


Figure IV-33: probability function of successful repair and recovery of manoeuvrability after Moore et al. (2001)

The disregard of tidal currents in the calculation of drift speed is only allowable as long as the effect of emergency measures changes linearly with time. This is probably not the case in the event of a risk reducing use of salvage tugs nor in the case of successful repair. Moore et al. (2001) therefore provide the probability function shown in Figure IV-33which, due to a discontinuity of the function 1 [h] is non linear.

IV-4.7.3.2 Calculation of collision frequency after the GL

The Germanische Lloyd (GL) has also developed a new method to determine the collision frequency between manoeuvrable ships with any fixed objects. The method is based on a Monte-Carlo Simulation.

IV-4.7.3.2.1 Principles of the Monte-Carlo Simulation

The Monte-Carlo Simulation evaluates the probability of a specific event by simulating the process through calculation. Random starting conditions are generated for the simulation and the process for these starting conditions calculated. The number of simulations, which lead to the start of the event, is counted. This value, divided by the total number of simulations yields the probability with which the event will take place. The principles of the Monte-Carlo Simulation to determine the collision probability is shown in figure IV-34.

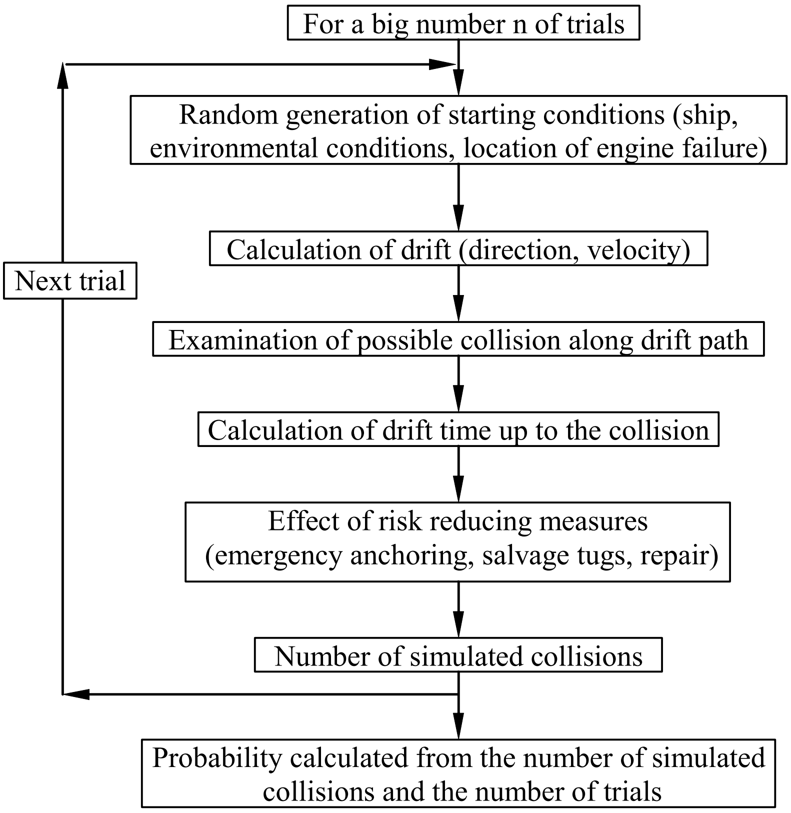


Figure IV-34: Schematic presentation of the Monte-Carlo Simulation

The single steps of the application of the Monte-Carlo Simulation for the calculation of collision frequency of disabled ships are given in the following sections.

IV-4.7.3.2.2 Generation of random starting conditions

As mentioned previously the Monte-Carlo Simulation requires random starting values with which the simulation is initialised. In the case of calculations of collisions between WEPs and disabled ships they are:

- ship related effects
- size, type
- shipping route related effects
- point of disaster
- environmentally relevant effects
- wind direction, wind force, current direction, current velocity, wave direction, and wave height

In order to display the listed factors correctly, the sum of all randomly chosen starting parameters have to correspond to the real existing distribution of the factors. Thus if all the randomly selected wind directions are analysed statistically, the distribution attained is the same as the actually measured wind directions in a specific area.

Random generators in computers generally produce normally distributed random numbers. I.e. the relative frequency (probability density function) of the generated random numbers is constant. Thus the cumulative frequency function (exceeding probability function) is a straight line. To generate random numbers with a defined distribution (e.g. distribution of wind directions) the normally distributed random numbers have to be transformed. The transformation follows:

$$P_e[X] = P_e[Y] \tag{IV-12}$$

In the equation (IV-12) $P_e[X]$ is the exceeding probability of the normally distributed random numbers $P_e[Y]$ the exceeding probability of the adapted random numbers (e.g. wind direction). Figure IV-35 shows the algorithm of the calculation of random initial conditions. The value x is randomly generated and the corresponding function $P_e(x)$ calculated. The value y is subsequently selected, where P(y) is equal to P(x).

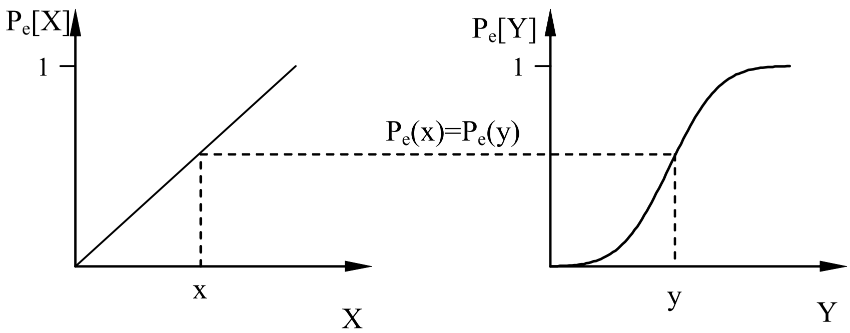


Figure IV-35: Transformation of normally distributed random numbers

The accuracy with which the individual factors are presented by the simulation increases with the number of runs. This converging behaviour for different numbers is shown in figure IV-36. In the individual diagrams, the solid line represents of the measured data. The broken line shows the relative frequency of simulated wind directions. It is clearly visible how the convergence between the two curves improves with an increase in number of runs.

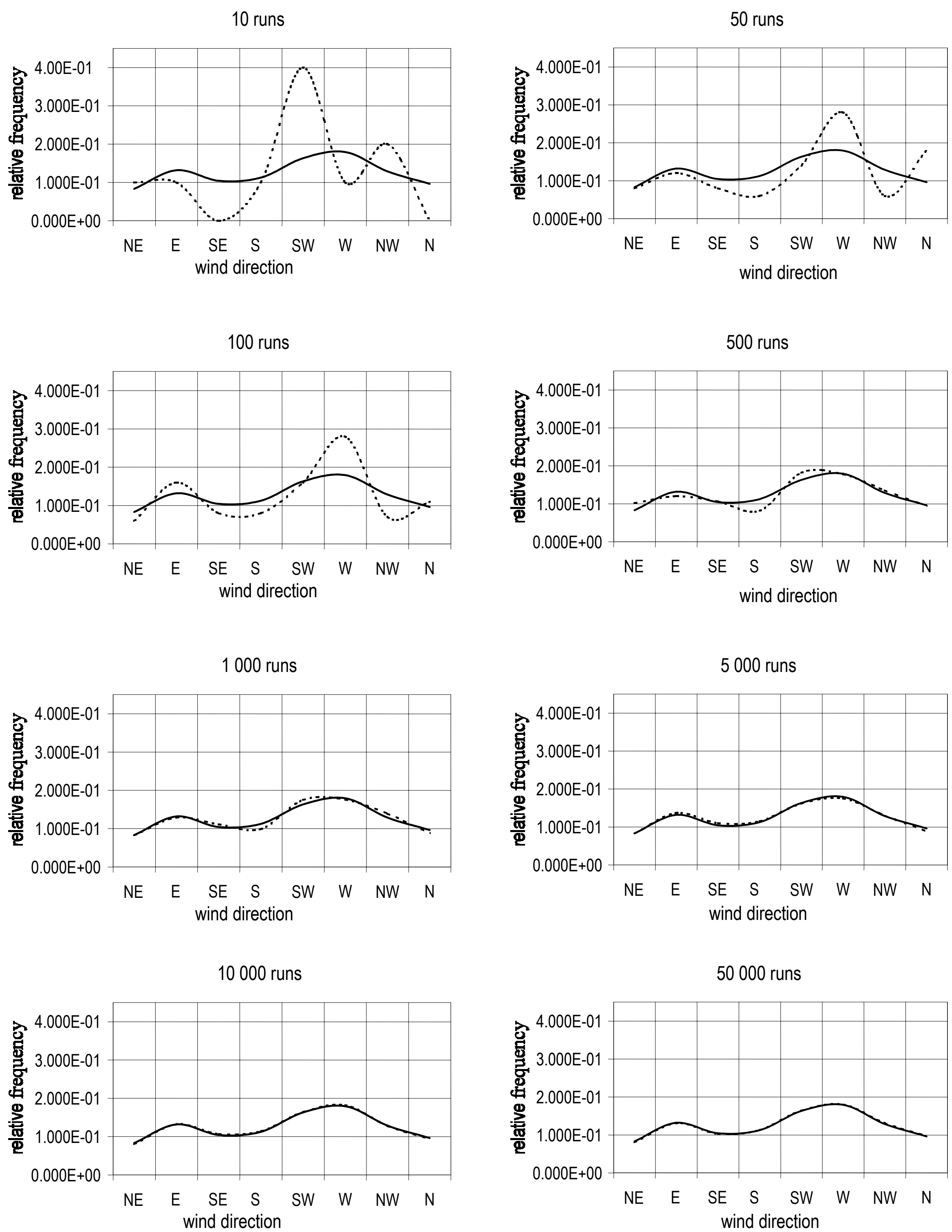


Figure IV-36: Convergence with increasing number of runs

By squaring the error integral, i.e. the square of the area between the two curves, it is possible to quantitatively determine the convergence. Figure IV-37 shows the square of the error integral against the number of simulation runs.

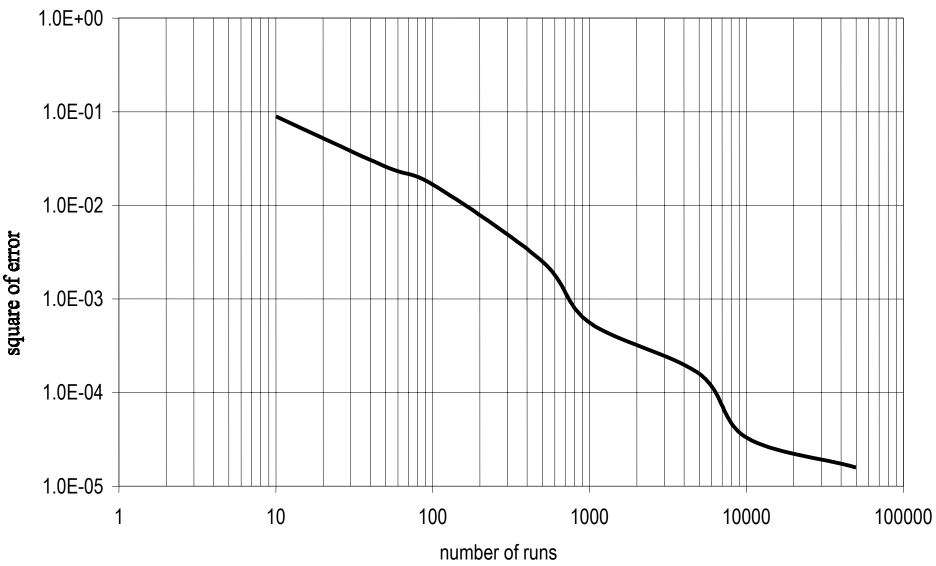


Figure IV-37: Quantitative description of convergence between the computed starting condition.

IV-4.7.3.2.3 Calculation of drift

The calculation of drift is necessary to determine if under specific initial conditions of a simulation the ship is drifting in the direction of a wind park or not.

The drift of a damaged vessel is determined by the equilibrium of the factors wind, wave and current forces acting on the vessel It is a expected that the vessels are still in motion immediately after the loss of manoeuvrability. A relatively constant drift is only expected some time of the ship has become disabled, when the effects of the remaining momentum are reduced. The period between the disaster and attaining constant drift is usually not taken into account. This is also not necessary since the ship is still navigable during the remaining momentum.

In order to calculate the drift movement of the disabled vessel individual force components need to be determined. Several procedures are available for this purpose. The possibilities range from complex processes of numerical current mechanics to empirical draft formulae. The decision as to which is the appropriate method for the simulation is facilitated by the estimate of computing time and the required accuracy of the results. It is important that the drift movements are carried out for a large number of simulation runs, which means that the available computing time is limited.

The basis of the force calculation of wind, waves and currents are the Bernoulli solutions. It was assumed that the ship lay transversely to the drift. This assumption neglects the fact that the rudder, the position, the size of the upper deck as well as the shape of the hull could result in a deviation of the position. These deviations are considered to be negligible and not significant for the drift speed. In addition, this assumption would always lead to higher drift velocities since the area exposed to the force are at their maximum in this position. It is therefore a conservative assumption, which will always lead to insignificantly higher collision probabilities.
The following formulae were used for the individual force components:

Wind force

$$\vec{F}_{Wi} = c_{d,Win} \frac{\rho_{Air}}{2} \cdot (\vec{v}_{Wi} + \vec{v}_S)^2 \cdot A_{l,Win} \qquad \text{(IV-13)}$$

where $c_{d,Win}$ = 0.72 (fully unloaded). 0.99 (ballast) - the drag coefficient of the hull in dependence of the state of loading (OCIMF) ρ_{Air} = 1.24 [kg/m^3] - the air density, v_{Wi} - the wind speed, $A_{l,Win}$ - the lateral surface area of the hull and v_S - the speed above ground.

Wave drift forces

$$\vec{F}_{We} = c_{d,We} \frac{\rho_W}{2} \cdot g \cdot \nabla^{1/3} \cdot \xi_b^2 \qquad \text{(IV-14)}$$

where $c_{d,We}$= 0.5 - the coefficient of the wave drift force, ρ_W = 1024 [kg/m^3] - the density of sea water, g = 9.81 [m/s^2] - the earth's gravity, ∇ - the displacement of the damaged vessel ξ_b - the significant wave amplitude.

The swell is a random process and comprises a number of different individual waves. It is usually described by two statistic parameters. These are the significant wave height H_s and the dominant wave period T_z. the significant wave height H_s is the mean of 1/3 largest wave in the swell. The dominant wave period T_z is the mean of the period between two points in time during which the sea surface exceeds the calm water level in a positive direction.

The wave drift force coefficient $c_{d,We}$ varies with the length of the wave hitting the ship (thus also with the wave period) and consequently would have to be adjusted to the to the spectrum of waves in the swell. The energy components of the individual waves would have to be summed in order to obtain the correct wave drift force. This complex procedure is avoided by using the mean of the wave drift force coefficients and half the significant wave height $H_s/2$ as wave amplitude. In Schellin & Östergaard (1995) a value of $c_{d,We}$ = 0.5 is given for the VLCC. In other words the problem lies in the fact that the deterministic parameters of the wave amplitude and the wavelength should be replaced by the statistic values of a swell. A single wave is therefore used for the calculation and fixes the parameters in such a manner so that there effect corresponds that of a swell. It is principally possible to distinguish between a wind sea and swell. The direction of the wind sea corresponds to the wind direction, whereas the direction of swell can deviate from the wind direction. Using a conservative approach it is possible to assume that swell and wind sea have the same direction, i.e. the wind direction, since this assumption leads to a higher drift speed and the procedure thus attains a higher probability of collision.

Current forces

Current forces are comprised of two components. The one arises from tidal currents and wind drift. Comprehensive data on these current components were obtained by the DWD and BSH for different years. This current component is measurable, when a fixed point is assumed. When a disabled ship begins to drift its movement above ground introduces another current component. . If both current components are considered the formula for the resulting force is:

$$\vec{F}_{St} = c_{d,St} \cdot \frac{\rho_W}{2} \cdot (v_S + v_{T,Wd})^2 \cdot A_{l,St} \qquad \text{(IV-15)}$$

where $c_{d,St}$ = 0.6 - the coefficient of current force (OCIMF) v_S - the ship speed over ground, $v_{T,Wd}$ - the velocity of the current and wind drift and $A_{l,St}$ - the lateral surface of the ship under water.

Assuming that all forces acting on the ship during constant drift are in equilibrium, the following drift movement (speed of ship over ground) is the solution for equation (IV-16).

$$\vec{0}=\vec{F}_{Wi}+\vec{F}_{We}+\vec{F}_{St} \qquad \text{(IV-16)}$$

IV-4.7.3.2.4 Examination of possible collision along drift path

The drift direction can be derived from the component analysis of the vector equation (IV-16). The next stage in the calculation is the test whether the drift of the disabled ship could lead to a collision between the vessel and the WEP. This requires the determination of the area (drift corridor) in which the vessel is drifting (Figure IV-38).

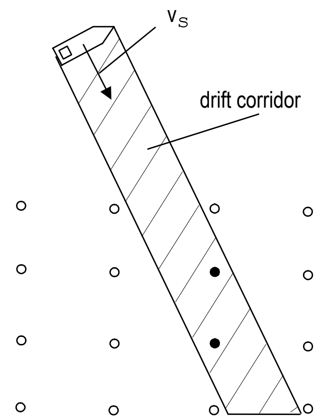


Figure IV-38: drift corridor of a disabled vessel

Should WEPs of a wind park lie within this corridor, the ship is potentially endangered. Now the effect of various collision reducing measures will show whether the simulation attempt can be regarded as a successful collision or not.

IV-4.7.3.2.5 The effect of collision preventative measures

Three collision preventative measures were tested in the simulation. Three probabilities, which establish the success or failure of the risk preventative measures, are determined during each simulation

Emergency anchoring

A measure to stop or slow down the drift of a disabled vessel is emergency anchoring. For this purpose one or two anchors are dropped to attempt a halting of the vessel. Should the emergency anchoring be successful, there is no more danger of a collision between vessel and WEP. This is valid since the environmental conditions are kept constant during the simulation. It is principally possible to anchor everywhere in the North and Baltic Seas due to the shallow depth of 30 - 50 [m]. For the anchoring to be successful it is important that the speed of the vessel is as slow as possible. If the speed is to fast, it will not be possible to stop the ship. The anchor will slide along the sea floor or break off. Thus the drift speed is the decisive factor for an n emergency anchoring to be successful.

A function was introduced into the calculation to include the risk reducing effect of an emergency anchoring Figure IV-39. The function describes the probability of a successful emergency anchoring in dependence on the drift speed of the disabled ship.

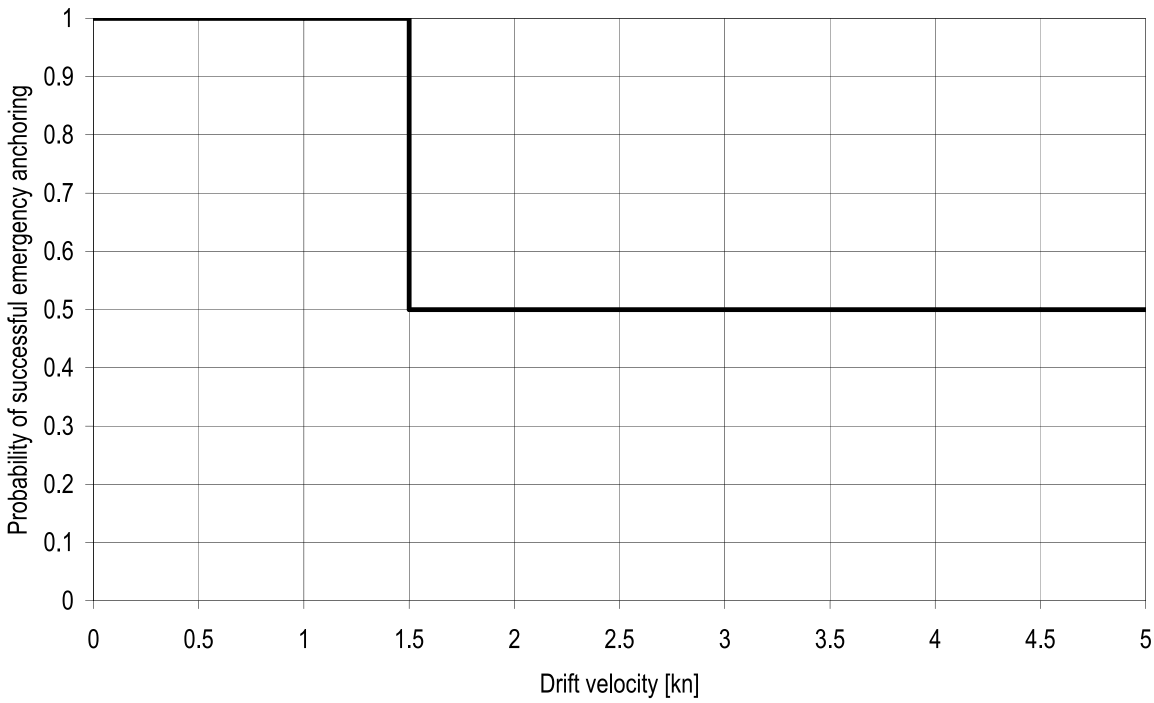


Figure IV-39: Effect of risk reducing measure –emergency anchoring

According to the expert opinion of the GL, emergency anchoring is possible up to a speed of 1.5 [kn]. It is therefore assumed that all emergency anchoring are successful up to this speed. When the drift speed lies above 1.5 [kn] only half the anchoring are expected to be successful

Recovery of manoeuvrability

The disability to manoeuvre is always attributed to technical failure. Thus there is usually always the possibility of repair of the break down and thus the recovery of manoeuvrability. Time is therefore critical. The probability of successful repair is therefore included in the simulation as a time dependant function (FigureIV-40).

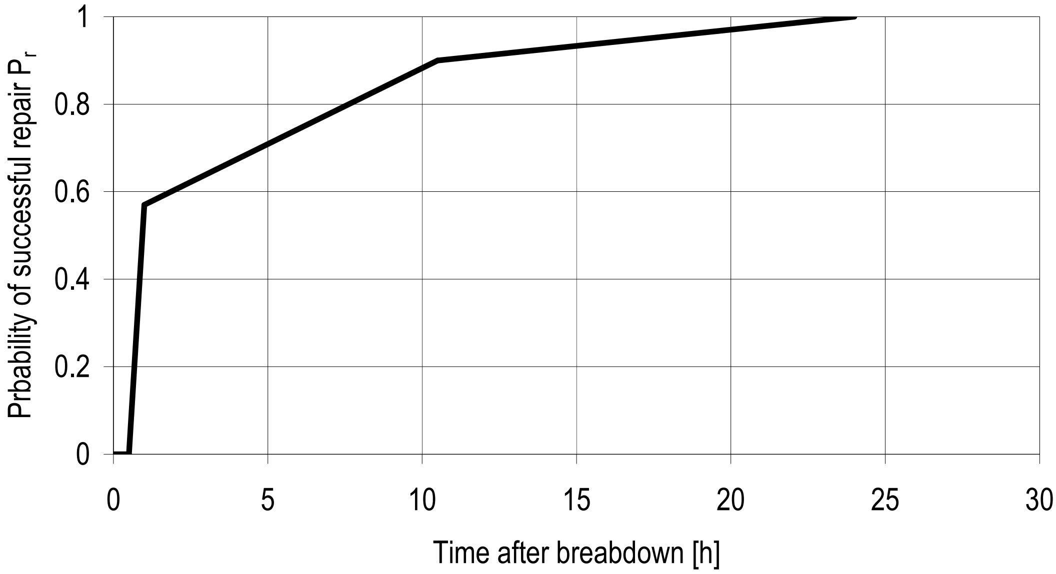


Figure IV-40: Consideration of repair measures in the Monte-Carlo Simulation

The function shown in figure IV-40 shows the probability of repair increases rapidly within the first hour and that more than half of all breakdowns are repaired within this time. It is assumed that 98 [%] all breakdowns are repaired within 24 [h] and the ship is again manoeuvrable. 2 [%] cannot be repaired by the ships. This time dependant probability of repair was applied after consulting experts of the GL. The function used by Moore et al. 2001 for the probability of a successful repair, see figure IV-33, is very similar to that in IV-40.

Salvage with tug support

The use of salvage tugs is another method to avert an ominous collision between a disabled vessel and a WEP. It is difficult to assess the probability of a successful salvaging with tugs and depends on several factors. In order to account for as many aspects as possible the following function of probability of success was introduced (Figure IV-41). It is, however, not universally valid. The function incorporates several time slots, which have to be adjusted according to the position of the wind parks as well as the capacity of available salvage tugs and the disabled vessel. t_{al} - alarm time and mobilisation

The time t_{al} denotes the time from the break down to when the tug puts out to sea. This period includes the time to notify the break down to the responsible authorities, the time to decide whether to use a salvage tug and to attain operational readiness. During this period the probability of success is zero, since there is no effect of the tug on the collision scenario

t_{ar} - time to access the disabled vessel

After putting out to sea the tug requires a certain time to reach the disabled vessel. Of course this period is dependant on the distance to the vessel. On the other hand weather conditions such as wind, currents and swell also affect the speed of the tug. During the period T_{ar}, the probability of success is also zero.

t_{co} - Time to secure tether disabled vessel and tug

Once the tug has arrived at the disabled vessel, time is required to secure a connection between the vessels. The time required depends on the equipment on the vessels f (Towing equipment etc.) and on the weather conditions (wind, swell) as well as on the experience and capabilities of the crew on both vessels. There is therefore no risk reducing measure for the collision risk scenario during this period.

t_{st} - Time for the disabled ship to stabilise

Once the towing connection has been achieved, it is possible to begin reducing the drift speed of the disabled ship and to tow it out of the danger zone. This period also depends on a number of factors. The size of the ship as well as the weather conditions determines the required towing forces. Various strategies are available to obtain an optimal position of the disabled vessel. These depend on the weather conditions and the hydrodynamic properties of the vessel. . Thus this period is also largely dependant on the experience of the tug crew and to which extent they have been trained for such an incidence. During this period, tugs have an influence on the collision scenario since they can possibly prevent a collision. Thus the probability of success increases during this time.

As mentioned previously it is not possible to provide a universally valid function on the effect of salvaging in emergencies. All the more so the definition of this function is dependant on the local features of the wind park and on the available resources of the salvage tugs. They need to be newly defined for every wind park. Figure IV-41 therefore only shows a schematic of the function.

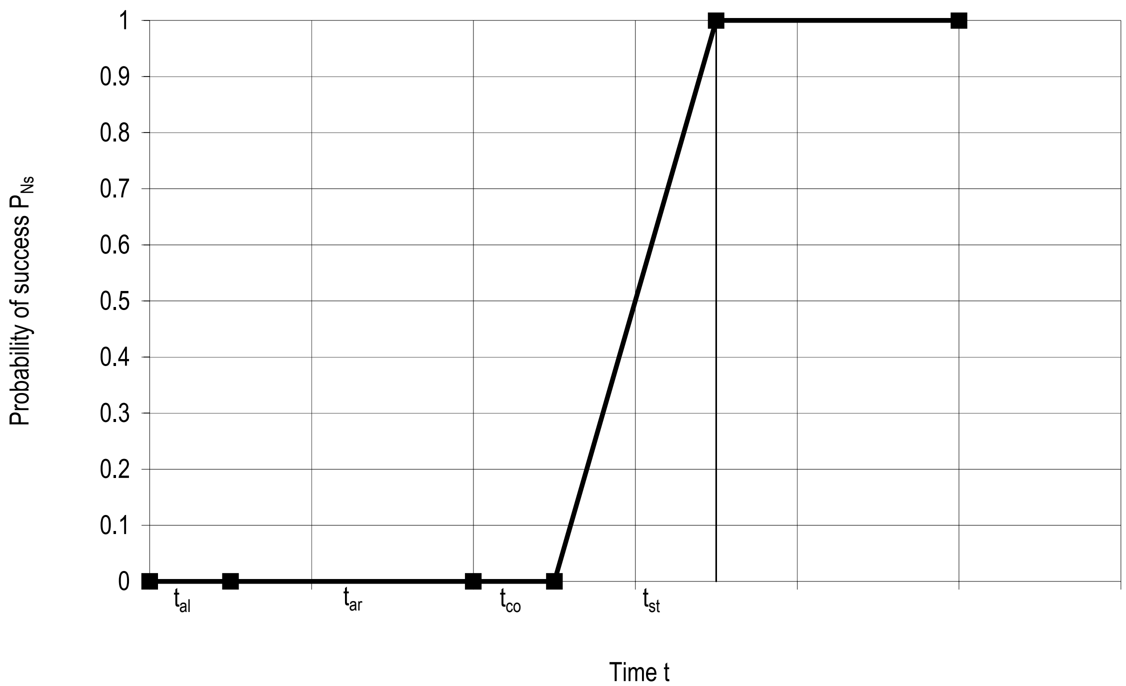


Figure IV-41: Probability of successes as a function of time

IV-4.7.3.2.6 Calculating collision frequency and convergence of the procedure

The probability of collision P_{coll} is obtained from the number of successful collision trials $n_{coll,sim}$ divided by the number of trials n_{sim} of the entire simulation. The second factor in equation (IV-17) is the mean probability of failure of risk reducing measures under the condition that the disabled ship drifts towards a WEP in the simulation.

$$P_{coll} = \frac{n_{coll,sim}}{n_{sim}} \cdot \frac{\sum_{i=1}^{n_{coll,sim}} (1 - P_{ea,i} \cdot P_{r,i} \cdot P_{Ns,i})}{n_{coll,sim}} = \frac{\sum_{i=1}^{n_{coll,sim}} (1 - P_{ea,i} \cdot P_{r,i} \cdot P_{Ns,i})}{n_{sim}} \quad \text{(IV-17)}$$

The frequency of a collision of a vessel with a WEP can now be calculated by multiplying the probability of a collision P_{coll} with the number of vessels n_S on the route under consideration.

$$n_{coll} = P_{coll} \cdot n_S \quad \text{(IV-18)}$$

As mentioned in section 0 the accuracy of the method is dependant on the number of simulation runs. A virtual wind park and assumed ship traffic were used to determine the number of simulations for the method to attain an acceptable accuracy. Figure IV-42 shows the results of these tests.

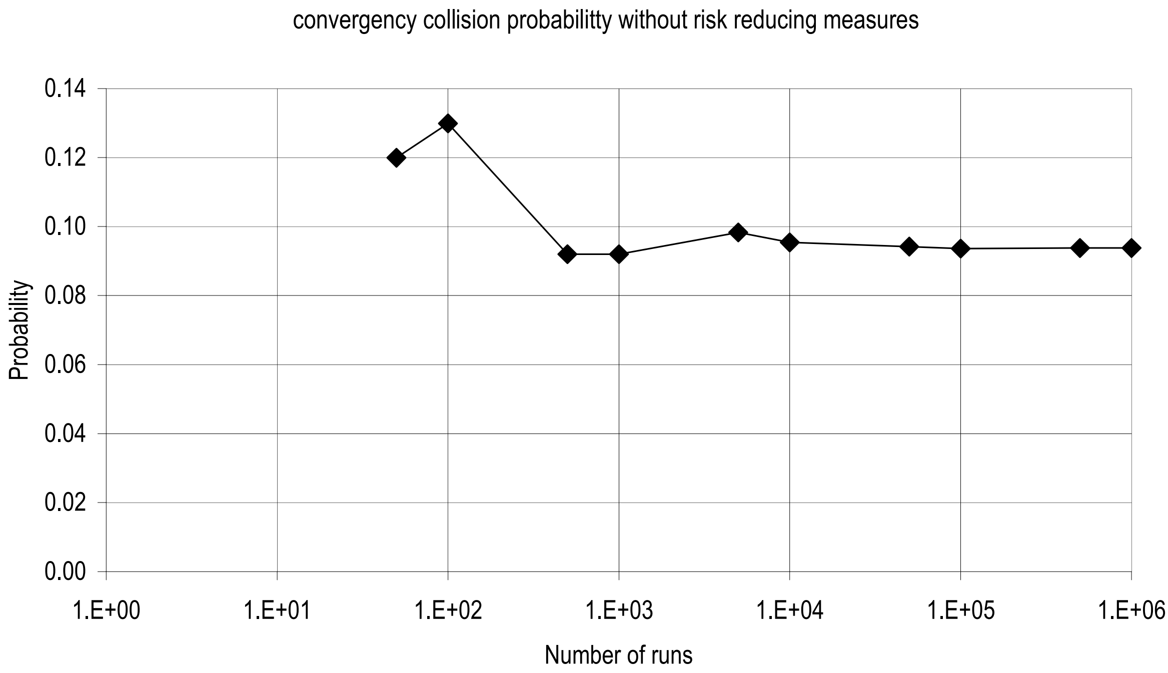


Figure IV-42: Converging behaviour of the calculation

The probability of collision varies in the range 50 to 10000 simulation runs. Thereafter it is clearly noticeable that the value tends to be more constant.
A further test of the method is the distribution of drift speed obtained from the simulation. Environmental conditions in the North Sea were used as test conditions together with the ship traffic on the TSS "German Bight Western Approach". FigureIV-43 shows the computed drift velocities. The modal value, i.e. the most frequent drift velocity computed lies at ca. 1.3 [kn].

The method was tested further by comparing the effect of the distances between WEPs. On the one hand large distances between WEPs enable disabled ships to drift between the turbines of a wind park without colliding. On the other hand the total area of the Windpark is increased which means that disabled ships which would have drifted past the wind park would drift into it. The results of the calculation are shown in figure IV-44. The results show the probability of collision between vessels and WEP on the one hand and on the other the probability of a ship drifting into the wind park. The difference between the two curves is the percentage of ships, which drift into a wind park without colliding with a WEP. It is clear that the less the distance between WEPs the less the probability of collision. Where distances are below 200 [m] almost every ship that drifts into a wind park collides with a WEP. Also shown is that the probability of drifting through the wind park increases with the increase in distance between WEPs. Generally it can be concluded from the figure that with regard to collision safety, the distance between WEPs should be kept a low as possible.

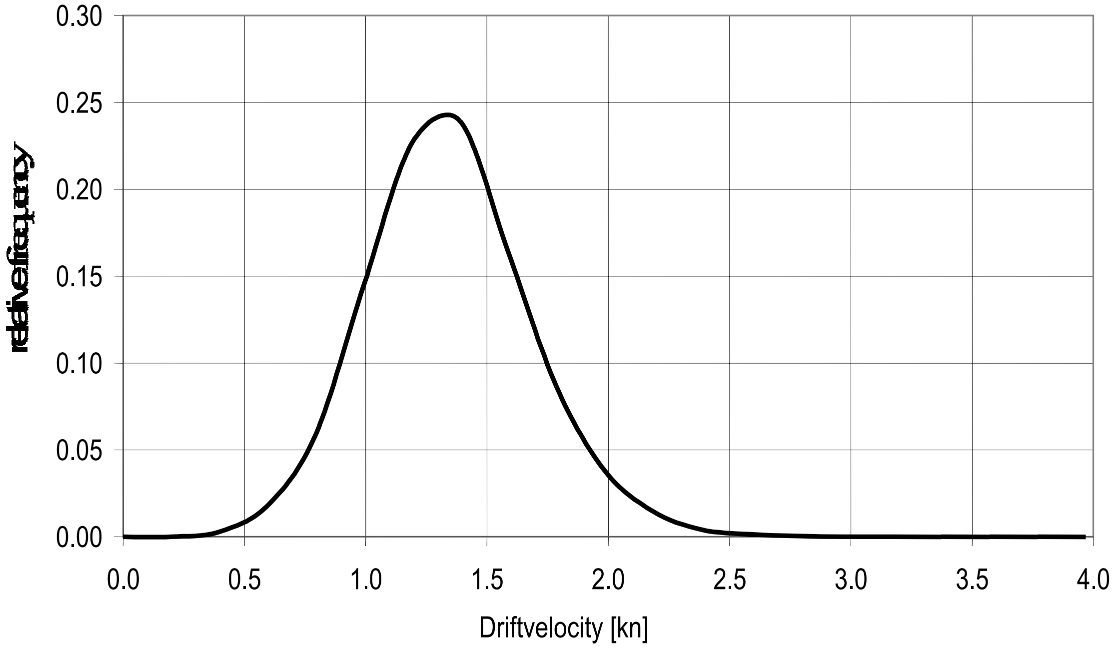


Figure IV-43: Distribution of drift speed of disabled ships

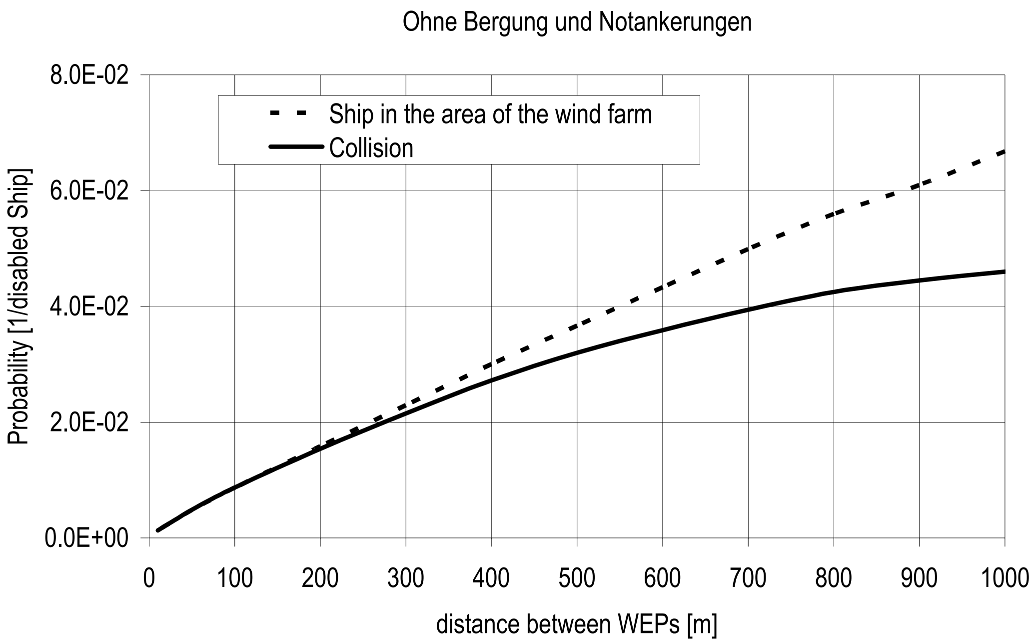


Figure IV-44: effect of the distance between WEPs on the probability of collision

IV-4.7.4 Calculation of consequences for collision scenarios

The second component of a risk is the consequences and results, which may occur due in collision scenarios. Should a collision between a vessel and WEP occur, the possibility arises that the vessel is damaged and consequently releases hazardous substances. It is therefore necessary to consider the structural damage as well as the amount of dispersed substances. .

IV-4.7.4.1 Calculation of the damage

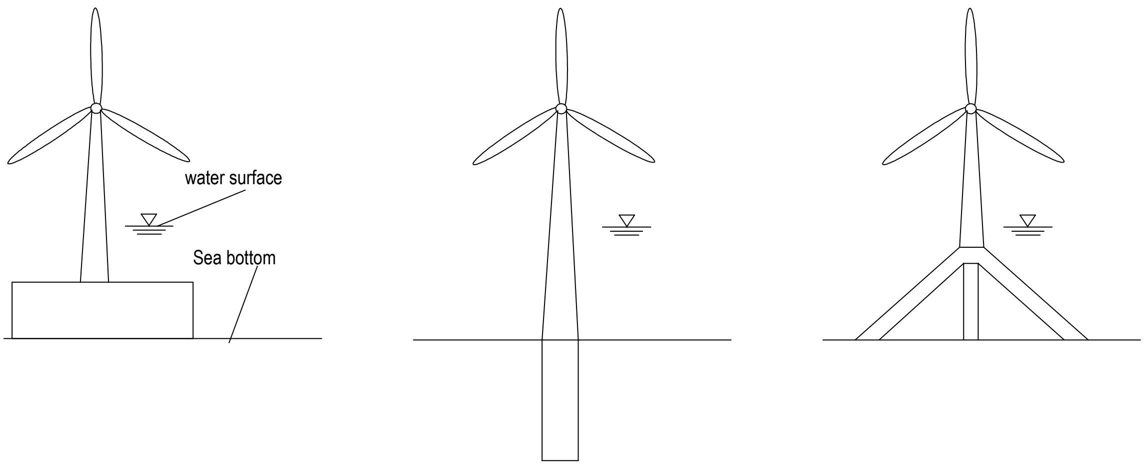
For collisions between ships and WEPs a distinction is made between the outer dynamics and the inner mechanics of a collision. The outer dynamics describes the conversion of kinetic energy of the ship due to a change in direction. Since the point of collision of a ship with a WEP does not automatically involve the centre of mass of the ships broadside a tortional moment arises which causes the ship to turn. The kinetic energy of the disabled vessels is thus reduced which has the same effect on the forces acting on the WEP. Methods to calculate the outer dynamics in ship-to-ship collisions were published by Pedersen (1995) and Pedersen et al. (1999).

The inner mechanics describes the conversion of kinetic energy of the ship into deformation energy of the ship's and WEP's steel structure. According to the understanding of the authors there are no simple methods of calculation to estimate the structural damage of such collision scenarios. This means that complex Finite Element computations have to be used to obtain preliminary information on the behaviour of ship structure in case of a collision with a WEP. It was not possible to apply this method on the different vessel and foundation during this study since these would have exceeded the available time and budget. Further research on the behaviour of ship structures in collisions with WEPs are necessary to obtain information on the size of leakages in the ships hull and thus on the possible loss of hazardous substances.
Qualitative estimates can be made as to which extent foundation size affects the amount of damage to ship structures.

Different foundation types are available for WEPs (Figure IV-45).

Gravity foundations
This foundation comprises a block of steel and concrete at the base of the pylon. The gravity keeps the turbine in place.

Driving of piles
The pylon is extended at the bottom and driven into the sediment by ramming. The depth depends on the type of sediment and the size of the pylon.



Gravity foundation Driving of piles Tripod

Figure IV-45: Foundation types for offshore WEPs

Tripod
This is a special gravity foundation type. However, additional support is achieved by three or more supporting structures. This construction is lighter than the simple gravity foundation.

With regard to the collision safety, the most suitable foundation would be one with the least damage to a vessel. Of the three available foundations, the gravity foundation and the pile foundation fulfil this criterion best, since a vessel would contact the foundation with its complete broadside. In this case the arising forces are distributed along the stringers and deck of the ship.

The tripod construction is inappropriate since the support legs have to be attached to the pylon as high as possible in order to achieve maximum support. This means that in an unfavourable case, the ship would contact the supporting leg of a tripod with its bilge plate. It is expected that the tensions in this case would be much higher than during the contact of a ship with a vertical pylon. A similar situation arises if a foundation block is constructed in such a manner that its top will come into contact with the bilge radius.

In order to prove that the shell plate of a drifting vessel will be perforated by a collision with a WEP, an exemplary collision of a 2 300 TEU Container vessel with a WEP was modelled. This vessel was chosen since a computational model already exists and thus only the WEP had to be modelled. Furthermore, the construction of this vessel is representative for many ships. The WEP foundation chosen was the tripod, since this constitutes the greatest danger to ships.

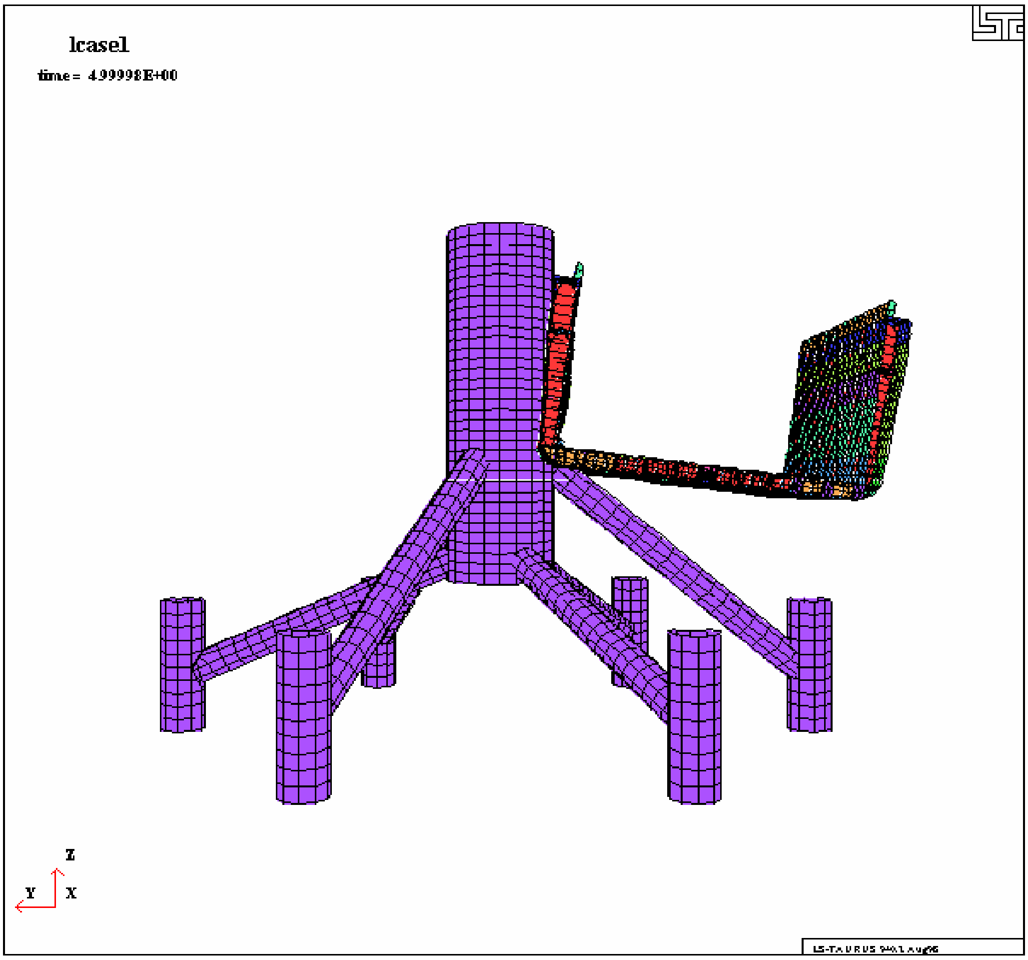


Figure IV-46: Finite Element Model of the structural calculation

A drifting speed of 4 [Kn] was assumed for the calculation. Figure IV-46 shows the Finite Elemente Model. It is clearly visible how the vessel hull will contact the supporting structure of the tripod. For this computation the structure of the foundation was given as being very rigid. I.e. the WEP foundation would not be deformed. This is a very conservative assumption, which means that the total momentum would act on the ships structure.

The result of the model is shown in the diagrams in figure IV-47. The left diagram shows the tearing of the shell plating in the region of the bilge radius by the support leg of the tripod. Also visible is the support leg is not deformed, which is due to the assumed rigidity given into the model.
The right diagram shows the deformation of the outer shell plate together with the stringers.

The example shows an extremely unfavourable configuration between a foundation and vessel. This way the mechanical strength of the bilge radius is very sensitive since there are no stringers in this region, which make the structure more rigid. In addition the collision forces act almost punctiform on the vessel hull, which locally results in a strong concentration of tension in this zone. In other configurations between collision partners, such as for example a vertical pylon, which is forced into the hull of a vessel, more energy can be absorbed by the vessel structure, since in this case there are more deck stringers involved in the deformation.

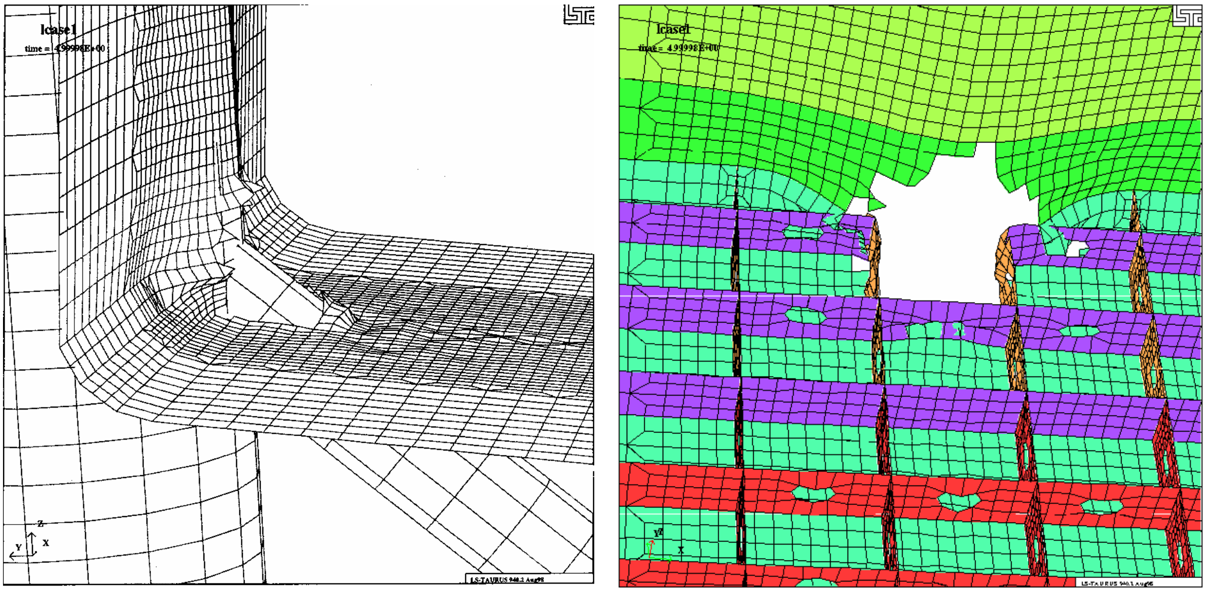


Figure IV-47: Damage due to collision of disabled vessel with a WEP

As mentioned such computations involve high costs and a lot of time. It is therefore hardly possible to model the different parameters such as ship volume, type, and drift speeds etc., using this method. Further research is necessary to obtain sufficiently accurate estimates of the damage extent for different input parameters of a collision scenario.

IV-4.7.4.2 Calculation of oil discharge

As an example, the discharge of fuel oil from a tank was simulated. The company ICCM was commissioned to carry out the numerical computation to determine the physical conditions during the discharge of oil from a defined tank (see Peric 2001). Since these computations are very complex, the GLO stipulated the tank configuration (Figure IV-18) and the essential parameters for the used material.

A portion was modelled with an opening at 6.5 [m] height, was modelled between the materials oil and water, to represent structural damage to a tank wall. Only half the tank was modelled under

consideration of the vertical symmetry. Figure IV-49 shows a section of the numerical grid[3] around the point of leakage.
The enlargement of the leak in the vertical and cross direction is shown in blue. The grid was wept coarse in regions where weak flow was expected. A finer grid was chosen in the zone where the oil streams out.

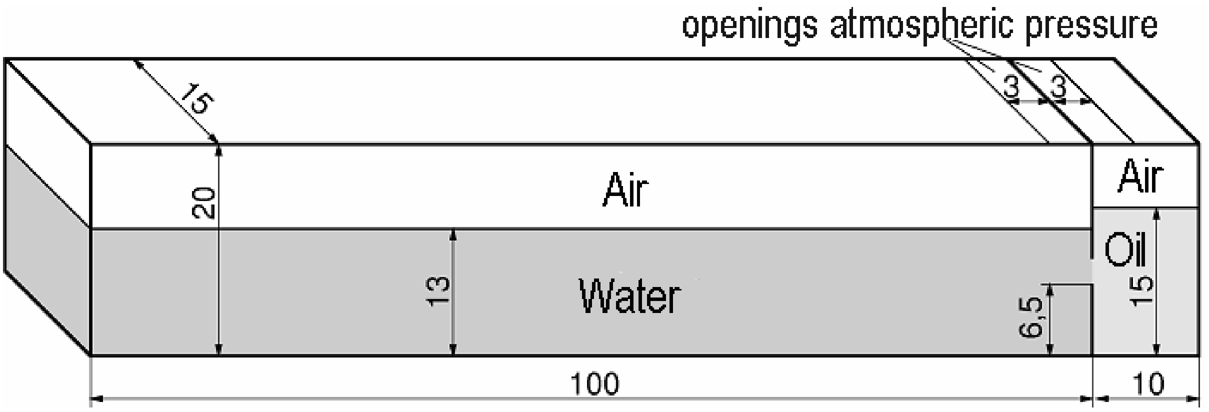


Figure IV-48: Geometry of the solution area (Dimensions in meters); the opening is 2 [m] high and 0,25 [m] wide, since only half of the tanks was simulated.

Adhesive conditions were predetermined for all walls and a portion of the upper edge simulated as an opening to the atmosphere. A constant ambient pressure was determined as boundary condition.

Table IV-13: Material parameters for simulation of oil discharge

	Density [kg/m^3]	Kinematics Viscosity [m^2/s]
Sea water	1 024	2.5E-06
Oil	990	6.5E-04

The numerical grid contained 138 850 control volumes. It was refined several times around the damaged area and the point of expected oil discharge The opening was divided into discrete cells, 64 in the vertical and 8 across, i.e. the cells in the opening were 3.125 cm 3.125 cm. Figure IV-49 shows a section of the grid around the opening. The partition between the two parts of the tank was 2 cm thick.

The Software Comet (Continuum mechanics engineering tool) of the ICCM GmbH was used to carry out the simulation. The turbulence was considered using the k-ε Model. Since the compilation of free surfaces (fluid-air and water-oil) requires small time steps O (0,001 s), in the integration was carried out in the time using the implicit Euler-Method of the 1. order. It can be assumed that the error of the integration is smaller than the spatial discretisation errors. The diffusive flows through the control volume boundaries were approximated with central difference of the second order. The first simulation used the 1st order Upwind-Method to approximate the convective term. Thereafter, the simulation was repeated, whereby the convective flows were approximated with the mixture of 90 [%] central and 10 [%] Upwind-differences. A comparison of the two simulations enables an estimate of the discretisation errors. The other method to calculate the error by systematic refining of the grid is not

[3] The area of consideration will be subdivided in a number of small control volumes (octahedron and Tetrahedron). The number of control volumes is called numerical grid.

practicable since the number of cells would increase to over 1 Million, and the computing time would take too long.

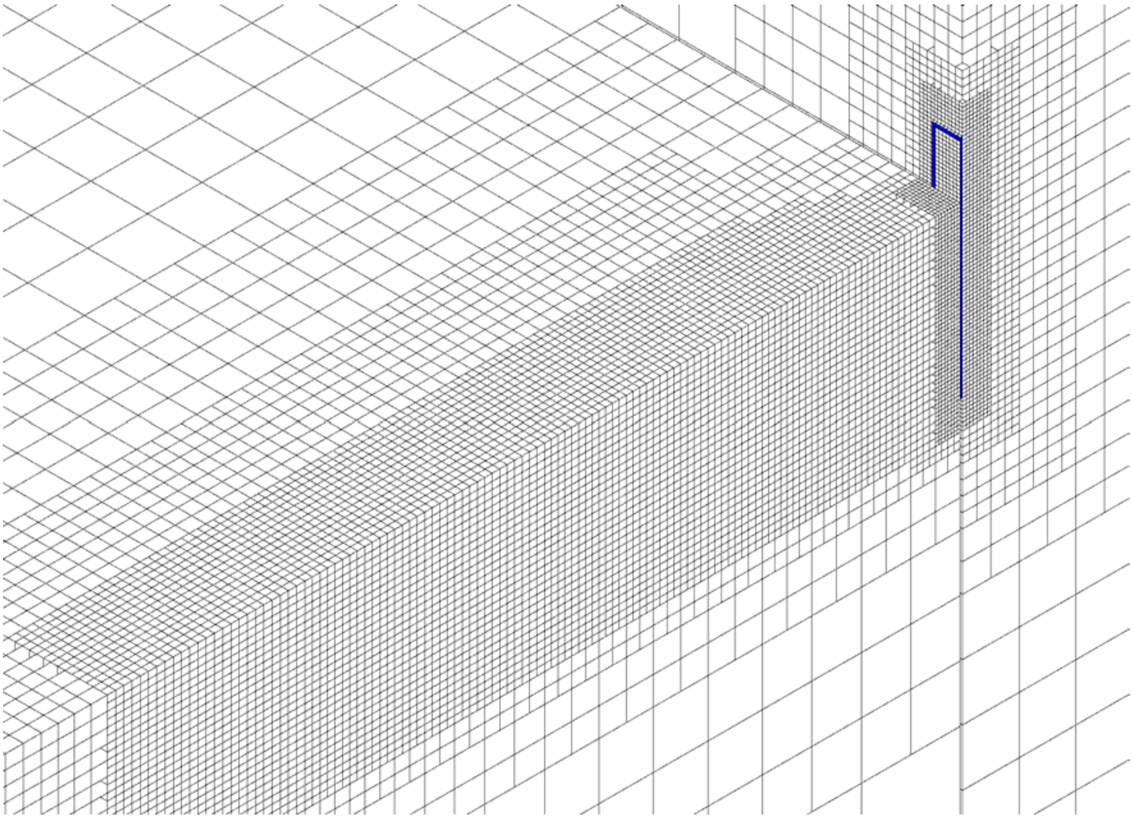


Figure IV-49: Numerical grid of oil discharge simulation

It is expected that the oil will flow from the oil filled tank into the water filled tank. The most significant result of the simulation is volume flow in the leakage, figure IV-50. The simulation using the upwind discretisation of convective flow yielded a volume flow of approx. 3.96 [m^3/s] after 3 [s], whereas the simulation with the 90 [%] central differences yielded approx. 4.18 [m^3/s]. The difference is about 5 [%]. It can therefore be assumed that the numerical error in solving this is of this order of magnitude, using the more precise (approx. Second order). Nothing can be said about the errors resulting from the turbulence modelling. Since the turbulence only arises behind the leakage, it is expected, that the turbulence model does not affect the prediction of flow volume.

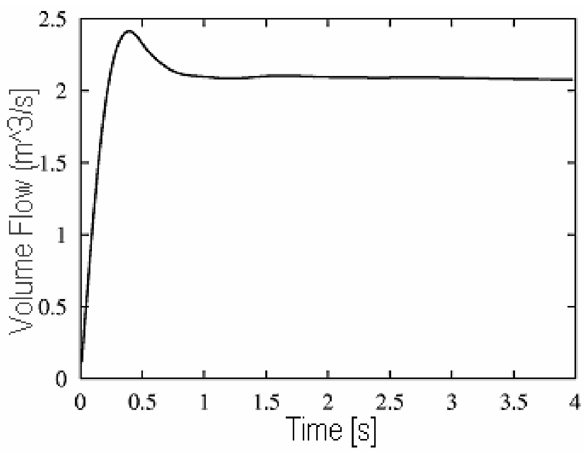
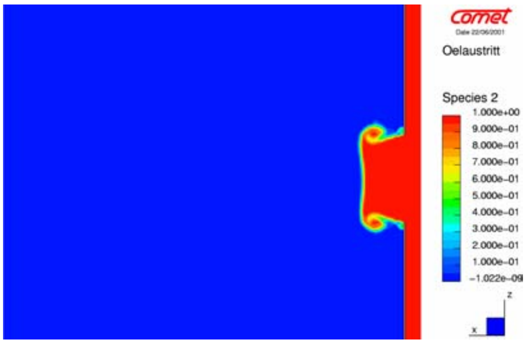
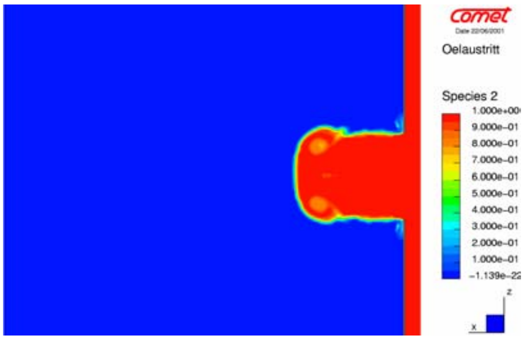


Figure IV-50: Volume flow through half of the leakage opening as a function of time

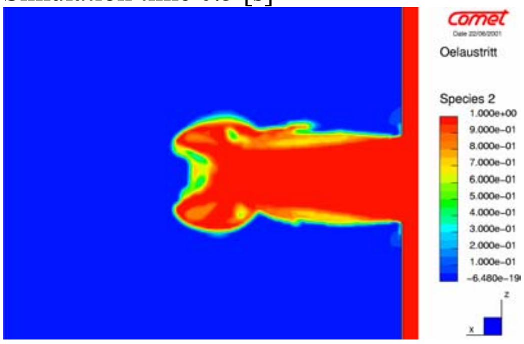
The following pages show diagrams of oil concentration, the distribution of velocity and pressure as well as the distribution of the kinetic energy of the turbulence in different slice planes.



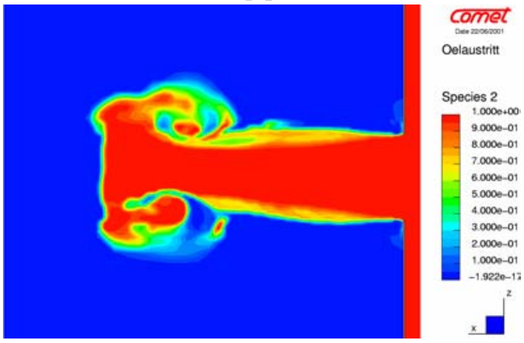
Simulation time 0.5 [s]



Simulation time 1.0 [s]

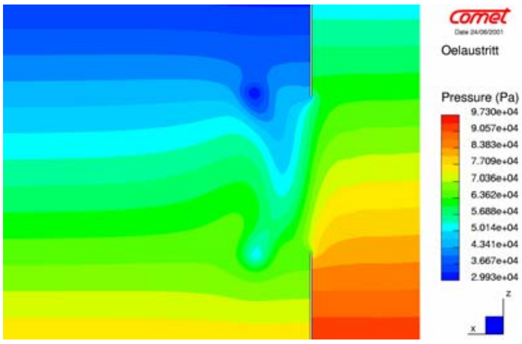


Simulation time 2.0 [s]

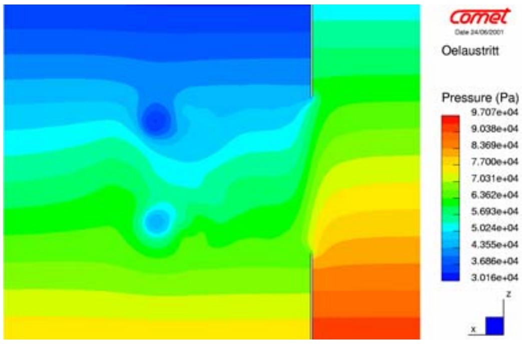


Simulation time 3.0 [s]

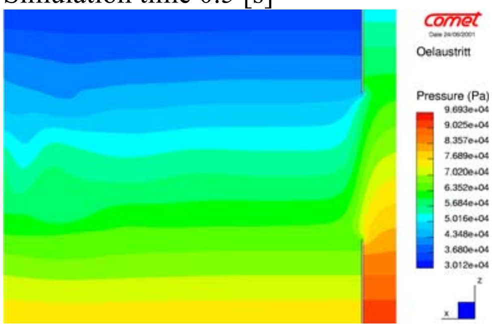
Figure IV-51: Oil distribution in the vertical symmetry plane (red oil / blue water)



Simulation time 0.5 [s]

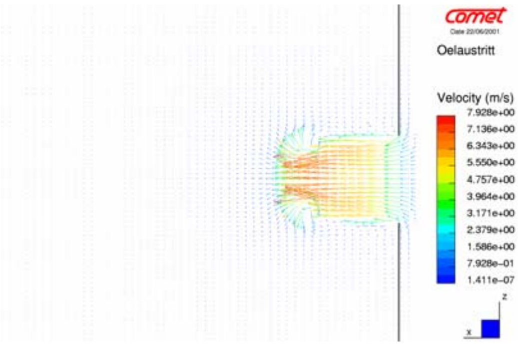


Simulation time 1.0 [s]

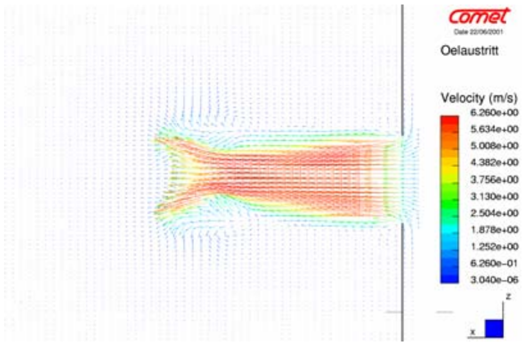


Simulation time 2.0 [s]

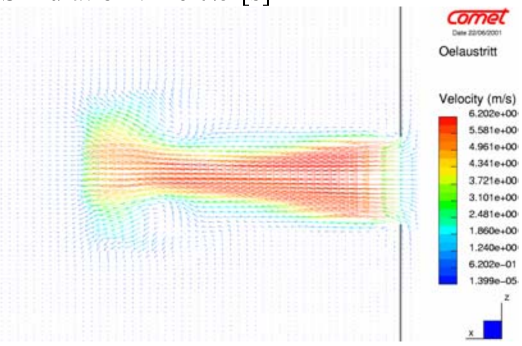
Figure IV-52: Pressure distribution in the vertical symmetry plane



Simulation time 0.5 [s]

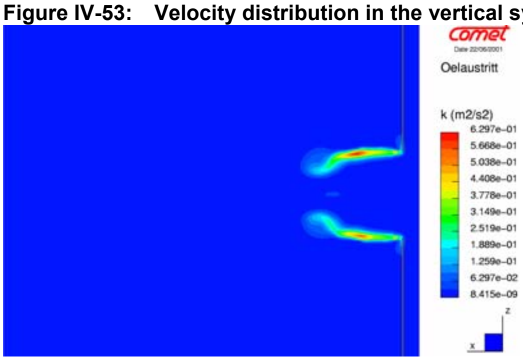


Simulation time 1.0 [s]

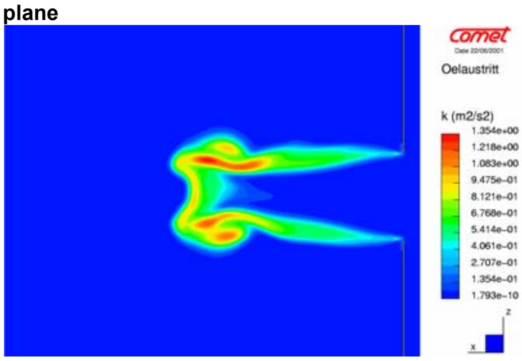


Simulation time 2.0 [s]

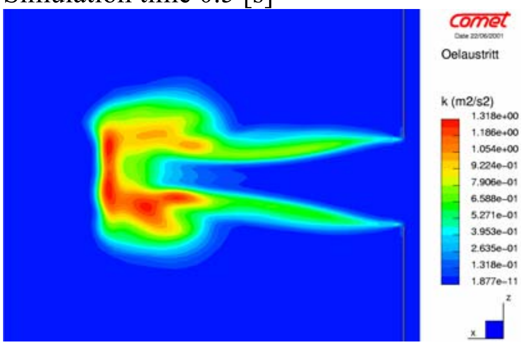
Figure IV-53: Velocity distribution in the vertical symmetry plane



Simulation time 0.5 [s]



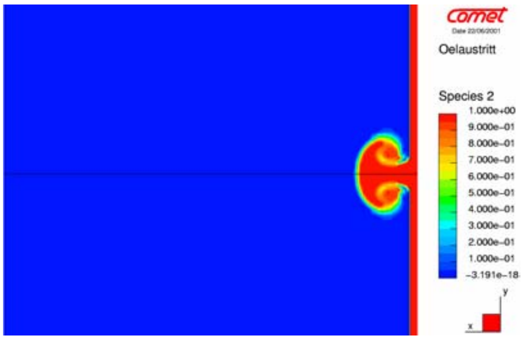
Simulation time 1.0 [s]



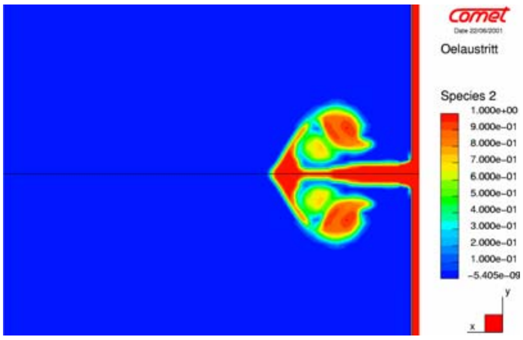
Simulation time 2.0 [s]

Figure IV54: Distribution of the turbulent kinetic energy in the vertical symmetry plane

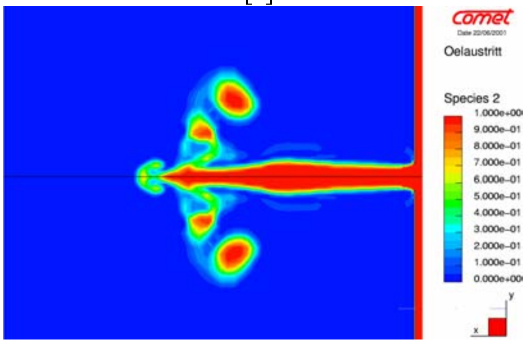
The following diagrams show the results for the horizontal slice plane (Plane of the water surface) in the middle of the leakage. Due to the symmetrical properties of the problem, it was only necessary to compute one side of the displayed area. The symmetry conditions allow the results to be mirrored.



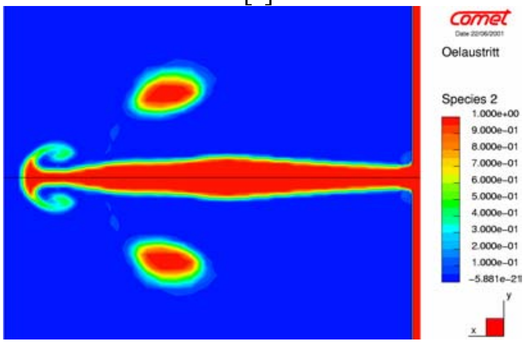
Simulation time 0.5 [s]



Simulation time 1.0 [s]

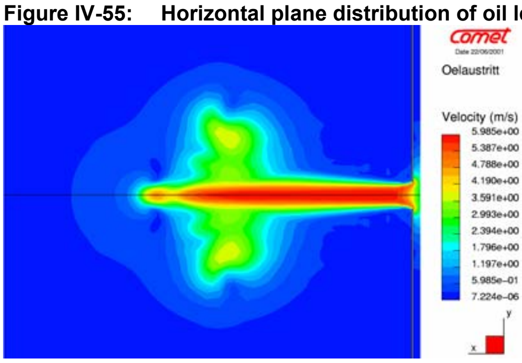


Simulation time 2.0 [s]

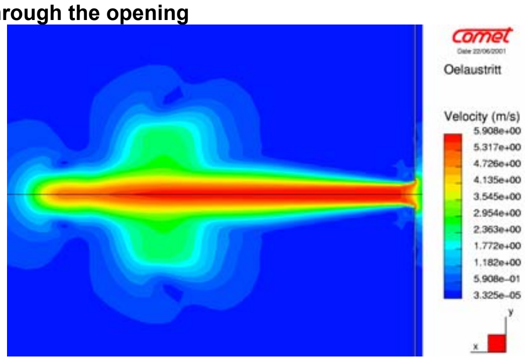


Simulation time 3.0 [s]

Figure IV-55: Horizontal plane distribution of oil leaking through the opening

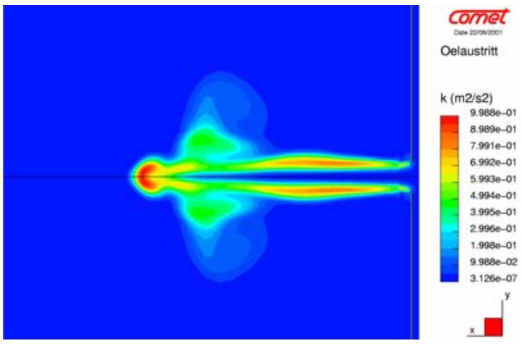


Simulation time 2.0 [s]

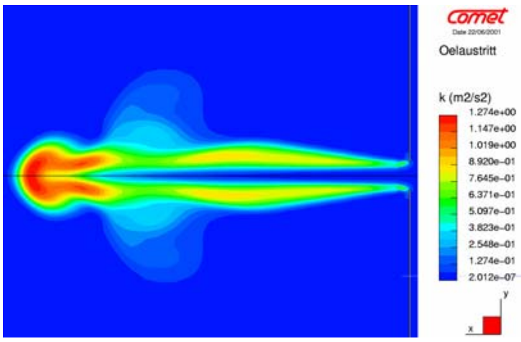


Simulation time 3.0 [s]

Figure IV-56: Distribution of velocity value in the horizontal plane



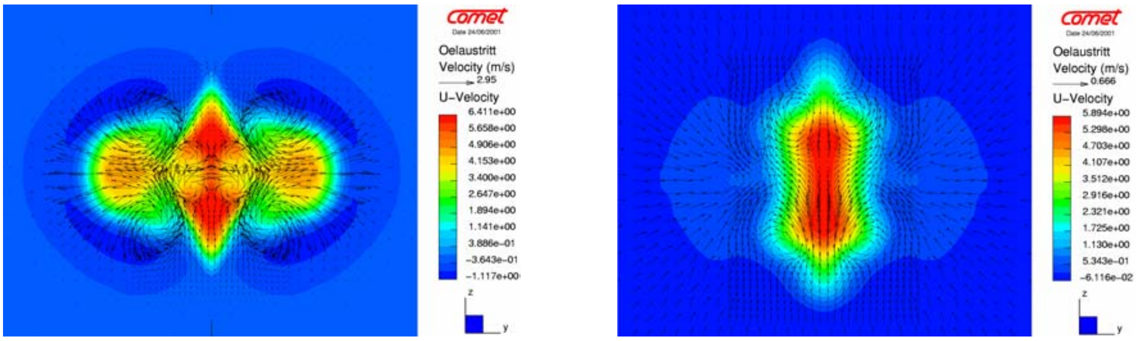
Simulation time 2.0 [s]



Simulation time 3.0 [s]

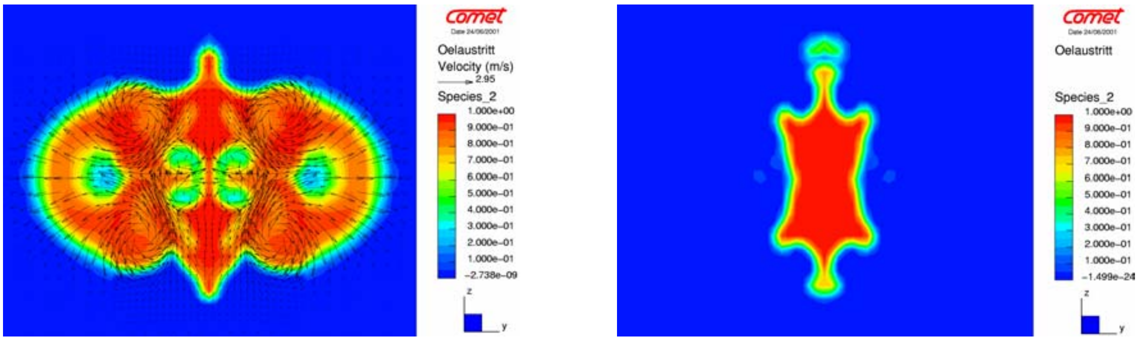
Figure IV-57: Distribution of turbulence kinetic energy in the horizontal plane

The following figures show the results of computation in the plane parallel to the partition between oil and water 2.5 [m] behind the partition.



Simulation time 1.5 [s] Simulation time 2.5 [s]

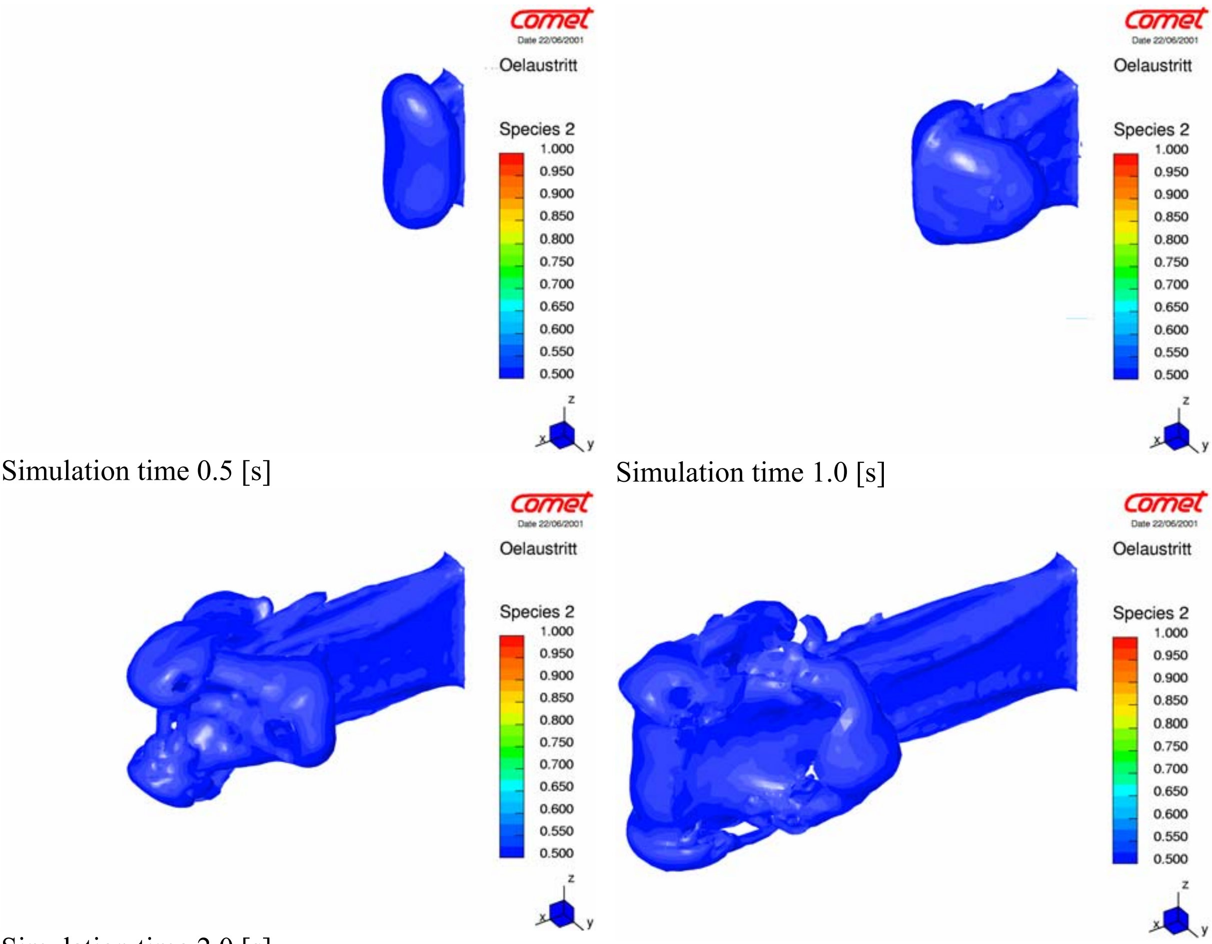
Figure IV-58: Distribution of velocity in the vertical plane 2.5 [m] behind the partition



Simulation time 1.5 [s] Simulation time 2.5 [s]

Figure IV-59: Distribution of oil along the vertical plane 2.5 [m] behind the partition

The following figures show a 3D projection of the discharging oil stream.



Simulation time 0.5 [s]

Simulation time 1.0 [s]

Simulation time 2.0 [s]

Simulation time 3.0 [s]

Figure IV-60: 3d presentation of the oil plume in water

Apart from using the complex CFD-computation with COMET, an attempt was made to use a simplified calculation method, which delivers an acceptable result in a shorter time. A rough calculation was made on the basis of the potential theory. The CFD results were used to verify the rate and speed of outflow obtained by the simple method.

Assuming a typical current vector diagram of the CFD analysis (Figure IV-61 left) the relevant current range for the potential theory was analyses. It was meant to be proven, that variables such as hydrodynamic mass do not have a significant effect on the current flow and the potential theory is therefore applicable for this problem. A closer scrutiny of the velocity distribution of the developing outflow (semi stationary), revealed three parts:

- The part in the oil tank, where the oil enters the plane of the damaged opening (extreme right in the current diagram)
- A part in the open water where the outflow is narrower and speeded up by secondary movement.
- The mushroom shaped tip of the outflow, which disperses, and a follow-up stream which causes wave like motion in the displaced water.

Figure IV-55 shows further, that the viscous oil flows out of a 0.5 [m] wide and 2 [m] high opening at a velocity of 4 [m/s] and accelerates to 5.5 [m/s] in the water due to a vacuum effect. The outflow is driven by a static pressure head of 2 [m] in the oil tank. Shown is the point in time 2 [s] after the initiation of the flow simulation.

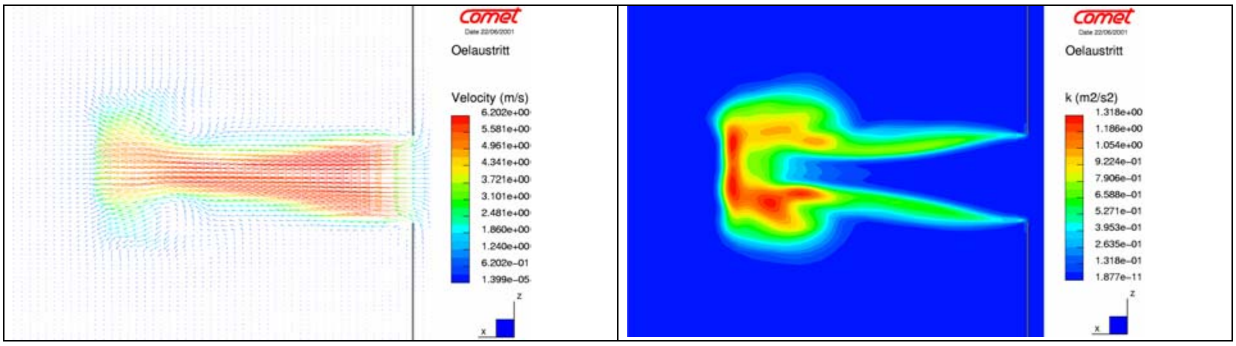


Figure IV-61: Distribution of velocity and dissipative energy after 2 [s]

In order to calculate the course of the outflow, the temporal velocity profile in the plane of the opening has to be known since the process is semi stationary, the hydrodynamic mass has no effect on the outflow behaviour.

Since figure IV-61 does not show the development of dissipative energy in the opening of the tank plane the flow velocity can be determined by the equation after Torricelli (IV-19).

$$u = \sqrt{\frac{2 \cdot \Delta p}{\rho_{Öl}}} \qquad \text{(IV-19)}$$

Where u – is the outflow velocity in the tank opening, Δp - the difference in static pressure due to the difference in height between the oil and water surface and ρ_{Oil} - the density of oil.
The application of equation (IV-20) results in the outflow from the tank opening of volume $\dot{V}$

$$\dot{V} = c_0 \cdot c_u \cdot A \cdot u \qquad \text{(IV-20)}$$

where A is the slice plane of the tank opening, c_0 the friction coefficient at the slice plane and c_u a coefficient which takes into account the contraction of out flowing stream. In Perry et al. (1997) the coefficients c_0 and c_u depend on the Reynolds number and the Froude number (Figure IV-62.

The Reynolds and Froude numbers, equation (IV-21), refer to the hydraulic diameter D_0, which is derived from the area A and the circumference U of the opening.

$$Fn = \sqrt{\frac{\rho_{Öl} \cdot g \cdot \Delta p}{D_0}};\ Re = \frac{\rho_{Öl} \cdot u \cdot D_0}{\mu} \qquad \text{(IV-21)}$$

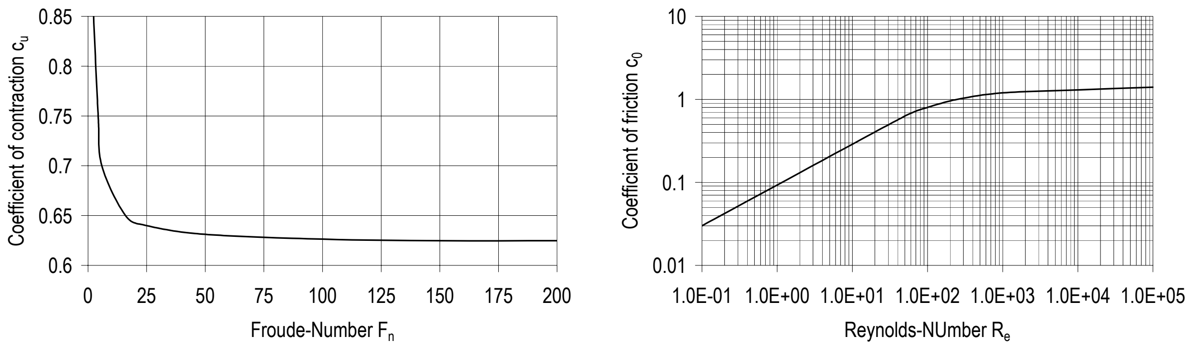


Figure IV-62: Coefficients for the computation of the stream volume 1

For non-quadratic openings, the hydraulic diameter corrects the proportions of the opening, equation (IV-22).

$$D_0 = 4 \cdot \frac{A}{U} \tag{IV-22}$$

In the case of a narrow gap opening, it is appropriate to relate the operating figures to the gab width instead of to the hydraulic diameter D_0 so as to guarantee a large effect of the friction boundary layer. A viscosity effect will occur at the boundary layer if the gap is very narrow (ca. 1 [cm]. Due to the low Reynolds number this procedure then looses its validity.

Since no elaborate calculations have to be carried out, the quantification of the amount discharged using the equation of Torricelli is convenient, particularly for probabilistic analyses.

IV-4.7.4.3 Calculation of oil dispersion

The BSH has for many years been using an operational model to compute actual currents and wave motion to support marine navigation, surveillance of the marine environment as well as for marine research.

The model is also applied to investigate the dispersion of hazardous substances due to shipping accidents in the sea. Basis for the calculation are the actual weather and swell predictions conditions, which are available for a period of 24 [h]. The results are time dependant charts of the distribution of hazardous substances.

The BSH carries out such computations in commission for the coastal protection. To calculate drift and dispersion of a released substance, this method idealises the process as a particle cloud (Lagrange procedure). Current, waves and wind drive the particles. In the simulation of oil dispersion, the physical behaviour of different oil types on the water surface is also taken into account.

The procedure calculates the progress velocity using a shear stress model (water, air, oil), whereby the mixing of oil with seawater and the evaporation in air are described with boundary layer turbulence models. Two examples of oil dispersion are calculated.

Figure IV-63 shows the computation of the discharge of 3 224 [t] crude oil, which drifts along the East Frisian Islands during winter with westerly winds.

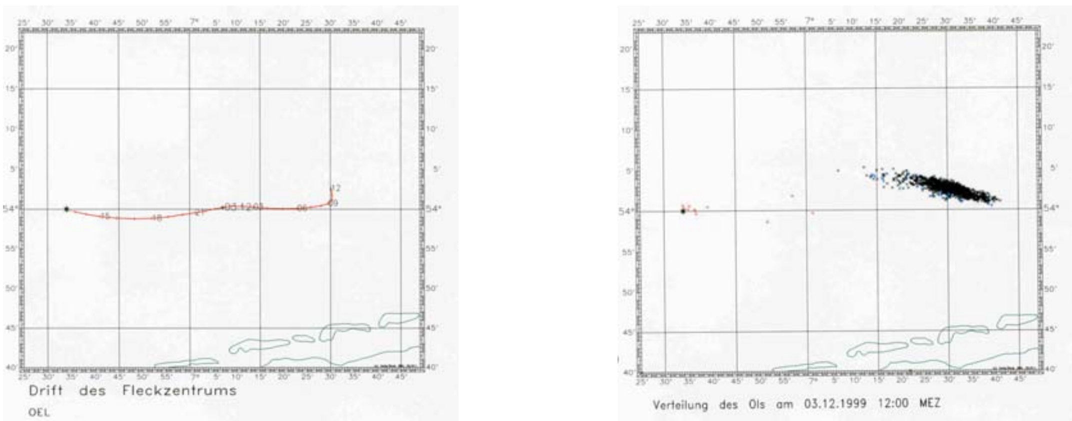


Figure IV-63: Drift behaviour of crude oil along the East Frisian Islands

Figure IV-64 shows the distribution of 496 [t] "intermediate Fuel Oil" (IFO) in summer with southerly winds.

The figures show the point of leakage (black dot), the remaining oil slick on the surface (black x), the remaining oil slick at depth (blue +) and the evaporated part (red o).

The Euler dispersion model simulates the temporal development of the distribution. It is used to predict the dispersion of soluble substances in water such as occurs during an accident with chemicals or radioactive material.

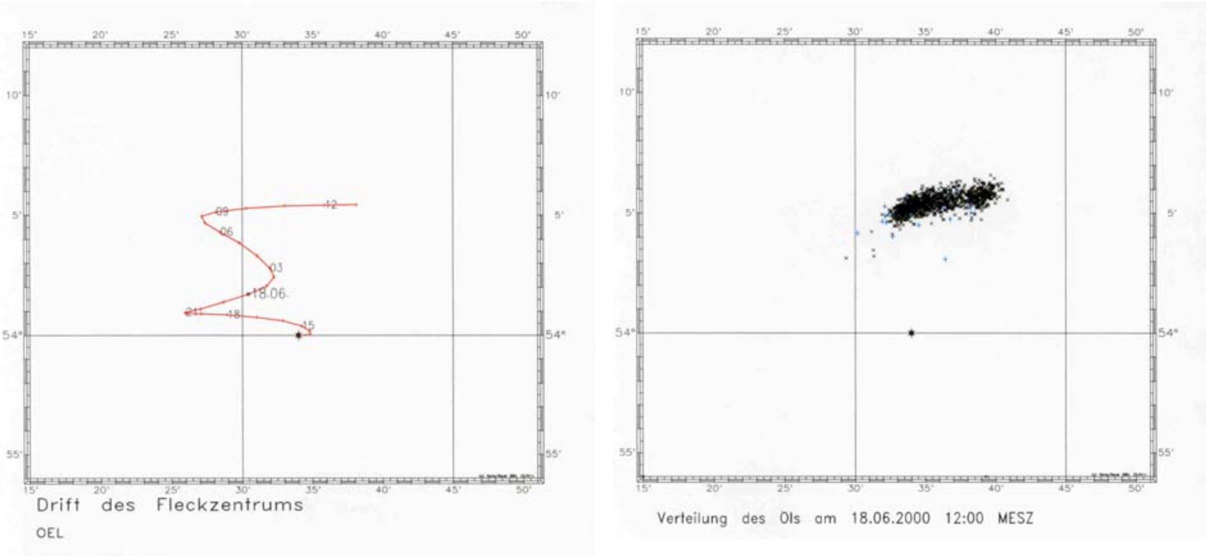


Figure IV-64: Dispersion of fuel oil

The numerical model presented here has the disadvantage that it is a cost intensive probabilistic method, which requires many reiterations to include all the combinations of weather, hazardous substances etc. However, no alternative less complex computation methods could be developed or are available. The dispersion of hazardous substances cannot be determined properly in risk analyses.

IV-5 Risk potential for the EEZ in the North and Baltic Seas

The aim of the collision potential shown in the following is to compare the different sea are with regard to the possible collision risks between ships and WEPs. For this purpose, the EEZ was divided into cells of 3 [sm]. A WEP is assumed to occur in the centre of each cell. This yields a “theoretical wind park” which covers the contemplated area of the North and Baltic Seas This assumption was necessary in order to be able to calculate the potential for all regions of the EEZ. This inevitably led to the fact that many WEPs were “positioned” in heavily frequented shipping routes, which in reality would not be the case.

Simulations, using these boundary conditions, were carried to determine the collision frequency, with the methods described in this report. The collision potential is described as the number of collisions per WEP. The collision potential does not include the damage severity since the model did not permit such a calculation. The collisions of both disabled as well as manoeuvrable ships were considered. This collision potential was attributed to the cell in which the corresponding WEP was assumed to be in. The results were normalized and divided into four classes, which ranged from 1 to 4. Where 1 represents the lowest collision potential and 4 the highest:

Collision potential	Lower boundary	Upper boundary
1	Minimum potential	Minimum potential + 1*interval
2	Minimum potential + 1*interval	Minimum potential + 2*interval
3	Minimum potential + 2*interval	Minimum potential + 3*interval
4	Minimum potential + 3*interval	Maximum potential

Two cases were evaluated. The first included all ship types, whereas the second case was used to determine the collision potential resulting from oil tankers. The results for all ship types are shown in figures IV-65 to IV-68.

The abscissa in figure IV-65 shows longitude and the ordinate shows the latitude. Land is shown in green, which also applies to the subsequent figures. The figures show the interpolation of the cell potential under consideration of the neighbouring cells. Thus, the isolines run through the cells. In the area of the North Sea EEZ, the highest collision potential of 3 was found to be in the TSS Terschelling German Bight. This is attributed to the high shipping traffic in the TSS. The lowest collision potential of 1 was established for the area of the western coast of Schleswig-Holstein and north of the TSS German Bight Western Approach

Figure IV-66 shows the collision potential for the Baltic EEZ. Here the maximum collision potential 4 was found for the area of Kadetrenden and northeast thereof. These are caused primarily by the transit traffic from and to the eastern Baltic. The lowest collision potential 1 was determined for the Pomeranian Bight.

A comparison between the North and Baltic Seas shows that the collision potential is higher in the Baltic. A collision potential of 4 was found in the Baltic, whereas the North Sea only had a maximum of 3. This result appears to be plausible, since the traffic density in the Baltic is often clearly higher than the highest in the North Sea. Figures IV-67 and IV-68 show the results for oil tankers only. The normalisation of the results on oil tankers was carried out separately with the result that the categories 1 to 4 are again represented. It is therefore not possible to carry out an absolute comparison of all ship types (see figures IV-65 and IV-66). In the North Sea there are two areas with a collision potential of 2. The first is in the region of the TSS Terschelling German Bight and German Bight Western Approach. The second includes the region of transit traffic out of the Straight of Dover to and from Skagen.

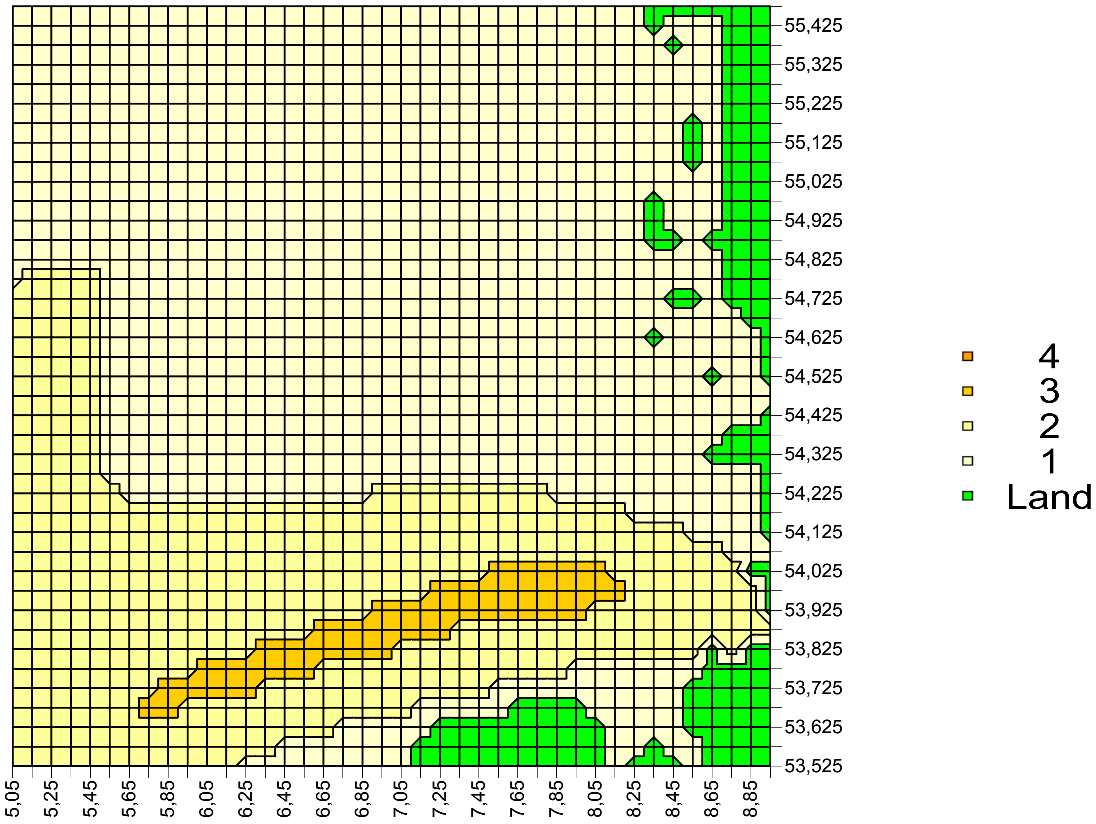


Figure IV-65: Collision potential North Sea: all ship types

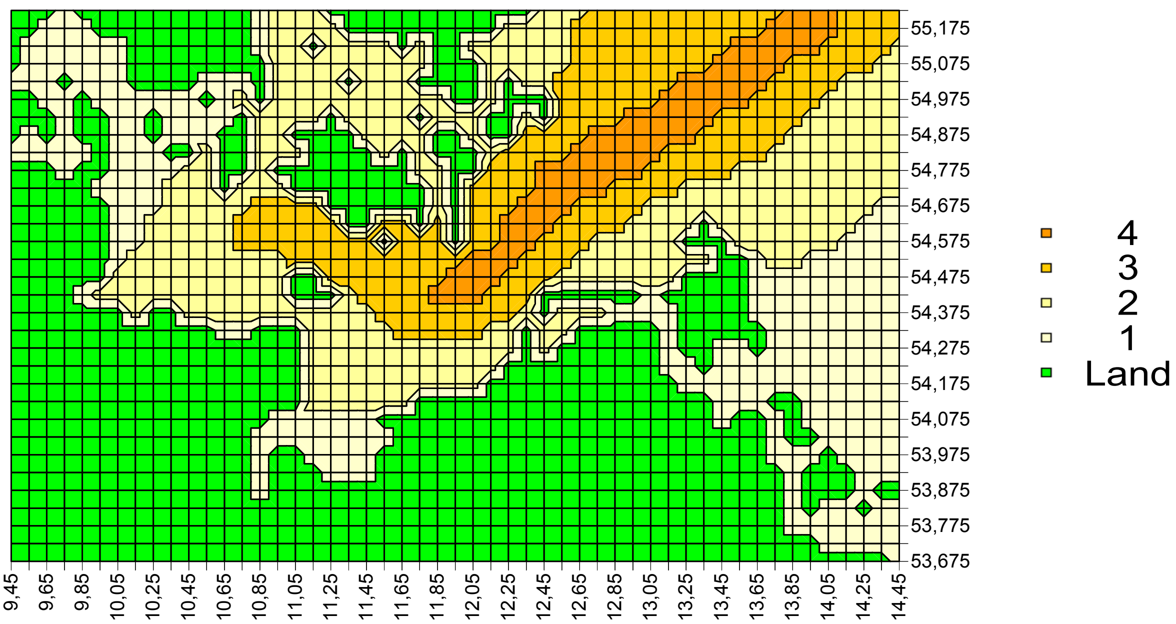


Figure IV-66: Collision potential Baltic Sea: all ship types

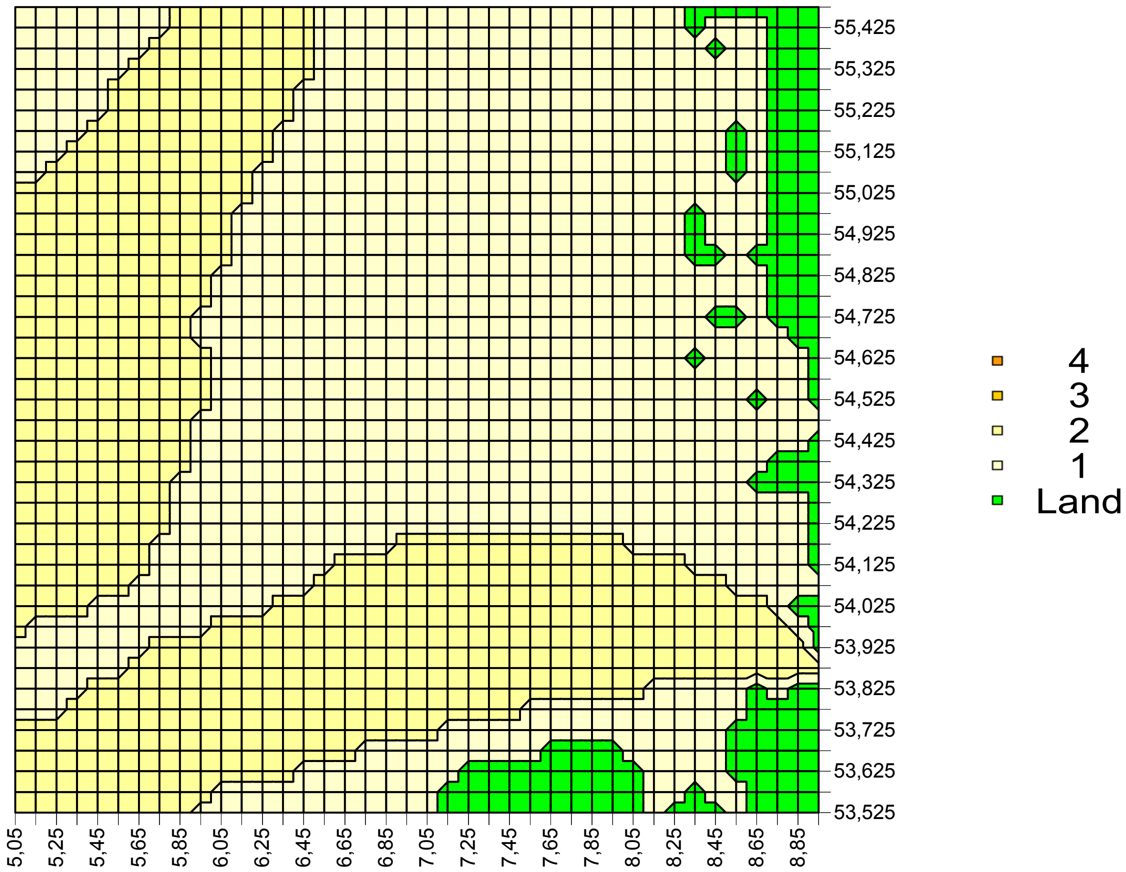


Figure IV-67: Collision potential North Sea: Oil tankers

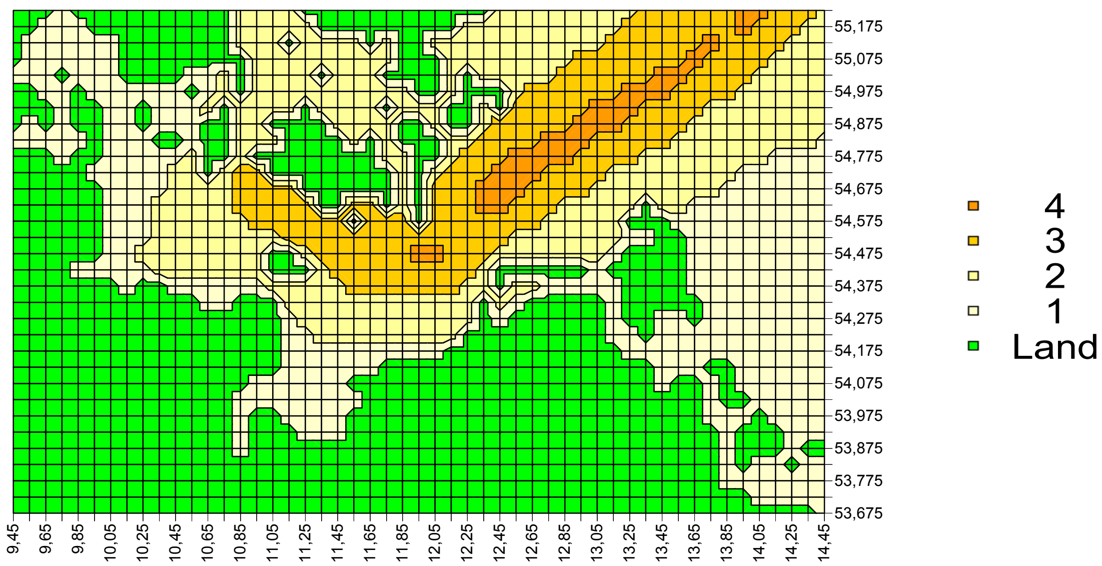


Figure IV-68: Collision potential Baltic Sea: Oil tankers

For the Baltic Sea there is very little difference between areas of collision potential of all ship types and oil tankers

If the differences between the collision potentials of all ship types and oil tankers between North and Baltic Seas are compared it becomes clear that there is a difference of two categories for oil tankers and only one between ships of all types.

The results also show a good correlation between the calculated collision potential and traffic densities. Differences are mainly attributed to the fact that disabled ships drift corresponding to environmental conditions and thus collide with WEPs in areas, which are not navigated by ships.

The collision potential cannot be used for absolute conclusions as to whether an area is suitable for the construction of wind parks or not. The reason for that is that they only permit a relative comparison between areas. This means that even an area with the highest collision potential 4 could still be appropriate. Or alternatively an area classified as category 1 could be inappropriate. Absolute statements on risk can only be made on the basis of risk analyses under consideration of the corresponding wind park configuration ands safety concepts.

Measures to reduce and avoid collision risks

This section deals with constructive and operative measures to reduce existing risks. Since the risk is a product of frequency and consequences a reduction is attained when either one or both of the factors is reduced.

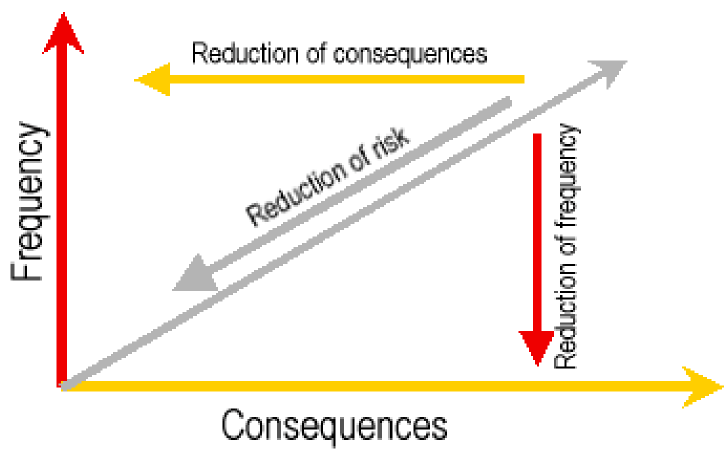


Figure IV-69: diagram of the effect of risk reducing measures

IV-6 Potential danger of ship collisions with wind energy plants for the marine environment

This chapter deals with the possible dangers for the marine environment resulting from collisions between ships and wind energy plants. The discussion is based on the sections IV-4 and IV-5, which deal with the collision risks and accident probability potential.

IV-6.1 Initial situation

The degree of probability with which a collision will occur and to what extent hazardous substance will be released into the environment has already been discussed extensively in section IV-4 and is therefore not dealt with here. To assess the potential dangers in connection with collisions between ships and WEPs it is assumed that a ship will spring a leak and release hazardous substances (e.g. oil as fuel or cargo) to the marine environment as described in section IV-4.The starting position is therefore comparable to other ship-ship collisions or grounding and springing a leak and its consequences as described in the literature (e.g. van Bernem & Lübbe 1997 and literature cited therein).

IV-6.2 Risks for the marine environment

Oil pollution and the likely consequences of ship accidents are the focus in discussions in the literature. The spilling of other hazardous substances through loss (leakage of chemical tankers, loss of containers with hazardous cargo) is not well document and does therefore not enable safe assumptions or statements on the dispersion and degree of damage. We will therefore concentrate on oil spillages (cargo / fuel) and the possible consequences for the marine environment which have been extensively dealt for different marine areas, in the literature (e.g. Armstrong et al. 1979, 1995; van Bernem & Lübbe 1997; Booman et al. 1995; Busdosh et al. 1978; Chasse & Guenole-Bouder 1982; D'Ozouville et al. 1979; Feder & Blanchard 1998; Hoepner et al. 1987; Jacobs 1980; Kingston et al. 1995; Kocan et al. 2000; Olenin 1990).

The impact of oil (and other hazardous substances) on marine organisms generally depends on various factors. These include type of oil or hazardous material, concentration, duration of contact, susceptibility of the organisms, geographic position and environmental conditions such as water temperature (Gin et al. 2001). The uptake takes place via water, food or sediment. If the animals are subjected to the substance for longer periods there is the danger that the substances will be incorporated in tissue such as fat (Lee 1977). The consequences could be death on contact or breathing paralysis on the one hand or the indirect uptake of sub lethal oil quantities or its derivates (Gin et al. 2001). The second case could lead to reduced resistance and thus introduce harmful substances such as carcinogens into the food chain (Gin et al. 2001). Bernem & Lübbe (1997) provide a general overview of the possible consequences of oil and its derivates.

IV-6.2.1 Discussion on the impact of oil and hazardous substance on marine organisms

The following section summarises the current state of knowledge on possible effects of oils and other hazardous substances on marine biota:

Effects of oil on pelagic organisms

Plankton organisms in the upper water layers in particular are subjected to the effects of oil (Gin et al. 2001). Summer investigations on zooplankton have shown that copepods dominate the larger zooplankton in the northern and central North Sea, whereas decapods and fish larvae dominate in the southern part. Plankton samples from the Baltic comprised 93 % Scyphomedusae (Möller 1980). Elevated concentrations of hydrocarbons cause a reduction in photosynthetic rate in algal cultures, a decrease in zooplankton biomass, a decrease in feeding activity of copepods and abnormalities in development, early death as well as reduced reproductive success. The invertebrate *Sphaerium* sp. proved to be particularly sensitive (Gin et al. 2001). Copepods consume oil particle from an oil slick and excrete a large proportion of the aromatic hydrocarbons with their faeces. A portion however, is retained by the animal for longer periods or until they die (Lee 1977, Teal 1977). *Crangon crangon* takes up sunken crude oil, which is retained until the next moult (Lee 1977). The zooplankton was investigated along the coast of northern Brittany after the *Amoco Cadiz* accident (Samain et al. 1979). The authors detected a reduction in the biomass and a retarded spring growth. Michael (1977) on the other hand rated the impact of oil on plankton organisms as low since the oil fractions rapidly disperse in the water and the concentrations decrease. Another reason is that the plankton populations have rapid generation times and are widely distributed. The author did not find any impact on zooplankton. The photosynthesis and growth of phytoplankton was only affected at very high unnatural concentrations of hydrocarbons, whereas low concentrations stimulated the photosynthesis (Michael 1977). One way by which natural chlorinated hydrocarbons enter the food web is by the metabolic conversion of Phytol ($C_{20}H_{40}O$), which results in pristanes and similar Olefins Such hydrocarbon production for example occurs in the copepod *Calanus*, which introduces the substances in to the food web e.g. fish (Teal 1977).

Effects of oil on fish, eggs and larvae

There is little danger that mature fish will come into contact with oil under natural conditions, since these are in a position to actively avoid polluted areas (van Bernem & Lübbe 1997, Gin et al. 2001, Lee 1977, Sharp et al. 1979). However, genotoxic lesions (DNA Adducts) were found in the gills and liver of the Teleost *Lipophrys pholis* 60 days after the accident of the *Sea Empress* (Lyons et al. 1997, Harvey et al. 1999). To which extent the DNA adducts continue to remain and result in the damage of subsequent generations (mutation, chromosomal aberrations), is unclear. Due to the long traceability of genotoxic substances, *Lipophrys pholis* has been recommended as a biomarker. Polycyclic aromatic hydrocarbons are thought to be responsible for the increase in liver tumours in flounders of the North Sea (Dethlefsen[4], Lang[5]). The many diseases of fish in the Baltic are also thought to be a consequence of harmful substances. The cod for example often shows tumours and skeleton deformation (Dethlefsen[6]). Experiments in which cod were subjected to different oil concentrations for 30 showed that the long chain aromatic hydrocarbons were apparently easily metabolised. There was no effect on DNA adducts (Aas et al. 2000). Some harmful substances are converted to genetically harmful and carcinogenic metabolites in the body of fishes (Malins et al. 1980). Adult rainbow trout, which were fed food mixed with crude oil during sexual maturation, had a slightly lower hatching success and higher mortality of larvae. However, the changes were not significantly different from the controls. Morphological or histological abnormalities were not detected in the offspring (Hodgins et al. 1977). Adult herring (*Clupea pallasi*), which were collected three years from an area covered by an oil slick

[4] http://www.sdn-web.de/Fishdis/HeadingNorth.htm

[5] http://www.sdn-web.deFishdis/Liver.htm

[6] http://www.sdn-web.de/Fishdis/HeadingBalt.htm

from the *Exxon Valdez* produced less offspring and less morphologically normal larvae than those from a cleaned control area. Particularly males from the affected area had more macrophages in the spleen, liver and kidneys (which could, however, also be related to the age of the animals). The females had grainy inflammations (Kocan et al. 1996). Distinctly higher concentrations of hydrocarbons were found in the gallbladder of the halibut from this region. These wee probably taken up through the food (contaminated mussels) (Armstrong et al. 1995). Eel and mullet were found to have higher concentrations of Toluene after contact with oil and tar clumps were found in the stomachs (Lee 1977). Fish take up hydrocarbons through their gills or via food. Plaice, which have consumed oil with their food, show an assimilation of n-alkanes in the liver, but not in the muscle tissue. The uptake from the water resulted in an accumulation in the liver and gallbladder. An uptake via food resulted in the accumulation in the stomach, liver and gallbladder in *Fundulus simulus* there was also an accumulation in the brain. Normally the substances are completely excreted via the urine and faeces, whereby Anthrazen (3 rings) is retained for longer than Naphthalene (2 rings) and Benzene (1 ring) (Lee 1977). However, many fish on the Californian shelf show evidence of hydrocarbon accumulation in their tissue, which is a sign of the ubiquity of these substances in the region (Rossi et al. 1979). A selective uptake of hydrocarbons into various organs was detected in the minnow *Fundulus*. The alkanes found in the muscle tissue resemble those from the water and are taken up via the gills from where they enter the muscle via the blood. The hydrocarbons in the liver resemble those from the sediment and are probably taken up via the food. They are transported through the blood via the intestine and absorbed by the liver. In Herring, however, there appears to be a rapid translocation of hydrocarbons from the intestines to the muscles. The excretion phase appears to take a long time (Teal 1977). Broeg et al. (1999) found that the diversity of fish is higher in unpolluted waters than in polluted ones. Differences in the degree of pollution were detectable with biochemical and histochemical investigations. Furthermore, the fish parasite *Trichodina* sp. also proved to be a good indicator since it reflects the degree of pollution (highest infection in heavily polluted waters). The contact of adult fish with pollutants can lead to a reduction in egg production of up to80% (von Westernhagen 1988).

Oil pollution also constitutes a danger for fish eggs and larvae, since these often occur near the sea surface. This is particularly critical during the spawning period from January to June (von Westernhagen, pers comm.). According to Conway et al. (1997) the most dominant species in the Irish and North Seas are the Sprat (*Sprattus sprattus*), Dragonet (*Callionymus* spp.), Dab (*Limanda limanda*) and to a lesser extent Rockling species, Sandeel (*Ammodytes* spp.), Whiting (*Merlangius merlangus*) and Flounder (*Platichthys flesus*). Most of the eggs are found in the to 50 m of the water column (number at the surface had their maximum distribution between 10 and 15 m). Eggs occur to greater depths than the larvae but there were no diurnal differences in vertical distribution. According to Möller (1980) Clupeid larvae dominate in the southern North Sea whereas Flatfish are mainly found in the central and northern North Sea. The author found mainly Goby larvae in the Ichthyoplankton east of Denmark. The early developmental stages are not only subjected to oil at an earlier stage, they are also regarded as being distinctly more sensitive as adults (Dethlefsen et al.[7], [8]). Poisons for instance contaminate the gonads of adults, which lead to an increased deformity in embryos. This is particularly the case in the Dab (Dethlefsen et al.[5]). Other species, which often show deformities, are the Whiting, Cod, Flounder and Plaice. These deformities could, however, also be connected to the water temperature (Dethlefsen[6], Dethlefsen et al. 1996). Hydrocarbons affect the development of fertilized eggs, perhaps by interacting with the decision of the cell membrane (von Westernhagen 1988). Eggs of the Baltic herring (*Clupea harengus membras*), which were subjected to the water-soluble fraction of various oils showed interference of the embryo activity such as slower heart rate as well as incomplete and retarded hatching. A large proportion of the hatched larvae was deformed or died after one day. Low concentrations of hydrocarbons already resulted in a reduction of the larval length (Linde 1979). Flatfish embryos and larvae would suffer large mortalities after an oil spill (Malins et al. 1980, Anonymous 2002). Larvae of the Pacific Herring (*Clupea harengus pallasi*) suffer high mortalities when the come into contact with the water-soluble fraction of oil. They also show a reduced swimming capability and rapid reduction in feeding rate. The animals were all smaller and

[7] http://www.sdn-web.de/Fishdis/Elbmal.htm

[8] http://www.sdn-web.de/Fishdis/Embryo.htm

weighed less than control animals. Up to 98% of the substances were excreted after the first day. Feeding with contaminated food increased the mortality of larvae, however, surviving larvae appeared more robust. Oil, taken up via the food did not appear to have an effect on growth, feeding behaviour or swimming (Carls 1987). Aberration tests of the anaphase of larvae were carried out on the Pacific Herring after the *Exxon Valdez* oil spill. These show that genetic effects were frequent, 2 months after the accident, but then declined. Although the effects were not detectable after 1991, the spawning capacity was reduced by a 3rd in 1993/94 (Hose & Brown 1998). Serigstad (1986) investigated the effect of water-soluble oil fractions on the uptake of oxygen by Cod eggs and larvae. During the egg stage there were no changes detectable. However, the oxygen uptake of the larvae was 50% lower than in the control, (also if they were only subjected to oil for 24 hours) and was about that which was measured in the dark. The rate of oil-exposed larvae was also 5% lower in the dark. There was also a dependency of oxygen uptake on the nutritional state of the larvae. The heart frequency of yolk larvae was not affected by oil. There is a strong effect of oil on the oxygen consumption during the phase of the last yolk absorption, 5-7 days after hatching (Serigstad & Adoff 1985). Similar observations are described by Booman et al. (1995).

Demersal eggs such as those of the Mummichog *Fundulus heteroclitus* are very sensitive to hazardous substance in the sediment, which gradually leaches out into the water column. Eggs subjected to this stress will have a lower developmental of subsequent stages, a lower hatching success and a lower survival rate as well as developmental abnormalities (Sharp et al. 1979). Von Westernhagen et al. (1987) subjected eggs of Flounder and Herring to harmful substances in the surface micro layer. The concentrations of the harmful substances were clearly higher than in the water below. A relationship between poison concentration and effects on hatching success, hatching time as well as number of abnormal larvae. Experiments by Kocan et al. (1987) on the effect of a contaminated micro layer on embryos of the Baltic Herring and Atlantic Cod showed a significant mortality and heavy deformities in hatched larvae. After the accident of the *North Cape* near Rhode Island benthic embryos of the Winter Flounder had morphological anomalies as well as in the chromosomes and the number of active mitoses. It is assumed that less than 50% of the embryos attained the larval stage (Hughes 1999). The effect of dispersants on the bioavailability of hydrocarbons for larvae has not yet been proven (Wolfe et al. 2001).

In summary, the following impacts of aromatic hydrocarbons on the embryo development can be expected: Blockage of the phosphorylisation of ADP (Effect on early cell decision), abnormal development of the spine, head or eyes, weakening of the heart function, retarded hatching and development as well as hatching success (von Westernhagen 1988). Sub lethal effect on the larvae of contaminated eggs include reduced size, induced mitochondrial malfunctioning, gross abnormalities, changes in the structure of mitochondria (causes changes in the energy transfer) as well as reduced larval activity (von Westernhagen 1988). Generally the initial larval stages are the most sensitive and with time the abnormalities become less. Frequent abnormalities in fish embryos are bubble like adenoid and deformation of the Notochorda. Temperatures increase the rate of deformation as does the input of harmful substances via rivers (Cameron & von Westernhagen 1997).

Effect of oil on benthic organisms

After the *Exxon Valdez* accident, the effects were investigated down to 20-150 m, by measuring the amount of polycyclic aromatic hydrocarbons (PAH) in various organisms (Armstrong et al. 1995). The PAH content of the Scallop, *Clamys rubida*, was elevated at the beginning of the investigation but declined in the subsequent year. The fertility of female *Pandalus hypsinotus* was 30 % lower than in those from unspoilt bays. Several species of shrimp, crabs and mussels were investigated, but there was no significant damage to these organisms (Armstrong et al. 1995). Other investigations between 40-100 m depth and 16 months after the accident showed that the distribution of the macro fauna at these depths was more likely determined by oceanographic conditions than by the effect of the oil spill of which there was no indication any more (Feder & Blanchard 1998). However during investigations near an oil field off Texas a clear relationship was found between Naphthalene –concentration and the number of species and individuals (Armstrong et al. 1979). The mussel *Mytilus edulis* accumulates

PAH when it comes into contact with oil and the profile resembles that from the water very closely (Baussant et al. 2001). Gesteira & Dauvin (2000) investigated the effects of the *Amoco Cadiz* and *Aegean Sea* accident s on soft bottom communities. The communities in both areas had similar structures and species composition as well as hydrological conditions. In both areas, the oil pollution caused the disappearance of amphipods. The order *Ampelisca* was particularly affected. The recovery of the amphipod fauna was slow but there was no increase in opportunists there was little influence on polychaetes. Based on these results, amphipods have been recommended as bio-indicators, whereby the relationship between amphipods and polychaetes can be used to determine temporal changes (Gesteira & Dauvin 2000). The benthic sea grass beds along the French coast were only briefly affected by the *Amoco Cadiz* accident (Jacobs 1980): Individual and species numbers decreased rapidly while small Crustacea, Echinoderms and other groups disappeared completely. However, within 1 year after the accident, the community was in the same state as before, with the exception that all amphipods were missing. The disappearance of the dominant *Ampelisca*-populations from the fine sand assemblages was also observed by Poggiale & Dauvin (2001) The only species which still occurred in low densities was *Ampelisca sarsi*. The sandy areas in this region are relatively isolated which is why amphipods from isolated populations. The resettlement of *Ampelisca* species is probably retarded by the settlement strategy. After 15 years the population appears to have recovered well and has reached comparable densities to the time before the accident (Poggiale & Dauvin 2001). After the accident of the *Sea Empress* Genotoxic effects were investigated in both fish and invertebrates (Harvey et al. 1999). In contrast to the fish, the invertebrates did not have elevated DNA Adducts. Seven years after the accident of the *Nella Dan* in Sub Antarctica, the benthic community of the eulittoral zone was investigated. The community did not differ from that of clean areas. Also the rhizome community of the kelp *Durvillaea antarctica* from heavily polluted was slowly recovering. The number of opportunistic species dropped and that of the sensitive species increased. The accident of the oil tanker *Braer* near the Shetland Islands did not have a significant effect on the structure, species number, abundance and diversity of the macro benthic community, although the sediment in this area was heavily polluted, particularly the fine sand. The reason for this could have been the low toxicity of the oil or the premature sampling (Kingston et al. 1995). After the explosion of the super tanker *Haven* in 1991 large amounts of oil accumulated around the wreck. The sediment in this region is coarse with a small muddy fraction. Sediment samples were fractionated vertically to obtain samples from different layers. A distinct vertical pattern of oil distribution was observed. Large clumps were inhabited by sessile organisms (Hydrozoans, Bryozoans, Serpulids). The composition of the macro fauna in the contaminated areas was very similar and was dominated by polychaetes. There were no differences in abundance or layering. The results therefore indicate that the community in the affected areas had almost completely recovered (Guidetti et al. 2000). Water samples were collected one month after an oil accident along the Swedish coast in 1976 and different benthic organism were investigated The content of hydrocarbons decreased continuously. In areas where chemical dispersants were applied, the content of aromatic hydrocarbons was much higher. The organisms had hydrocarbon concentrations of up to 20 µg/g fresh weight whereby Dibenzothiopenes had higher concentrations than Naphthalene and Phenantrene (Grahl-Nielsen et al. 1978). Grassle et al. (1981) Test the effects of heavy oils on marine shallow water ecosystems by carrying out experiments in ecosystem tanks. The sediment used was sandy mud and the macro fauna was numerically dominated by *Nucula annulata* and *Mediomastus ambiseta*A single dose of oil did not have any visible effect on the meio and macro fauna. However, a simulated chronic pollution over a period of 5 months did result in a drastic reduction of individual numbers. *Mediomastus ambiseta* decreased continuously during the months after oil application and after a while had completely disappeared. *Nucula annulata* also decreased dramatically. The only suspension feeders in the tanks were *Crepidula fornicata*, *C. plana* and *Anadara transversa*. The usually frequent clam *Pitar morrhuana* was missing. Overall the oil resulted in a reduction of the Meiofauna, particularly the crustacea (Harpacticoida and Ostracoda are the most sensitive groups). The nematodes also had significantly lower abundances Foraminifers and Ciliates, however, were more frequent in the oil tanks, which could be attributed to lower competition. After stopping the regular application of oil, the oil content of the water decreased rapidly. However, the sediment samples did not reveal a decline in oil concentration, even after 2 months. The Meiofauna groups did show signs of recovery after 2 months. However, the macro fauna did not show any signs of recovery (Grassle et al. 1981).

The effect of temperature on the uptake of Naphthalene by mussels was investigated in laboratory experiments: the lower the temperature the higher the concentration of Naphthalene in the tissues of the mussel. Salinity only had a minor effect. However, the factors did not have any effect on the excretion of the substance (Fucik & Neff 1977). *Mya arenaria* reacts with high mortalities to the contact with oil. A reduction in numbers is still observable after 3 years (Michael 1977). *Mya arenaria* rapidly accumulates hydrocarbons. The excretion also takes place rapidly, however it remains incomplete even after 2 weeks in clean water (Stainken 1977). For *Macoma baltica* a thin layer of oil on the mussel beds has insignificant effects. In the presence of the water-soluble fraction in the surrounding water or in the sediment, the clam's digging activity is reduced and it comes to the surface, which makes it easy prey for predators (Taylor & Karinen 1977). The Echinoderm *Coscinasterias muricata* localises its prey with chemoreceptors and the search for prey is therefore severely affected by the presence of oil. This process is, however, reversible (Temara et al. 1999). A sub tidal sandy bottom community in Norway was exposed to low concentrations of oil (Bakke & Johnson, 1979, Bakke et al. 1982). No significant enrichment of hydrocarbons was observed in the sediment, which seems to indicate a rapid biological remediation. The Chlorophyll a content of the sediment was elevated which either indicated a reduced grazing by the sediment fauna or an increased production due to the oil. The nematode abundance gradually decreased but harpacticoid Copepods showed no reaction. Overall the degree of pollution was regarded as being insignificant (Bakke & Johnson, 1979, Bakke et al. 1982). Die Copepod species *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* appear to be very resistant to oil pollution. They tolerate concentrations 6 times higher than those tolerated by fish eggs and larvae This critical concentrations for krill and larger crustaceans of the genus *Parathemisto* (Amphipoda) the critical concentrations lie between those of the copepods and yolk larvae (Booman et al. 1995). Experiments with the benthic Amphipod *Anonyx laticoxae* have shown that the uptake of hydrocarbons from contaminated water in a turbulent system is distinctly higher than under static conditions. The uptake is also much lower if only the sediment is contaminated which indicates that the bioavailability of Naphthalene is very low. The amphipods mainly accumulated Alkylnaphthalenes. The excretion of the substances appeared to depend strongly on the solubility of the components (Anderson et al. 1979). Investigations on crab larvae (*Cancer magister*) have shown that acute toxicity of single hydrocarbon compounds is related to the degree of Alkyl-Substitution. Thus Naphthalene and its derivates may be more toxic than benzene and its derivates, but are less concentrated in the water-soluble fraction of crude oil (Caldwell et al. 1977). In an investigation on small-scale oil pollution of an estuary, polychaetes colonised the area in low numbers after a little while. Nematodes also immediately colonised the area without a time lag. Of the meiobenthic copepods only one species showed a reaction to the presence of oil in the top layers of the sediment: *Enhydrosoma woodini*. Initially the species occurred in low abundances, however, after 60 days it had attained abundances, which were higher than in clean sediment. The results indicate a rapid recovery of lightly polluted areas (Decker & Fleeger 1984). Ewa-Oboho & Abby-Kalio (1994) released oil on a mudflat (70 % silt) to test the effect on the snail *Tympanotonus fuscata* and the Fiddler crab *Uca tangeri*. Both species showed drastic changes in the densities immediately after oil application, whereby the biomass of *Uca* increased. In addition the intrusion of oil was observed to occur to a depth of 11 cm in the sediment. . The respiratory rate and the percentage body fluid in juvenile crabs (*Rhithropanopeus harrisii*) increases in the presence of Phenathrene (Laughlin & Neff 1979). The survival rate of Horseshoe crab (*Limulus polyphemus*) eggs in the presence of water-soluble oil fraction whereas the breathing rate increased (Laughlin & Neff 1977). There was strong interaction between salinity and the water-soluble fraction. Mecklenburg et al. (1977) dealt with the effect of oil on the moulting of crab larvae and found that the larvae react very sensitively to pollution during the moulting. The consequence being that there was a reduced success of moulting and many larvae died. A similar sensitivity in larvae was also found by Neff & Anderson (1981). Mussels and barnacles, which are subjected to petroleum hydrocarbons in the sediment, show concentrations of these substances in their tissues. However, there were no signs of any change in their distribution, reproduction or growth. Only some barnacles which were covered in tar, revealed a reduced reproductive success. (Straughan 1977). Animals from other heavily polluted sediments also maintained a strong colonisation. Abnormalities were also not found. No hydrocarbons were found in the muscle tissue of commercially exploited species such as abalone or Lobster (Straughan 1976). The tissue of the estuarine shrimp *Palaemonetes pugio* rapidly accumulates Naphthalene. The excretion is also rapid, but remains incomplete. Particularly Dimethylnaphthalene is retained (Tatem 1977). A further effect is the lowering of the breathing rate. The contact of gravid females with oil results in a clearly reduced hatching success of the larvae. The growth of the larvae is also reduced (Tatem 1977).

Lee (1977) presented an extensive report on the impact of petroleum hydrocarbons on various benthic organisms. Many species of shrimps, crabs and lobsters take up Petroleum hydrocarbons from the water or via the food. -In *Calinectes sapidus* most of the hydrocarbons taken up via the food is not assimilated by the tissue, but rather eliminated by the animal. The main organ of accumulation of hydrocarbons in crabs is the hepatopancreas. The metabolism of crabs facilitates the elimination of the hydrocarbons via the faeces and urine. Most shrimps and crabs are able to totally eliminate hydrocarbons within 2 –to 10 days. However, *Uca* still had hydrocarbons derived from an oils spill many years after the spill, which could have been taken up from contaminated sediment, however. Oysters and mussels seem to require longer to eliminate hydrocarbons than crabs and shrimps. Deposit feeders take up hydrocarbons bound to sediment particles Polychaetes such as *Capitella capitata* live in areas with a high oil input. These, and probably other worms too, have enzyme systems, which convert petroleum hydrocarbons. The hydrocarbon metabolism enables a rapid excretion. *Neanthes* is capable of a rapid uptake and also eliminates these relatively fast and completely. Naphtalene from the sediment or food do not pass through the intestine and are removed with the faeces. *Nereis virens* and *N. succinea* take up Benzanthrazene from contaminated sediments. This is excreted again within 24 days in clean sediments. Sipunculids also eliminate absorbed hydrocarbons within 14 days. Snails, which filter large volumes of water to feed, take up and concentrate large amounts of hydrocarbons (in solution or adsorbed to particles). They have a micellar layer on the surface of their gills, which enables the absorption of hydrophobic compounds such as hydrocarbons. Mussels and oysters exposed to heavy oil, concentrate these in the body. , Differences in the uptake rate are probably attributable to the different filtering rates and lipid content. Hydrocarbons tend to accumulate in lipid storage tissues due to their low water solubility. Heavily contaminated mussels eliminate up to half of the accumulated substances within 3-4 days in clean water. However, 12 % are still retained after 8 weeks. . Other measured half-life values range from 48 –to 60 days, depending on the degree and duration of poisoning. Normally the half-life is shorter, though. The excretion is usually rapid in the beginning; however, a residue usually remains for a relatively longer period. Snails eliminate hydrocarbons slowly in areas with an oil slick, which is probably due to the continued input of oil to the sediment (Lee 1977). Crude oil in the water or sediment causes the Sipunculid *Phascolosoma agassizii* to accumulate hydrocarbons. The excretion is very rapid in clean water so that the animals are completely free of hydrocarbons after about 2 weeks (Anderson et al. 1977). In an experiment with oil contaminated sediment, Anderson et al. (1978) that there was no reproduction of benthic organisms in the sediment. The sensitivity of polychaetes is dependant on the type of oil involved (Carr & Reish 1977, Neff & Anderson 1981*). Capitella capitata* and *Cirriformia spirabrancha* appear to be resistant to several oil types, whereas *Ophryotrocha puerilis* and *Ophryotrocha* sp. react very sensitively to different types. The water-soluble fraction of heavy oil was more toxic than that of crude oil. *Cirriformia spirabrancha* reacts sensitively to crude oil after longer exposure, however. *Ctenodrilus serratus* reacted sensitively to fuel oil, but was relatively resistant to the long-term effect of the crude oil. In general *Capitella capitata* was the less sensitive species. Reproductive investigations on *Ctenodrilus serratus* and *Ophryotrocha* sp. revealed a significant reduction in the offspring (Carr & Reish 1977). In *Arenicola marina* the contact with oil leads to a clear reduction in the population (Levell 1976). A dominance of polychaetes of up to 92% was observed in areas in Brazil, which have been polluted by oil for a long period (Peso-Aguiar et al. 2000).

Impact on sea birds

Sea birds are affected by the direct uptake of oil and during cleaning. Life important functions of the animals (protection against cold / water repellence) are affected and even small patches of oil on their feathers can result in death oil enters the alimentary canal when birds try to clean themselves. The pathological consequences of oil contamination were proven in experiments (van Bernem & Lübbe 1997 and Lit. cited therein). Abnormal development of embryos as well as indirect damage due to contamination of breeding sites and feeding grounds has also been recorded. (van Bernem & Lübbe 1997). Even small oil quantities may result in large losses of birds (Burger 1993), whereby the recovery of stocks to the numbers before a spill may take decades (Heinemann 1993). To what extent birds are affected by an oil spill also depends on the behaviour of the birds. Species, which spend a lot of time on the water and attain high population densities but have a slow reproductive rate, are particularly sensitive. Carter et al. (1993) developed an "Offshore Vulnerability Index", which is used as a sensitivity index for different sea birds (see section IV-7).

IV-6.2.2 Contamination pathways

It is clear from the discussion and presentation of possible accident scenarios (Sections IV-3 and IV-4) as well as from the discussion in section IV-6.2.1, that almost all parts of the marine environment will be affected by the discharge of hazardous substances in the event of an accident (Ship - Offshore WEP). The major contamination pathways are shown below:

Ship collision

↓

Discharge of contaminants

↓

Spreading / Dispersion / Solution / sinking / Stranding of the substances

↓

Uptake by Biota

Sea surface
(seabirds)

Pelagic System
(phyto- and Zooplankton, eggs and larvae of fish and invertebrates)

Benthic System
(Macrozoobenthos, demersal fish, diving sea birds)

Eulittoral and shore zones
(makrozoobenthos, sea birds)

Figure IV-70: Contamination pathways and affected biota after discharge of hazardous substances due to a ship collision.

IV-7 Spatial risk analysis using a grid model

As mentioned in sections IV-3 and IV-4, it is only possible to calculate values of an overall risk for the marine environment due to an accident between a ship and installed offshore WEP for this specific project. However, in order to arrive at a conclusive statement as to which geographic areas are particularly at risk in the context of the question “Accident and its consequences”, for the construction of an offshore WEP, it is not necessary to calculate an absolute risk. The estimate of a relative risk is sufficient, since only the spatial comparison is required to make a statement regarding the spatial distribution.

The overall risk is for the entire region of the German EEZ in the North Sea is computed using a grid based model and shown in charts. There were insufficient data on biota for the Baltic region (particularly the occurrence of birds) to carry out calculations. Thus, only the relative accident probability, as determined by the Gl in section IV-5, is given for the Baltic EEZ (Figures IV-66 to IV-68).

Basis of the model is a geographic grid with sides of 3x3 sm (=3x6') per cell (Figure IV-71).

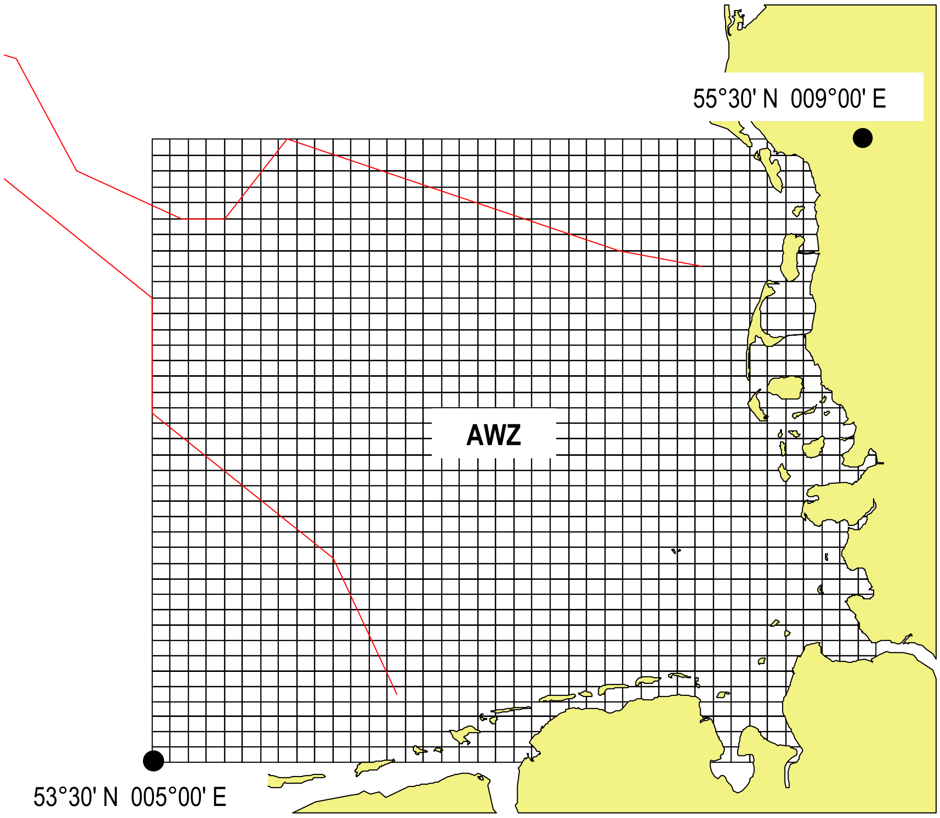


Figure IV-71: Model grid to determine the relative accident risk

The geographic grid includes the largest part of the EEZ (Exclusive Economic Zone of Germany) marked in red, with the exception of the so-called “Entenschnabel” (Figure IV-71). The southern limit is at 53°30'N, the western at 005°00'E, the northern at 55°30'N and the eastern at 009°00'E.

The borders of the grid are dictated by the database on shipping traffic and the resulting relative accident probability as well as the data on the occurrence of sea birds. The area of the ”Entenschnabel” up to the Dogger Bank couldn’t be accounted for.

IV-7.1 Basic of the model and the accident scenarios

Attributes of the accident probability and sensitivity of the biota to a potential contamination are provided or calculated for each cell of the grid (see below). The sensitivity of the benthic communities and sea birds to pollution (oil/hazardous substances) are considered in the calculation of the sensitivity of the biota. The pelagic system is not taken into account since there are not enough data in the literature on the spatial distribution in order to determine the geographic distribution of sensitivity indices.

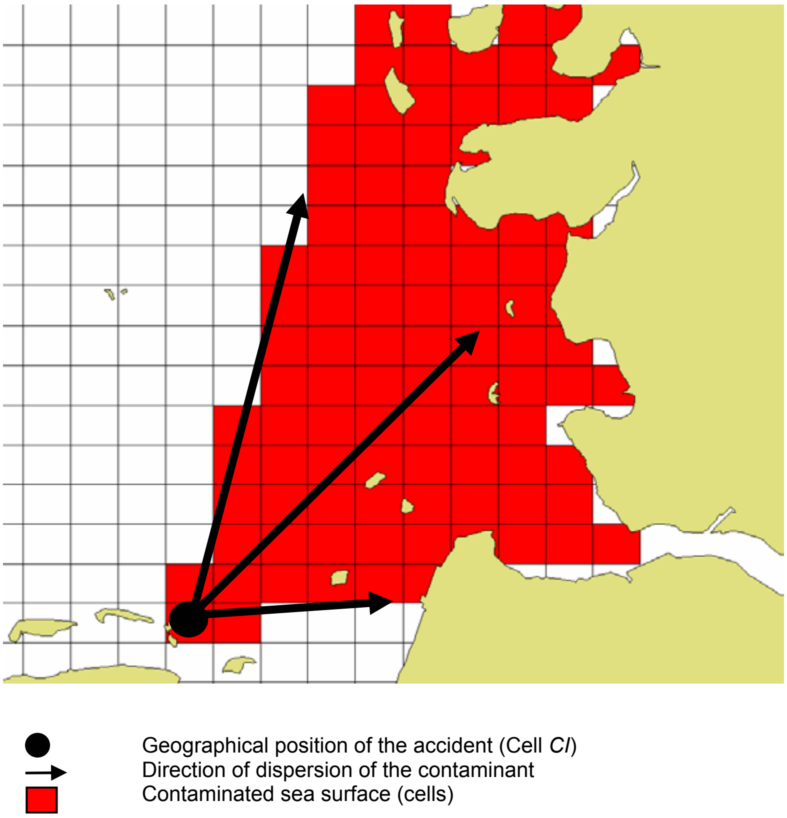


Figure IV-72: Basics of the model

Every cell in the grid is a potential location for an offshore WEP. Should an accident occur between a ship and a WEP, in one of the cells, and should the damage be so high that hazardous substances are discharged, the substance will disperse according to its chemical/physical behaviour as well as to the meteorological and hydrographical conditions. It will contaminate a specific sea surface area as well as the shores along the coast (Figure IV-72). The damage to the WEP is not considered, nor are the possible associated ecological consequences, since these are regarded as being insignificant compared to the other scenario. The relative risk is determined for each cell *CI* of the grid, under consideration of the assumptions made for the dispersion of harmful substances (see section IV-7.2.4) and is presented in geographic charts.

Explanation:
Assuming that a relatively high accident risk was calculated for a cell C1 and the neighbouring cells in the direction of dispersion are relatively sensitive, the relative total risk of C1 will be high. The same accident probability was determined for a second cell C2, however, the cells in the direction of dispersion are relative insensitive to pollution, then the relative total risk for cell C2 will be smaller than for C1.On the other hand a cell C3 will have a relatively low total risk if there is a very low

accident probability, despite the neighbouring cells having a relatively high sensitivity to the dispersion of the substance released.

IV-7.2 Basis for the calculation of the model

IV-7.2.1 Calculation of the relative overall risk

If we determine the cell in which an accident takes place to be *CI*, the relative total risk RR_{ci} of a collision (ship - WEP) for the environment going out of the cell *CI* is the relative sensitivity RS_{bio}, *of* the contaminated area (affected cells shown in figure IV-72) and the relative accident probability RP_{acci}, which was computed for the cell *CI* (see section IV-5):

$$RR_{ci} = \left[\left(RS_{bio} + SK_{bio}\right) \cdot RP_{acci}\right] / 4 \qquad \text{(IV-23)}$$

where	RR_{ci}	: relative risk, which goes out from the cell *ci* t	[RU]
	RS_{bio}	: relative total sensitivity of the contaminated cell	[RU]
	RP_{acci}	: relative accident probability in the cell *ci* (section IV-5)	[RU]
	SK_{bio}	: constant for general sensitivity towards pollution = 1	

All the risks, probabilities and sensitivity indices are normalised to relative values [RU] where:

RU	**< 1.5 = 1 very low**	(blue)
	1.5 - 2.5 = 2 low	(green)
	2.5 - 3.5 = 3 high	(yellow)
	> 3.5 = 4 very high	(red)

(IV-24)

See also the discussion by the GIO in section IV-5 for the relative accident probability RP_{acci}.

IV-7.2.2 Calculation of the relative sensitivity of biota in the affected sea area

The relative ecological sensitivity of the affected area is calculated as the mean of the individual sensitivity indices for the contaminated cells. The maximum sensititivty value of the biological partial component is also included. Only benthic communities and sea birds were regarded as biological partial components due to the data situation as discussed above. The relative sensitivity is therefore determined as follows:

$$RS_{bio} = \left(\sum_{i=1}^{ncc} \max \left| RSbottom_{ci}, RSbird_{ci} \right| \right) / \, ncc \qquad \text{(IV-25)}$$

Where	RS_{bio}	: relative total sensitivity of the contaminated cells	[RU]
	$RSbottom_{ci}$	: relative sensitivity of benthic communities in the contaminated cells *ci*	[RU]
	$RSbird_{ci}$	: relative sensitivity of sea birds in the contaminated cell *ci*	[RU]
	ncc	: Number of contaminated cells	

This means that only the higher sensitivity value is considered in each cell. The other possibility would be the elimination of $RSbottom_{ci}$ and $RSbird_{ci}$. This would, however, result in an unacceptable reduction of the sensitivity index in such cells where $RSbottom_{ci} \neq RSbird_{ci}$.

The calculation of the sensitivity of benthic communities $RSbottom_{ci}$ is based on the following assumptions: According to Bernem & Lübbe (1997) the sediment coast with their eulittoral and shore areas are particularly affected by oil pollution. This is on accord with information in the literature (see discussion in section IV-6.2.1). A sensitivity study has been carried out for the North Sea (van Bernem et al. 1994), which provides different high-resolution sensitivity indices for the individual coastal sections. Using the data from this study together with the literature (section IV-6.2.1) it is concluded that the entire near coastal area and eulittoral zone, the islands off the coast and the shoreline of the mainland can be classified as relatively very sensitive and that the sensitivity decreases with increasing water depth since the degree of contamination decreases with increasing depth (sinking of the contaminant and accumulation on the sea bottom). Simplified it is possible to calculate the sensitivity *Rsbottom* for every cell *CI* using the water depth of each cell.

Thus the calculation of the relative frequency of benthic communities follows a function of the water depth:

$$RSbottom_{ci} = f(WD_{ci}) \qquad \text{(IV-26)}$$

where	$RSbottom_{ci}$	: relative sensitivity of benthic communities of the bottom in cell *ci* *ci*	[RU]
	WD_{ci}	: Water depth in cell *ci*	[m]

Whereby the following function was chosen:

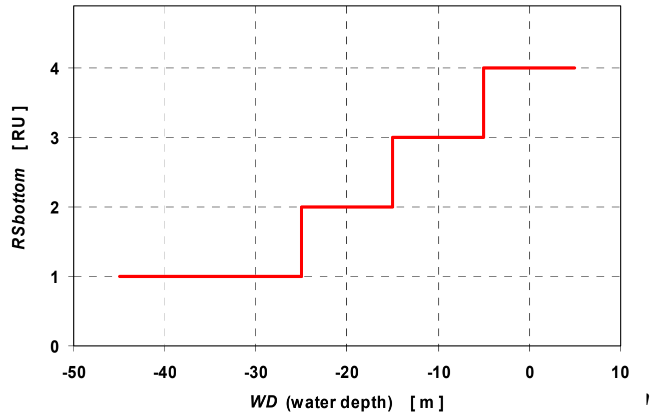


Figure IV-73: Relatio

The highest relative sensitivity therefore is attributed to the water depth between -5 to +5 m, i.e. the near coastal area with its sub and eulittoral zones as well as beaches and shores (FigureIV-74).

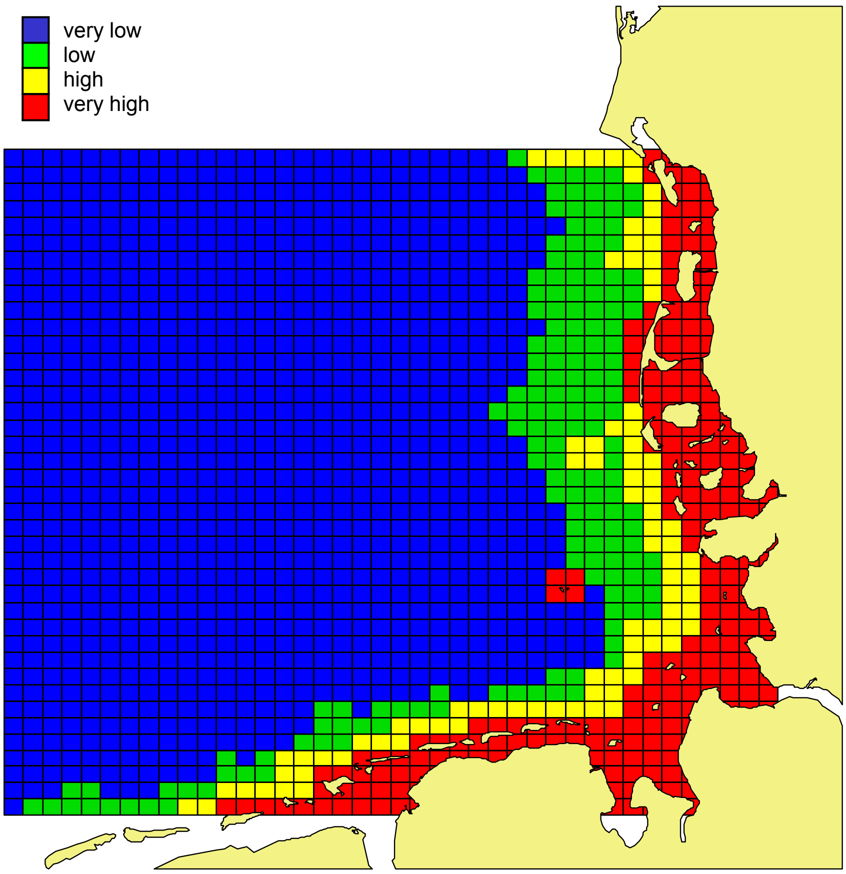


Figure IV-74: Grid of relative sensitivity of benthic communities (*RSbottom)*

The occurrence of seabirds in the summer months (number of individuals per species and cell in the geographical grid) was used as a data basis to calculate the sensitivity indices $Sbird_{ci}$. The data were obtained from the sub project II (Chapter II). Missing data in some cells were interpolated from mean values of the data from neighbouring cells. It is not possible, however, to use the number of individuals per species and area as the sole criterion of sensitivity, since the individual species are affected differently by pollution. Carter et al. 1993 therefore developed a so called "Offshore Vulnerability Index", which is based on the proportion of time which the birds spend on the water, the population size, the recoverability after a reduction in the population as well as the dependency on habitat. , Logarithmic values on bird density were used to account for the dominance of some species.

The sensitivity index *Sbird* in the cell *CI* is therefore calculated as follows:

$$Sbird_{ci} = \sum_{bs=1}^{nbs} \ln(D_{bsci} + 1) \cdot ovi_{bs} \qquad \text{(IV-27)}$$

where	$Sbird_{ci}$	: Sensitivity of sea birds in cell *ci*	
	D_{bsci}	: Density of species *bs* in cell *ci*	[density/sm^2]
	ovi_{bs}	: Offshore Vulnerability Index (Carter et al. 1993)	
	nbs	: Number of species in cell *ci*	

The calculation of the values for $\boldsymbol{ovi_{bs}}$ was done after Carter et al. (1993):

$$ovi_{bs} = \left[2ptw_{bs} + 2sbp_{bs} + rpr_{bs} + rme_{bs}\right] \qquad \text{(IV-28)}$$

where	ovi_{bs}	: Offshore Vulnerability Index (Carter et al. 1993)
	ptw_{bs}	: Proportion of time the bird species bs spends on the water
	sbp_{bs}	: Size of the population
	rpr_{bs}	: Potential recoverability after reduction in abundance
	rme_{bs}	: Habitat dependency

To avoid that some cells are overrated by coincidentally high or low indices, the mean of the cell as well as that of the neighbouring cells was calculated

$$Sbird_{ci} = \left(\sum_{xi=-nc}^{nc} \sum_{yi=-nc}^{nc} Sbird_{xiyi} \right) / (2nc+1)^2 \qquad \text{(IV-29)}$$

where $Sbird_{ci}$: Sensitivity of the birds in cell *ci*
xi : Neighbouring cell in x-direction
yi : Neighbouring cell in y-direction
nc : Number of cells in a geographic direction

The calculated absolute value $Sbird_{ci}$ were then normalised to relative sensitivity values using the unit [RU], on a logarithmic scale $RSbird_{ci}$ (see above)

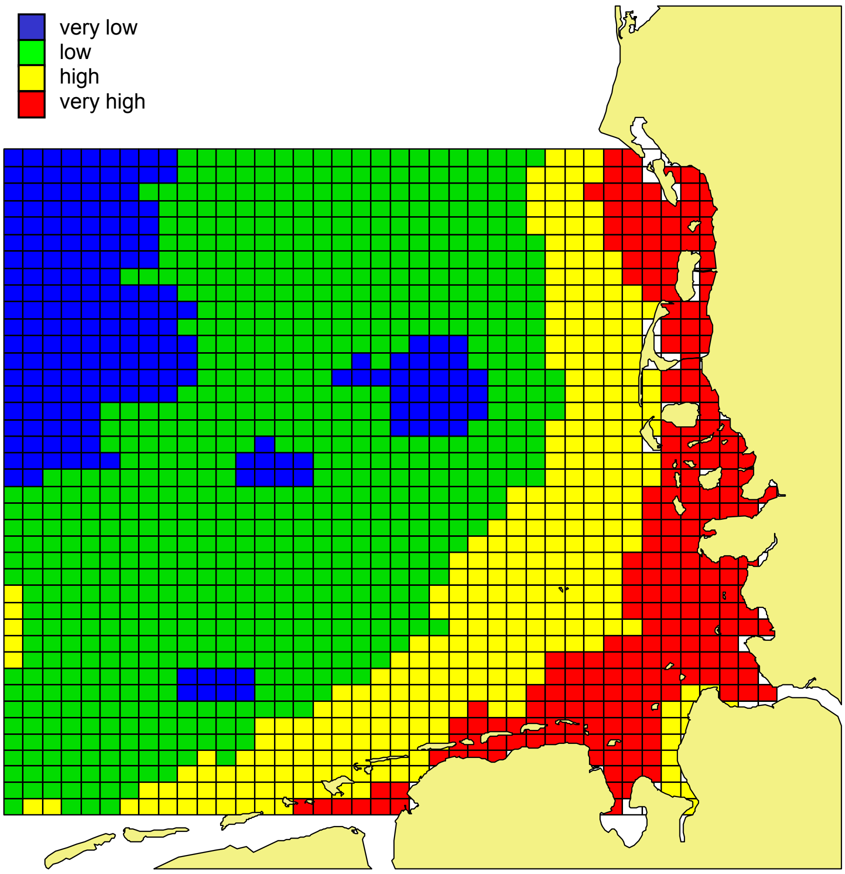


Figure IV-75: Grid of relative sensitivity of sea birds (*RSbird*)

The geographic distribution of the relative sensitivity of sea birds *Rsbird* (FigureIV-75) shows high values for the near coastal zone up to the 20m depth isoline. Only with an increasing distance from the coast are the values relative low (see chapter II on the occurrence of sea birds).

IV-7.2.3 Calculation of the relative accident probability

The calculation rule to obtain the relative accident probability has been described in detail in section IV-5The results for the German Bight are again presented below for the sake of completeness (Figure IV-76).

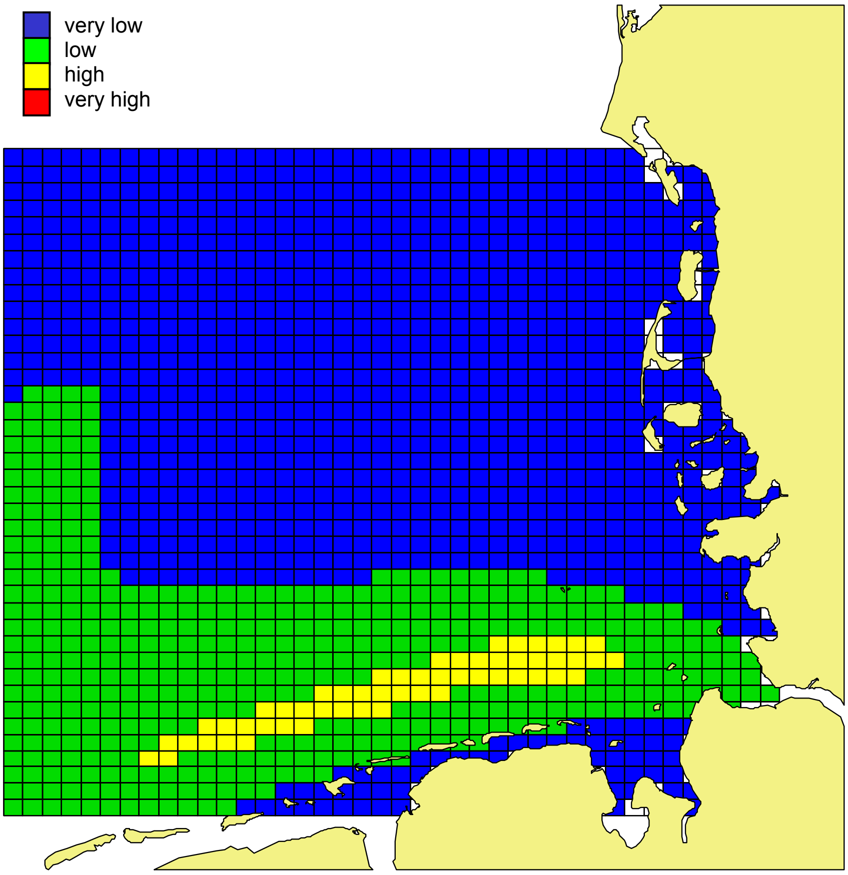


Figure IV-76: Grid of the relative accident probability (*RPac*)

There is a relatively high accident probability in the TSS of the German Bight. For the Baltic Sea, the GL determined relatively higher probabilities for the area of the Kadetrenden relative (FigureIV-66). Since the North and Baltic Seas were computed together, there are no areas in the German Bight of the category 4 (very high) The geographic distribution of accident probability, computed by the GL, for every cell *CI*, was used as input parameter for the model.

IV-7.2.4 Model of the dispersion of harmful substances and calculation of the contaminated area

Another critical factor in the calculation of the relative risk for every geographic cell *CI* is the calculation of the dispersion of discharged hazardous substance. There are several numerical models for the different areas, available in the literature (e.g. Al-Rabeh et al. 1993, Dahlmann & Müller-Navarra 1997, Dick & Soetje 1988, Dick & Soetje 1990, Dippner 1983, Galt 1997, García-Martínez & Flores-Tovar 1999, Gillibrand et al. 1995, Gin et al. 2001, Goodman et al. 1996, James 2002, Lehr et al. 2002, Matjaz et al. 2000, Müller-Navarra et al. 1999, Müller-Navarra & Mittelstaedt 1987, Roux 1979, Sobey & Barker 1997, Westeng et al. 1977).

Dick & Soetje (1988, 1990) and Soetje & Brockmann (1983) describe the drift and dispersion of oil in the German Bight. The model comprises a current model (with several sub models) and dispersion model, which take into, account the behaviour and environmental parameters. This operational model which is used by the BSH (Bundesamt für Hydrographie und Seeverkehr) is used in decision-making in the combating of accidents and for risk assessments (Huber & Dick 1991). It uses a Lagrangian dispersion model and a Euler dispersion model (Anonymus[9],[10]). Both are based on current prediction in the operational circulation model (Anonymus[11]). Jäger & Dick (1994) describe the use of a computer model to calculate the dispersion of different harmful substances in the North Sea. The model is based on stored tidal current fields of the German Bight and defined wind data and takes into account size, shape and submersion depth of harmful substances. The Federal Water and Shipping Agency (WSV) uses a *Computer supported maritime accident management system* (REMUS), which supports the assessment of damage as well as the choice of appropriate preventative and combating measures after oil accidents (Anonymus[12]).

However, an operational model is neither necessary nor advantageous for the questions asked in this investigation since very concrete dispersion scenarios are modelled and the conclusions are based solely on that special case. A simplified and general method for the calculation of the geographic distribution is much more appropriate. As approach we used the basic assumptions on the transport also used by Dick & Soetje (1988) The transport of an oil slick in the German Bight is governed significantly by the wind field, whereby the drift is determined by a percentage component of the wind velocity (Wind factor) in the direction of the wind. The distance traversed D_d is determined as follows:

$$D_d = W_s \cdot W_f \cdot D_t \quad \text{(IV-30)}$$

where	D_d	: Drift distance	[sm]
	W_s	: Wind velocity	[kn]
	W_f	: Wind factor	
	D_t	: Drift factor	[h]

The most frequent values for the wind factor W_f were around 0,03. However, values in the literature range from 0,008 to 0,058 (Pahlke 1985 in Dick & Soetje 1988). The drift direction is also determined by the wind direction. The lateral drift or horizontal dispersion is another important parameter, other than the main direction of drift and velocity. According to Dick & Soetje (1988) it is determined mainly by the turbulence of the current field. Another factors which affects the dispersion is the spreading, which is driven by the gravitation as well as the aging and vertical dispersion of the oil (Dick & Soetje 1988). Studying the results of models (e.g. published by Dick & Soetje 1988) a highly simplified model on the dispersion characteristics of oil can be adapted, which is sufficient for the purposes of this study.

[9] http://www.bsh.de/Meereskunde/Modelle/m13_disp.htm

[10] http://www.bsh.de/Meereskunde/Modelle/m13_mosys.htm

[11] http://www.bsh.de/Meersekunde/Modelle/m13_circ.htm

[12] http://www.wsv.de/Schifffahrt/Bekaempfung_von_Meeresverschmutzungen/Remus/Remus.htm

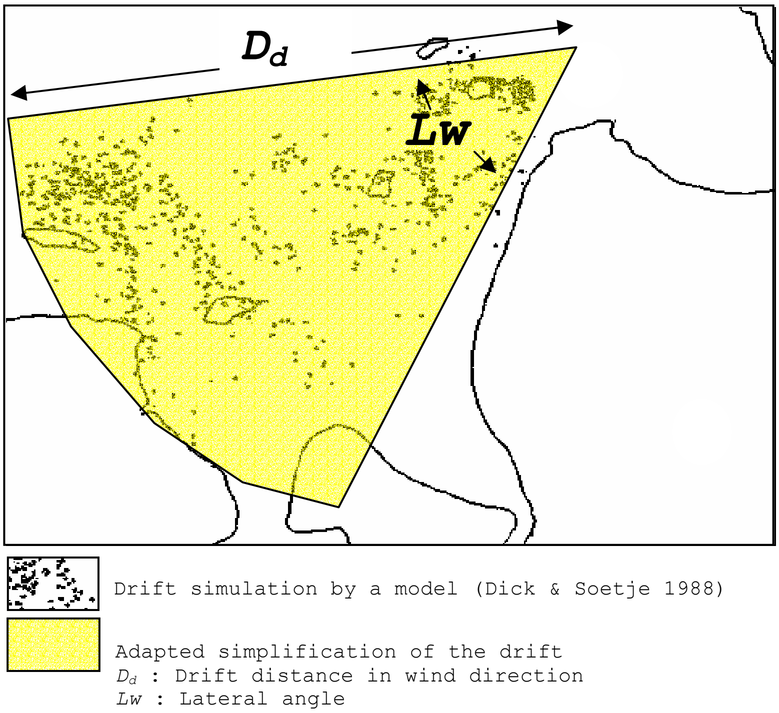


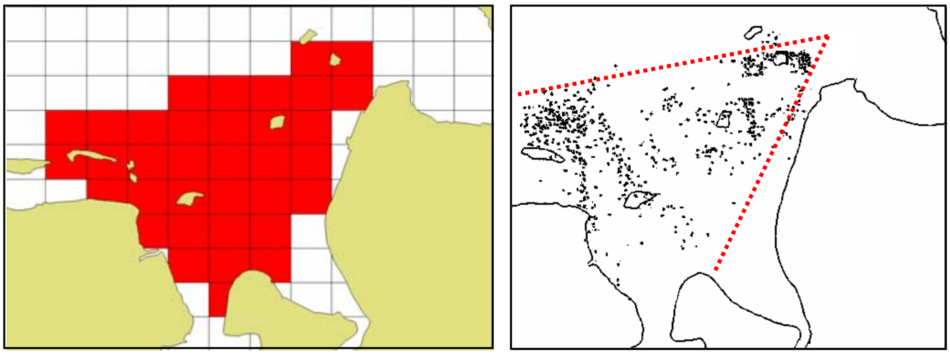
Figure IV-77: Idealised assumption of an oil slick dispersion

From this example it is not difficult to see that the sea surface, which is covered by an oil slick during the drift, resembles a circle segment, the centre of which is the point of the accident. Its radius is determined by the drift distance D_d and its alignment by the wind direction. The spread angle (Lateral angle) Lw represents the horizontal or lateral dispersion. The area, which is contaminated during the transport of the harmful substance, is described adequately by the following parameters:

- Wind velocity W_s
- Wind direction W_r
- Wind factor W_f
- Drift period D_t
- Lateral angle L_w

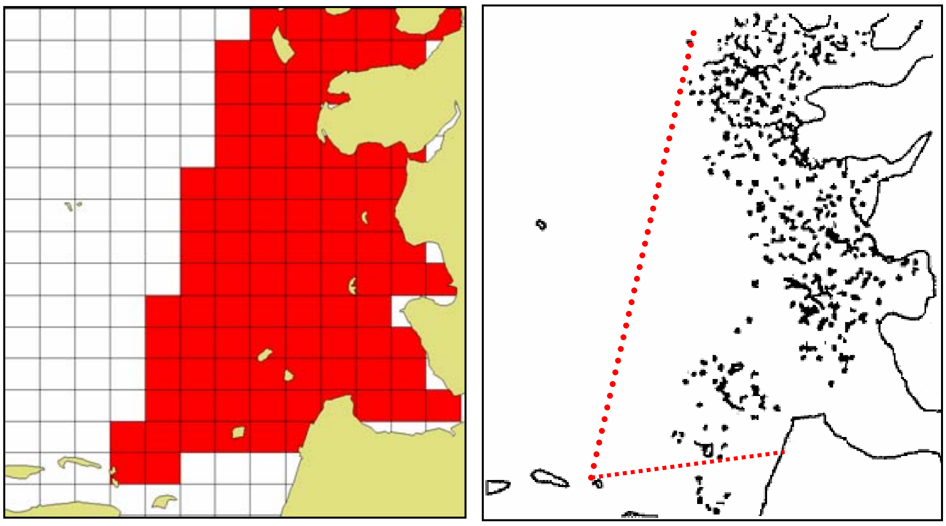
The geographical position as well as the number *ncc* of contaminated cells in the grid by an iterative model in which all cells in the circle segment are determined, based on the affected cell *CI* .The above parameters are set.

In the following, the simplified dispersion model is compared to a simulation published by Dick & Soetje (1988) and van Bernem & Lübbe (1997)



Model		simplified	Dick & Soetje 1988
Wind direction	W_r	045°	045°
Wind velocity	W_s	7 m/s	7 m/s
Wind factor	W_f	0,03	0,03
Drift period	D_t	72 h	72 h
Lateral angle	L_w	50°	------
Quantity of oil		------	10 000 t

Figure IV-78: Comparison of simplified dispersion model with that of Dick & Soetje 1988



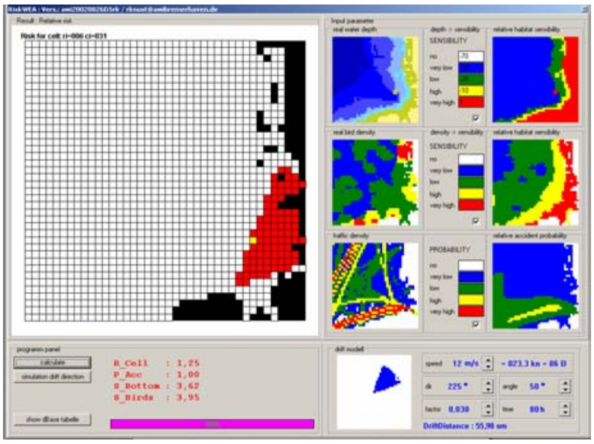
Model		simplified	van Bernem & Lübbe 1997
Wind direction	W_r	045°	045°
Wind velocity	W_s	15 m/s	15 m/s
Wind factor	W_f	0,03	0,03
Drift period	D_t	80 h	80 h
Lateral angle	L_w	50°	------
Quantity of oil		------	40 000 t

Figure IV-79: Comparison of simplified dispersion model with that of van Bernem & Lübbe 1997

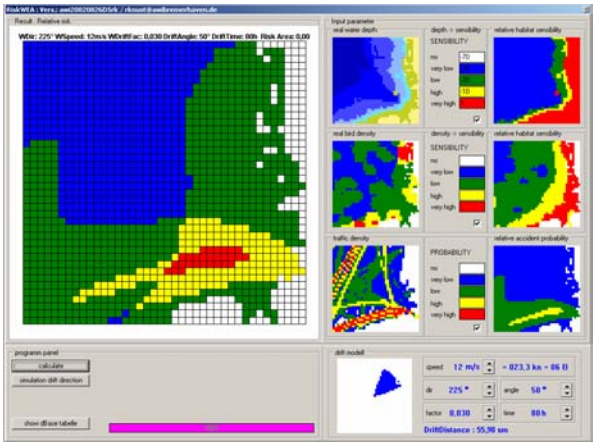
The input scenarios used by Dick & Soetje (1988) and van Bernem & Lübbe (1997) are based on a heavy accident during which 10.000 t and. 40.000 t oil are discharged to the water, respectively. The wind conditions set by Dick & Soetje (1988) at 7 m/s from 45° were considered good, whereas van Bernem & Lübbe (1997) used 11m/s from 225° which is considered rough with a corresponding swell. Despite these differences in the metrological input parameters, there is a good correspondence between these scenarios and our simplified model, concerning the other model simulations. Thus, the dispersion scenarios for the drift times D_t (12h - 24h - 48h - 72h Dick & Soetje 1988) and (5h - 38h - 80h van Bernem & Lübbe 1997) show a good correspondence with the distance traversed and the covered surface area when a lateral angle $L_w = 50°$ is chosen. The results of two simulations of 72 h and 80 h are shown in figures IV-78 and 79.

IV-7.2.5 Model implementation and model runs

The computer model was realised in Pascal (Delphi Vers.5) on a PC and Windows 2000 The data were in the dBaseIV format to enable a direct application in the Graphic information System (ArcView GIS 3.2).



Programme desktop showing the dispersion of hazardous substances



Programme desktop showing the geographic distribution of the relative overall risk

Right: the geographic distribution of input parameters for the relative sensitivity of the sea bottom, sea birds and the geographic distribution of the accident probabilities.

Figure IV-80: Programme desktop

IV-7.2.6 Model computation and results

Several scenarios were modelled to determine the geographical distribution of the overall risk *RR*. The basic assumption was that 10.000 t to 40.000 t oil were discharged, a conservative assumption which represents a "worst case scenario". Two simulations were carried out (Model run A and Model B). The parameters and results are presented in the following.

Model run A:

The computation was done using different wind data and keeping the other metrological data and parameters constant (Run A, Table IV-14).

Table IV-14: Model run A - Changing wind conditions

Run A						
Nr	W_R	W_S	W_f	L_w	D_t	Results in figure
1	000°	11 m/s	0,003	50°	80 h	IV-81
2	045°	11 m/s	0,003	50°	80 h	IV-82
3	090°	11 m/s	0,003	50°	80 h	IV-83
4	135°	11 m/s	0,003	50°	80 h	IV-84
5	180°	11 m/s	0,003	50°	80 h	IV-85
6	225°	11 m/s	0,003	50°	80 h	IV-86
7	270°	11 m/s	0,003	50°	80 h	IV-87
8	315°	11 m/s	0,003	50°	80 h	IV-88

Results of run A:

Preliminary comment: To interpret the data it must be remembered that relative low risk categories are shown for the areas of the Jade and Weser rivers. This does not reflect the true conditions and is explained by the fact that the traffic and the correspondingly calculated relative accident probabilities are not rendered correctly because Bremerhaven and Wilhelmshaven were regarded as virtual ports within the Jade-Weser-Approach (compare section IV-3). These results should therefore be negated. This constraint is, however, acceptable since the area covered in this project is limited to the EEZ.

A shown in figures IV-81 to IV-88 the region with the relative to very high risk potential is limited to the Traffic Separation Schemes. This is attributed to the relatively high probability categories in accident frequencies (Figure IV-76). Depending on the wind direction other areas in front of the East Frisian coast and the mouth of the Elbe River are also classified as risk category 3 and 4. This is particularly the case when winds are from the Northwest to Northeast (315°/000°/045°, figures IV-88, IV-81 and IV-82) since the hazardous substance would drift towards the coast and reach relatively sensitive areas. The least relative overall risk was calculated for winds from the East and Southeast (090°/135°, figures IV-IV-83 and IV-84).during these conditions harmful substances are drifted out of the German Bight into less sensitive areas.

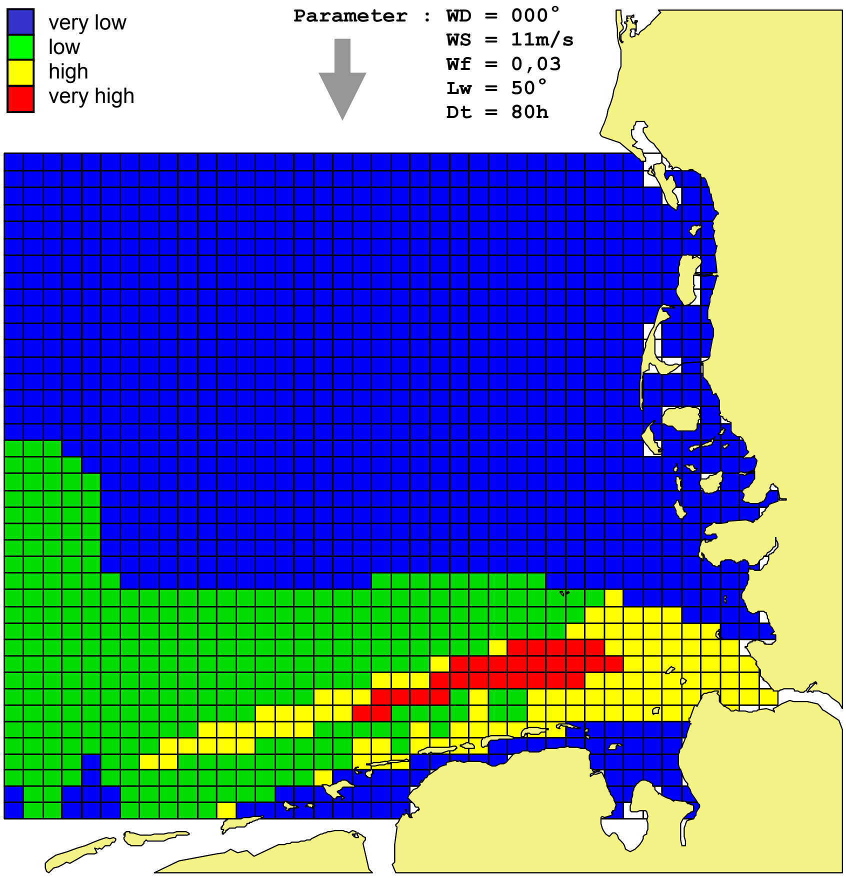


Figure IV-81:

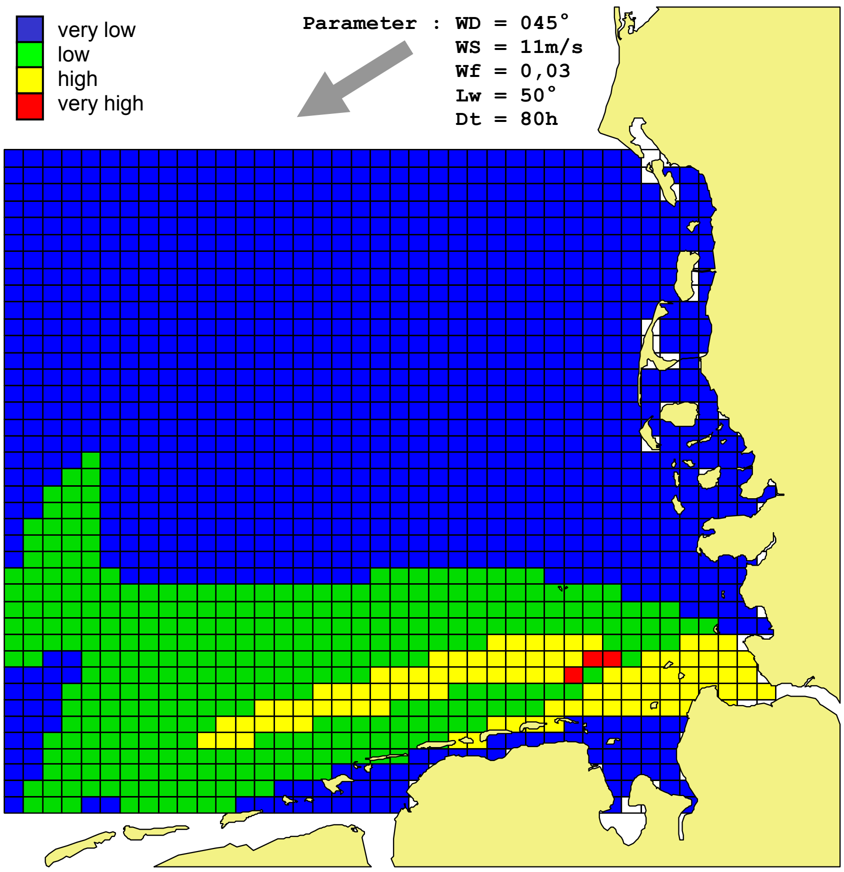


Figure IV-82:

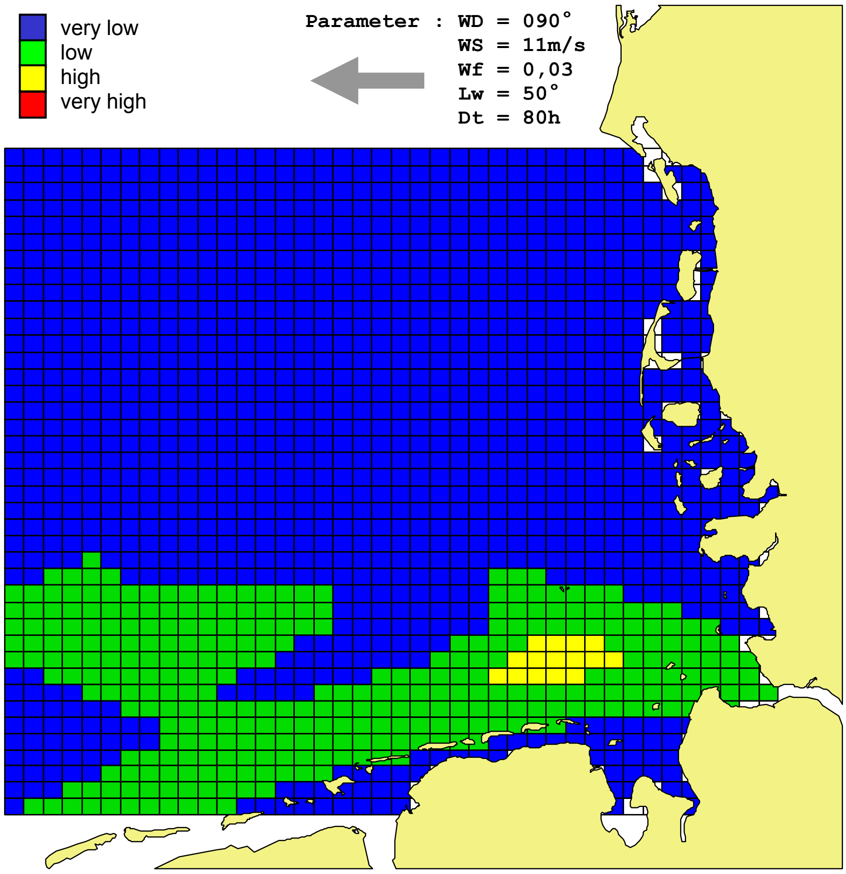


Figure IV-83:

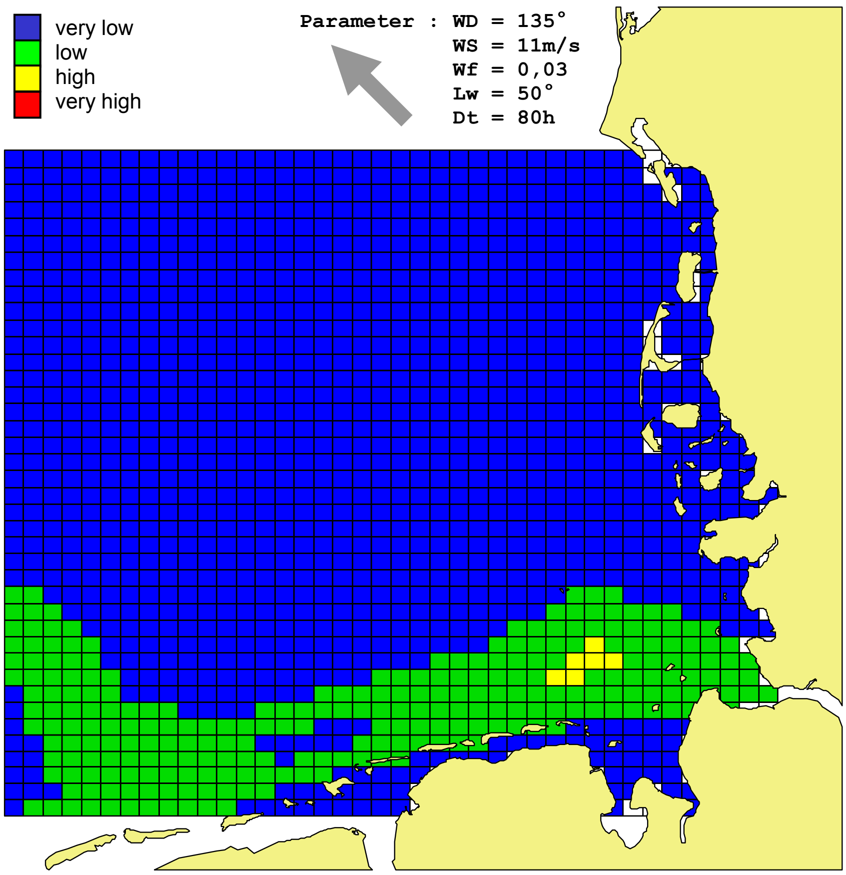


Figure IV-84:

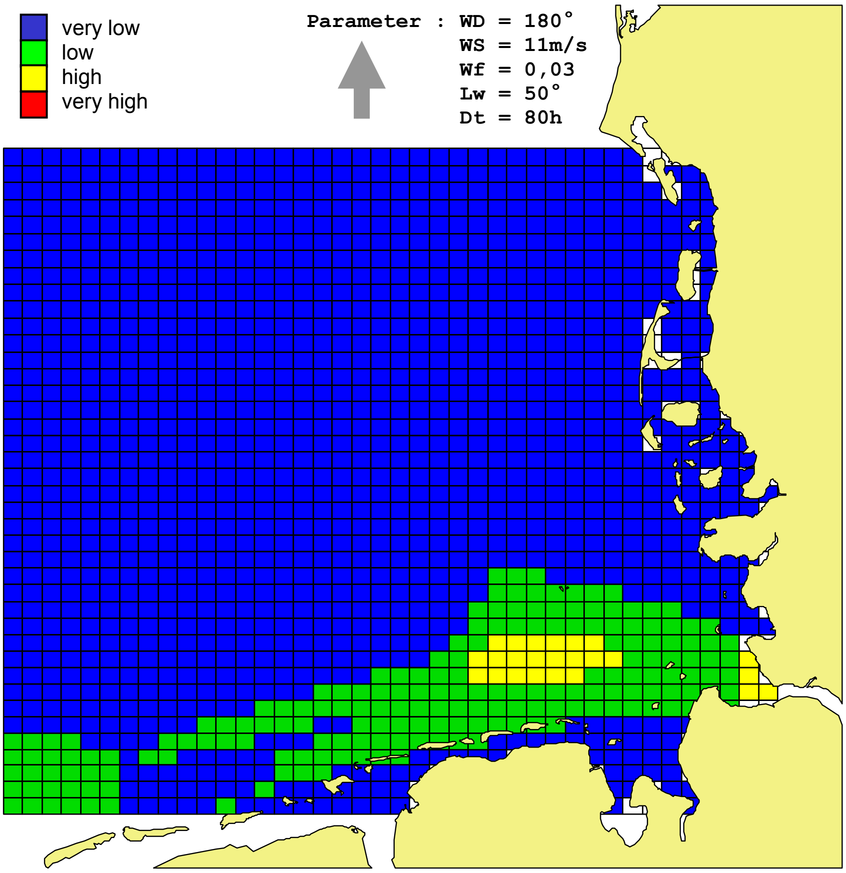


Figure IV-85:

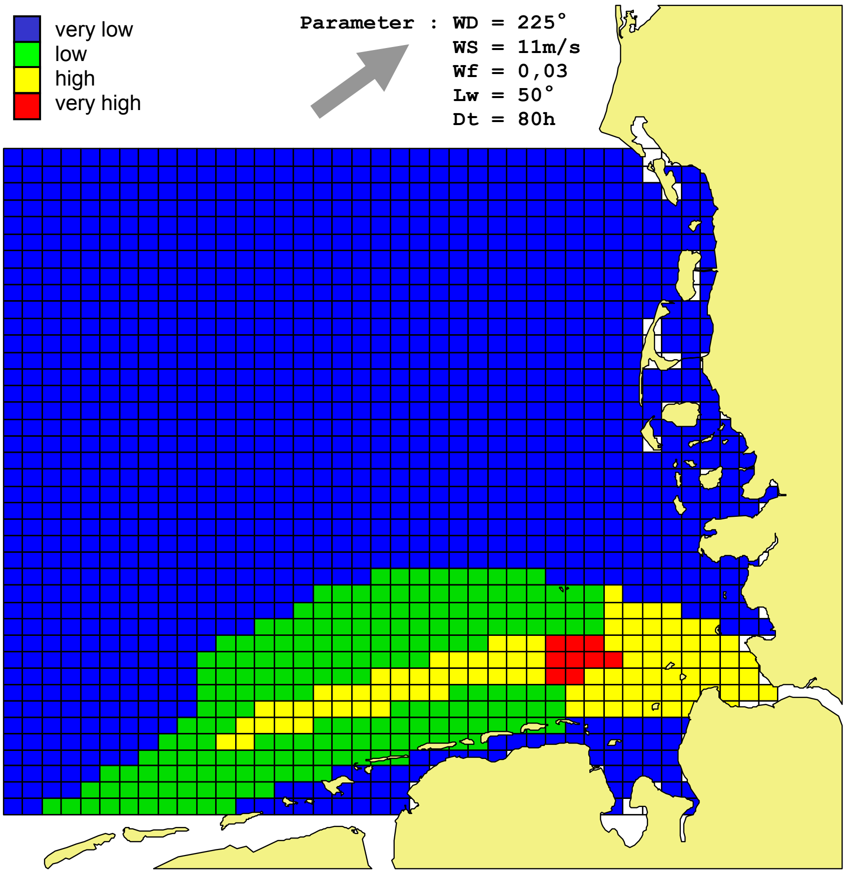


Figure IV-86:

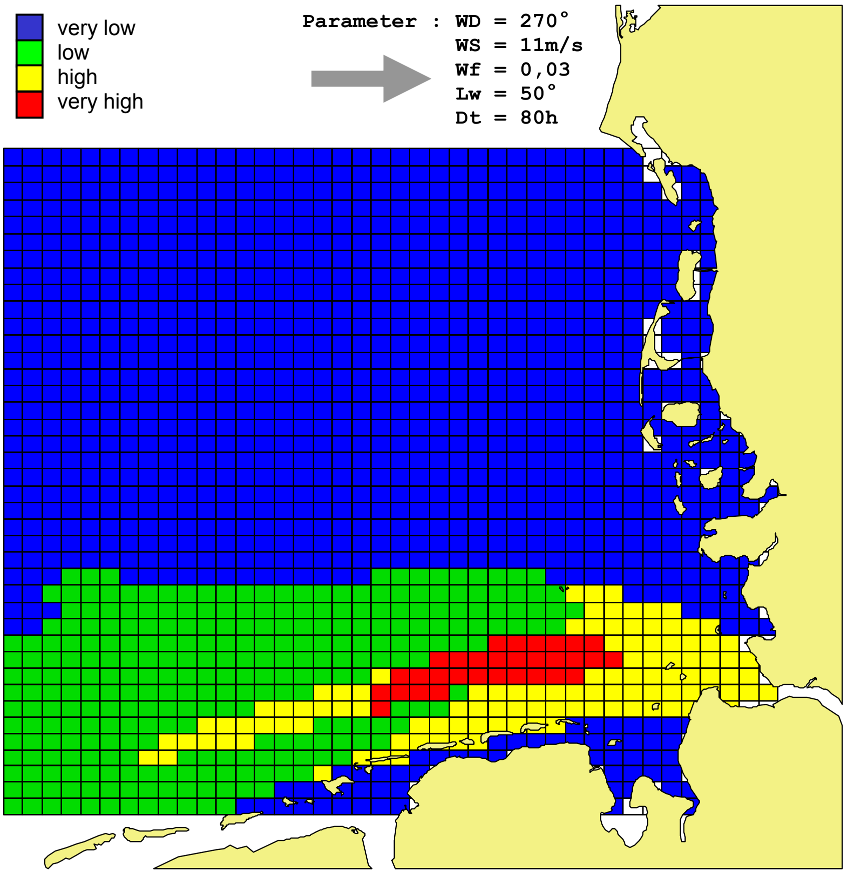


Figure IV-87:

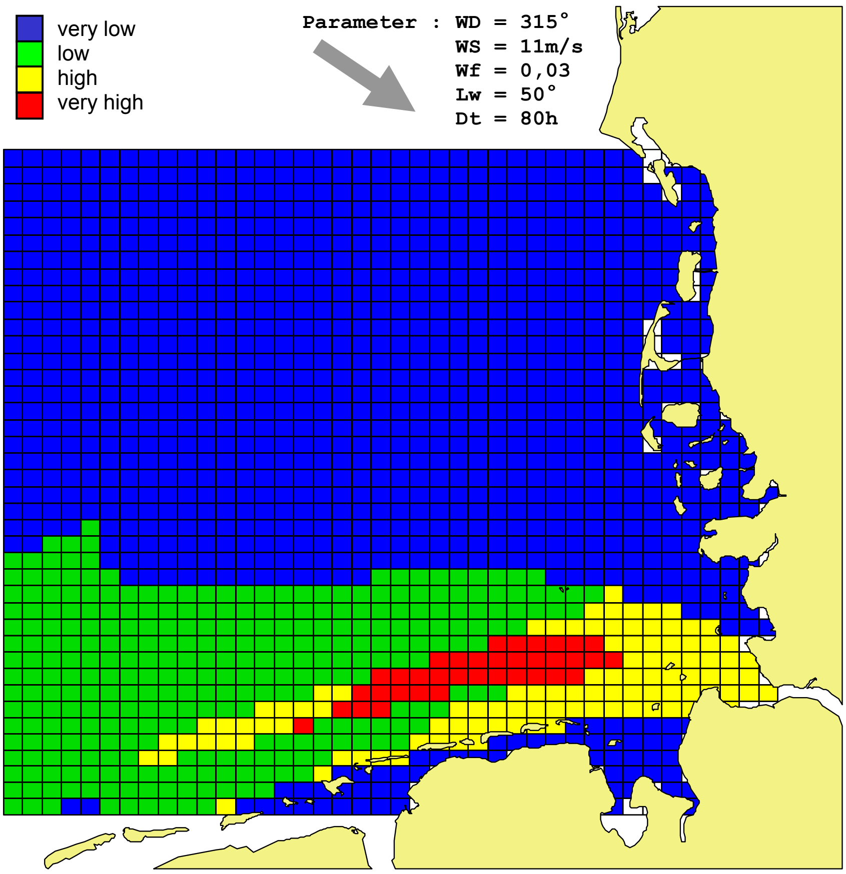


Figure IV-88:

Model run B:

Winds from the Southwest (225°) predominate in the German Bight. (Long-term data from the DWD). During storms, the winds often come out of the Northwest (315°) The geographic distribution of the overall risk *RR* was determined using different wind forces for both wind directions (Weak wind 5m/s = Beaufort 3 and stronger storm 21m/s = Beaufort 9). The basic assumptions for the accident risk are the same as fro model run A.

Table IV-15: Model run B - wind direction from Southwest and Northwest

Run B						
Nr	W_R	W_S	W_f	L_w	D_t	Results in Figure
1	225°	05 m/s	0,003	50°	80 h	IV-89
2	225°	21 m/s	0,003	50°	80 h	IV-90
3	315°	05 m/s	0,003	50°	80 h	IV-91
4	315°	21 m/s	0,003	50°	80 h	IV-92

Results run B:

Preliminary remarks: The same restrictions regarding the Jade river and Weser mouth apply as for model run A.

The results are shown in figures IV-89 to IV-92. The highest relative accident categories 3 and 4 occur in the TSS and the Elbe river mouth, when winds out of the Southwest (225°) prevail the zone of category 4 is in the area of the "Weser-Jade-Approach", northwest of the Weser and Jade river mouths. A comparison between weak winds and storm shows that the core risk area does not change. Only the dispersion attains a wider range (Figure IV-89 and IV-90). This also applies to the wind direction out of the Northwest (315°) (Figure IV-91 and IV-92). In this wind direction the core zone in Category 4 is significantly larger than for the wind direction out of the southwest, because the drift of hazardous substances takes place in the direction of the East Frisian coast and the area of the Elbe-Weser.

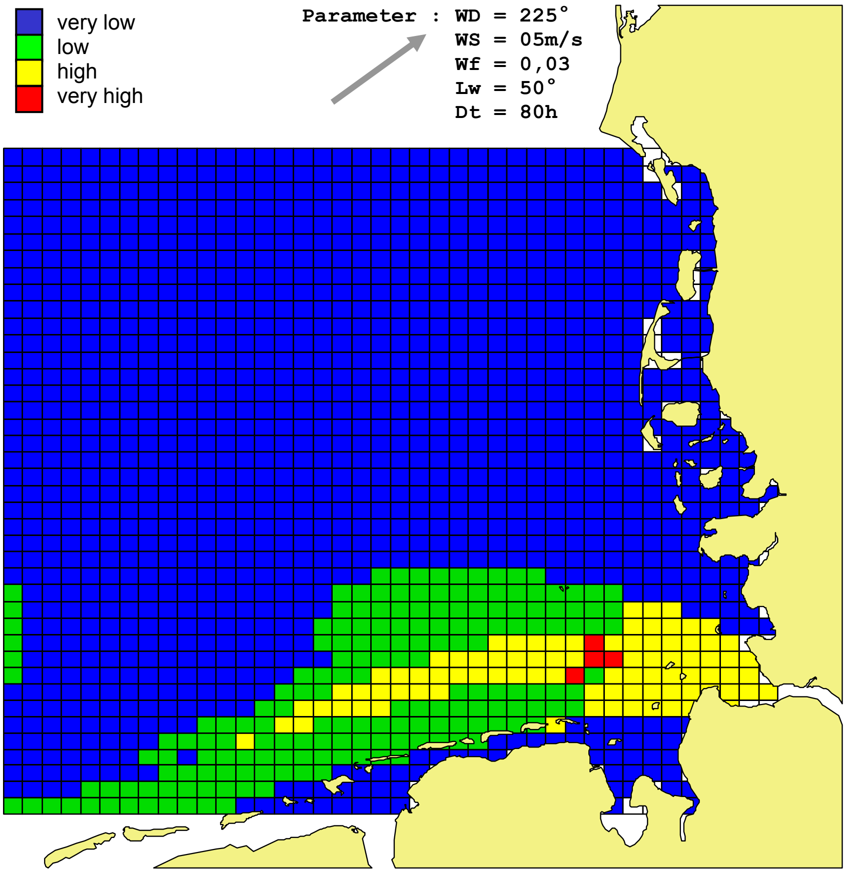


Figure IV-89:

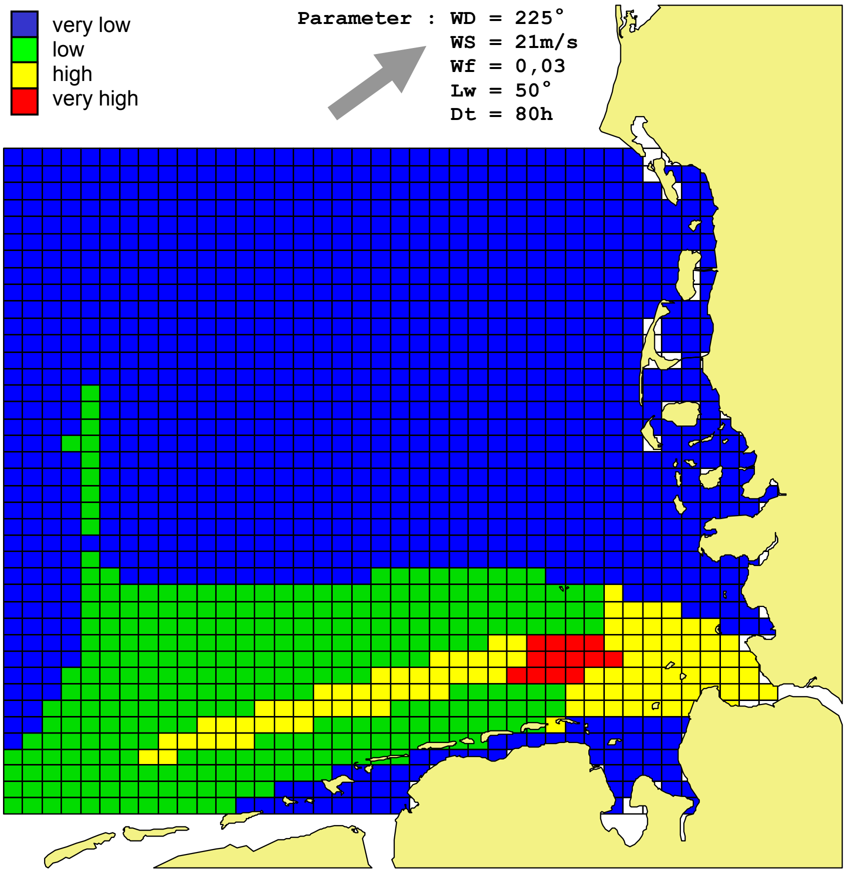


Figure IV-90:

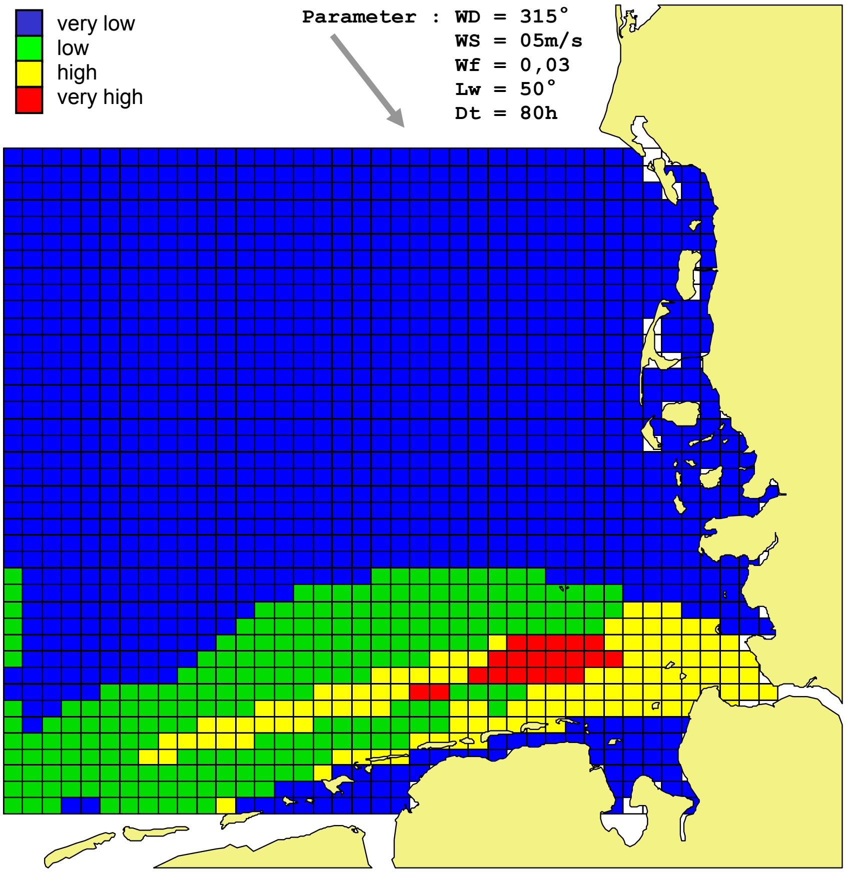


Figure IV-91:

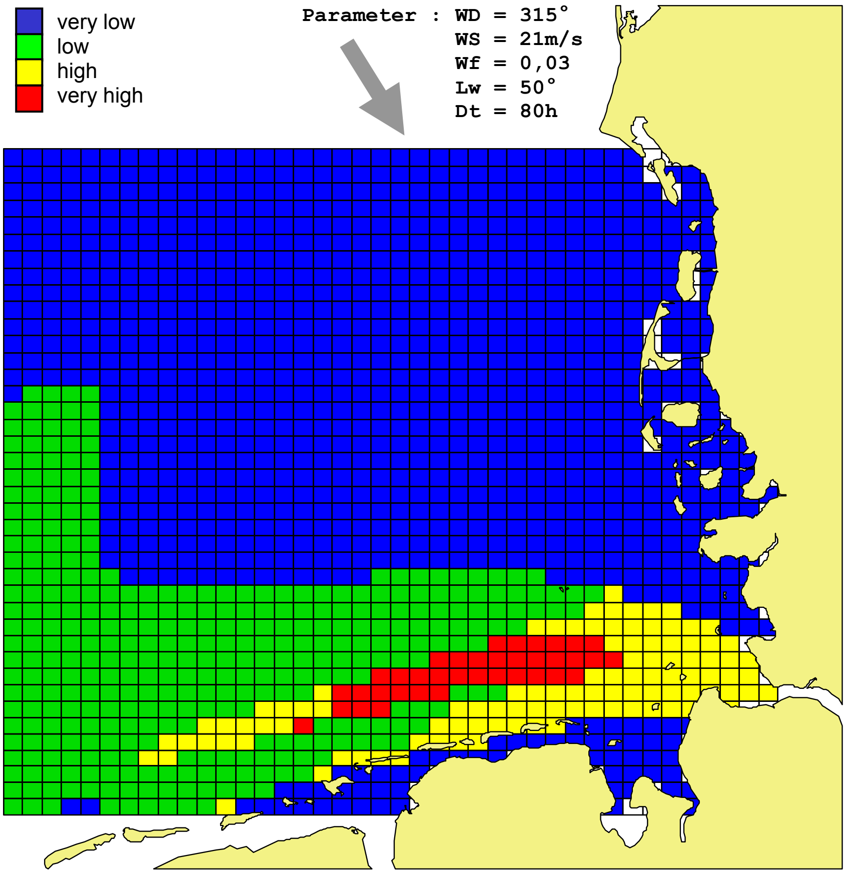


Figure IV-92:

IV-8 Measures to reduce and avoid collision risks

IV-8.1 Risk reducing measures at the Wind Park and the plants

The following risk reducing measures have the aim to reduce the probability of a collision accident. Possible risk reducing measures are:

- To denote a wind-energy park as prohibited zone in nautical charts and manuals.
- To enter the wind-energy park flight obstacle in aeronautical charts
- to permanently monitor the shipping traffic in the sea area around a wind-energy park in order to increase the awareness of potential collision candidates.
- to compile a safety manual on procedural instructions and emergency plans and to have this officially endorsed.
- to implement a safety management system,
- to illuminate the WEP according to the IALA guidelines to assign a safety zone around each WEP.

Possible measures to reduce the risk of severe damage are:

- To equip the WEP and the electric power substation with cooling agent for the transformers, of high environmental compatibility.
- To equip the WEP and the substation with an oil “pan” to contain any leakage.
- To equip the WEP with an emergency trip switch and braking system to stop the rotor in the event of a threatening collision and during salvaging.
- to install a docking system for SAR, tugs and SUBS at the power substation.
- to select a collision friendly method of constructing WEPs so as to keep the damage (above and below the water level) at a minimum in the event of a collision with a vessel.

IV-8.2 Risk reducing measures on a vessel

The following risk reducing measures are recommended for vessels operating in the sea area. They have the aim of reducing the occurrence of collisions:

- Equip vessels with AIS systems,
- Equip vessels with redundant navigation systems,
- Equip ships with redundant propulsion and control systems.
- Equip ships with emergency towing gear,
- ships, which do not have emergency towing gear, require a towing wire on the bow or stern of the vessel.
- The anchor must be made clear in the vicinity of the wind-energy park or only secured by a chain stopper during bad weather.
- Adhere to the existing safety regulations through intensive port state controls and monitor the classification societies
- Equip ships with manoeuvre aids such as bow and stern thrusters.

Appropriate measures to reduce consequential damage to vessels and environment are:

- Double hulls for tankers
- Maintain empty tanks
- Installation of high performance pumps.
- Division of loading area into several cells of defined charges (e.g. max. 10.000 cbm per tank for oil tankers),

A certified and implemented safety management system based on the ISM-Code on both the vessels and the office of the shipping company are another the risk reducing measure which will help to reduce the frequency as well ass the consequences of collision scenarios. An implemented safety management system is an important prerequisite to avoid collisions and to react appropriately and responsibly in the event of a disaster.

Some of the above mentioned measures are integrated in the SOLAS convention (e.g. Double-hull tankers, Emergency towing gear for tankers, AIS). Other measures (e.g. redundant drive and control systems, emergency towing gear for all vessels) are still being discussed in working groups of the IMO.

Requirements which already have to be implemented, such as double-hull tankers, emergency towing equipment, AIS systems redundant radar systems (from 10.000 GT upward), ISM as well as port state control will reduce the collision and oil accident considerably

IV-8.3 risk reducing measures for the sea area

The following measures to reduce risk in the sea area are already an integrated part of the safety concept of the German coast[13]. Their aim is to reduce the frequency of collisions:

- The introduction of Traffic Separation Schemes and prohibited areas.
- Traffic surveillance and support by traffic centres:
- Surveillance of the area,
- Surveillance of the ship traffic and flow of traffic
- Support of the traffic in guaranteeing safety and ease of navigation.
- Accident management,
- Ship signalling system with compulsory registration of all arriving and disabled ships
- Appropriation of salvage tugs / SUBS,
- Introduction of an average command
- Carrying out of ship averages and emergency exercises (2 to 3 -times per year), to test and continuously improve the ability of the ship accident management.
- Introduction of traffic safety system with a central reporting and command post where all information on shipping traffic is compiled and from where, in the event of an average, the necessary safety and protective measures are co-ordinated.

The safety concept of the German coast includes the following procedures to reduce the severity of damage:

- Supply of oil combating vessels/ SUBS,
- Supply of appropriate material and trained personnel to clean the oil contaminated Wadden Sea and beaches.
- supply of salvage vessels and SAR-helicopters.

Some of the risk reducing measures have been implemented (e.g. Stationing of salvage tugs, ZMK and ELG in Cuxhaven, emergency training exercises).

[13] Wasser- und Schifffahrtsverwaltung der Bundesrepublik Deutschland (http://www.wsv.de): „Sicherheitskonzept Deutsche Küste“

Apart from the currently implemented risk reducing measures for the German coast, further measures are conceivable. These are listed and discussed below.

- Establishment of a Particularly Sensitive Sea Area (PSSA)[14] with defined surveillance, engagement and protected zones
- Possibility of sovereign acting outside of the territory of traffic safeguarding.
- Operating of shipping routes with a safety margin to wind-energy parks, according to traffic infrastructure
- Stationing of additional emergency salvage capacities,
- Introduction of radar and radio surveillance for all shipping routes along a wind-energy park.
- Introduction of a code of conduct in the case of an average near a wind-energy park.
- Publication of the code of conduct on navigation charts and nautical manuals.
- Implementation of a comprehensive traffic census for the entire sea area (e.g. registration of all ship movements including fishing vessels and others not in the VTGs, registration of individual vessel size, registration of engine failures as well as other undesirable events) in order to obtain improved data for future risk analyses.

IV-9 Further research requirements

During the course of this project, the authors uncovered a number of points requiring further investigation. This concerns both the statistic acquisition of ship traffic data as well as the processing and computation.

Collection of traffic data

As mentioned, there are a number of uncertainties regarding the statistical analyses of the ship traffic in the North and Baltic Seas. A comparison of the available data revealed considerable differences between the sources. To achieve comparable risk analyses it is necessary to use standardized methods and comparable data. Therefore a verification of the data as well as the availability of such data would be desirable to carry out reliable risk analyses. .

Improved methods of computation

The investigate methods were used mainly to calculate collision frequencies. The computation of the degree of damage to ships, as well as the discharge and dispersion of hazardous substances can currently only be done by using numerical models. These are not appropriate for probabilistic analyses because of the complex modelling and computational effort involved. The development of more simple methods should be looked into. Projects to develop such simplified methods (e.g. parameter studies) should be initiated.

Generally speaking, the technology is not sufficiently developed to carry out risk analyses in a probabilistic sense in an acceptable time period. As already mentioned the main reasons for this are to be found in the estimate of consequences due to collision events which are usually only covered conservatively by "worst case" scenarios. Considerable progress was made in the ship/ship collision research in recent years (Pedersen et al. 1999). A similar development concerning ships and WEPs would be sensible, desirable and of general interest.

[14] WWF-Deutschland: „Schutz des Wattenmeeres vor Schiffsunfällen durch Einrichtung eines PSSA-Wattenmeer“; Oktober 2000

IV-10 Summary

The report deals with the results of sub-project 4 "Collision risk of ships with wind-energy plants and the danger of pollution in coastal regions " project "Investigations on the avoidance and reduction of environmental load by offshore wind-energy plants off the North and Baltic Sea coast".

Description of the ship traffic in the EEZ of the North and Baltic Seas

Comprehensive data sets on ship traffic in the Exclusive Economic Zone of the North and Baltic Seas were analysed and compared. It was shown that the statistics differed considerable in certain aspects. It is only possible to speculate as to why these differences occur. One reason is to be found in the origin of the data. Some sources, for instance use radar images from the surveillance of traffic areas to count ship movements. Others use port departure and arrival data. Several data sources need to be compared when using traffic data for the determination of collision probabilities so as to establish the degree of deviation and the effect of the deviation on the calculations.

The only information available on the transit traffic, i.e. the vessels that pass through the EEZ without calling on a German port, was that for the Traffic Separation Schemes in the North Sea. The areas in the North Sea north of the TSS as well as the areas in the Baltic EEZ have not been monitored with the result that no statistics on ship traffic are available. The GLO commissioned the company ANATEC UK Limited to compensate for this deficiency by closing the gaps in the data. Thus a source is now available for the all the regions of the EEZ in the North and Baltic Seas.

Risk potential can be identified to the extent that one can assume that a higher traffic concentration entails a higher collision risk potential. Statements on the environmental risk can only be made in connection with the effects of hazardous substances discharged after a collision. The results of this study should therefore be linked to results of the other sub-projects.

Analysis and description of methods to compute collision risk between ships and WEPs

The main focus of the analyses on collision risks between ships and WEPs are the scenarios "Collision of manoeuvrable ships with WEPs" and " Collision of disabled ships with WEPs ". Different methods to compute these scenarios were investigated. Three computation methods to determine the collision of manoeuvrable ships were identified and their advantages and disadvantages discussed.
Only one method was identified for the determination of the scenario " Collision of disabled ships with WEPs ". In addition, a new method based on a Monte-Carlo Simulation was developed and tested by the GLO. According to the authors there are thus sufficient accurate methods to determine collision frequencies.

The effects of collisions on the vessels structure were also investigated. No simplified computation method was identified, despite intensive research. Thus, a "worst case" scenario was calculated using non-linear finite-element computation. This analysis showed that in an unfavourable case (construction of ship and WEP or environmental conditions) a vessel could be damaged leading to the discharge of hazardous substances.

A numerical method of computation was also applied to determine the discharge of oil from ship tanks. The discharge was simulated for an idealised tank using the CFD-Programm COMET. The result showed that the discharge rate was also accurately computable using a simplified method, as long as viscosity effects in at the wall of the vessel were neglected. (

The dispersion of the discharged oil can be estimated by using algorithms provided by the BSH. Examples were computed and shown in the report.

The aerial distribution of the overall risk for the region of the German EEZ in the North and Baltic Seas was determined with a grid based model and plotted cartographically. Attributes on the accident probability and the sensitivity of the biota to possible contamination were determined for each cell, based on the traffic density data and the accident probabilities derived there from. The biota included benthic communities and sea birds. Another important factor was the determination of dispersion of discharged oil in relation to different wind conditions.

The model runs showed that there were high to very high-risk potentials in the region of the Traffic Separation Schemes and that these correlated strongly with the high accident frequency probability categories. Winds from the Northwest to Northeast have a high to very high risk potential because they would cause oil to drift into areas of the East Frisian coast and the mouth of the Elbe River, which are classified as being relatively sensitive.

Southwesterly winds, which according to long-term averages, prevail in the German Bight, result in the highest relative risk category to be in the regions of the Traffic Separation Schemes (TTS) and the mouth of the Elbe River.

C Overall concept

C-1 Requirements and procedure

The goal of this report was to assess the potential impacts of planned offshore wind energy plants on the marine environment in the German Exclusive Economic Zone (EEZ) considering the following boundary conditions:

- **The plants intended for the production of electrical energy by wind force, in the offshore areas of the North and Baltic Seas, have not yet been constructed. The only information available on the extent and technical configuration was in the form of plans, whereby many technical details were not available or not provided by the interested companies (potential operators) due to competitive reasons.**

- **Wind energy plants in marine zones, such as those operating or planned in Denmark and Sweden, are only conditionally comparable to those planned in the German EEZ. This is because the Danish and Swedish plants are built close to shore in shallow depths. Furthermore they differ both technically and in the dimension of the parks since they are significantly smaller than those planned in the German EEZ.**

Due to these circumstances, the project group was only able to present an estimate of the potential risks for the marine environment. Many technical and logistical details concerning design and construction of the plants are not yet available. For this reason it was difficult to obtain a reliable assessment of the potential impacts. Many aspects were thus generalized and superficial. In some cases it was not possible to make any assessment at all. Despite the fact that the project community would have liked to have submitted concrete statements regarding one or other position on impacts for the environment or measures of avoidance or mitigation, we refrained from doing so. Speculative comments and considerations were disregarded and instead, where applicable, positions were discussed superficially and reference was made to the lack of information (research requirements).

As a base for the assessment of potential effects of offshore wind energy plants, we used available data from the literature and other available sources on the occurrence, temporal and geographic distribution as well as migratory behaviour of the different subjects of protection to assess their likely reaction to offshore constructions. Data on bird migration and resting bird occurrence were complemented by limited field studies. A further important instrument to estimate potential impacts on the environment by offshore wind energy plants as well as to determine measures of avoidance and mitigation, was the consultation of national and international experts. The original protocols of these discussions can be found in the annex (German version only).

The following subjects of protection were dealt with in this report:

- **Marine bottom communities**
- **Resting and migratory birds**
- **Marine mammals**

The following potential impact pathways were identified and considered *a priori*:

- **Changes in habitat structure on the sea floor due to the introduction of artificial substrata into essentially typical soft bottom communities as well as changes in the small and meso-scale hydrography and sediment characteristics.**
- **Impact on bird migration due to bird strike and barrier effects.**
- **Impact on resting birds due to loss of habitat, bird strike and changes in the food availability.**
- **Emission of sound into the marine environment.**
- **Impact of electromagnetic fields during the discharge of electricity.**
- **Accidents between ships and wind energy plants and the ecological consequences**

Whereby three impact phases were differentiated:

- **Construction phase**
- **Operation phase and maintenance**
- **Dismantling of the plants after operation**

The evaluation of the risks for the marine environment resulted in formulation and presentation of proposals for mitigation and avoidance of such risks. Further more gaps in the knowledge were identified and recommendations made for further research. Another aspect was the drafting of scientific methods to investigate environmental risks during the three impact phases, which were already published in 2002 (www.uba.de). These were further developed into a “standardized concept of investigation” through intensive discussion. This “Standardized concept of investigation” was published by the authorizing agency (Federal Maritime and Hydrographic Agency) (BSH 2003). Hüpopp et al. (2002b) developed a research concept for migratory and resting birds.

The most important results and conclusions obtained from the available data are summarized below and synthesized into an overall concept.

C-2 Major impact pathways, potential effects, technical and logistical measures of avoidance and mitigation, research requirements. .

Benthic communities

The expected impacts during the construction phase can be reduced to a minimum and carried out in a reduced time by technical measures such as ramming/vibration of foundations. However, the regeneration may take from 2 to 5 years if no reef building species are affected (e.g. Sabellaria). The ramming of foundation anchorages is the conventional technology in the offshore zone and does not require fundamental changes. To what extent the vibration techniques are applicable in the offshore area, with regard to sound protection, has yet to be tested technically (see below and sub project sound). The laying of cables is also a temporally restricted undertaking resulting in a comparable regeneration time, whereby it is expected that the cables will be jetted in without a sustainable change in sediment structure, for instance by rip-rap. It is expected that similar effects will arise during the dismantling of the plants.

The largest areal coverage is expected from the construction of gravity foundations. These, however, will not be used in depths greater than 20 to 30 meters. Depending on the technical development, it is highly probable that monopiles or jacket construction techniques will be applied. Central to the evaluation of possible impacts is the availability of artificial substrates in the primarily soft bottom communities and the changes in hydrodynamics and consequently in changes of sediment characteristics. Distinct changes in the form of hard substrate colonizers, scouring and differences in the fauna are expected to occur in the proximity of the individual piles (up to 100m). Such effects are known as "wreck effects". According to current understanding, single plants within a wind park are expected to be about 600 to 800 meters apart. These distances are expected to result in a mosaic pattern, which is brought about by effects in immediate proximity to the piles and by areas, which are not directly affected. These effects are restricted to the individual wind park and can thus be regarded as being local.

The question as to what extent the regional current regime will be changed by single wind parks or cumulative effects still has to remain unanswered. Model calculations for the North Sea, however, have shown that only very limited, minor effects are expected. Whether this is also attributable to the Baltic Sea has to be determined by further modelling and validated by field measurements on the first wind parks built. This requires appropriate research. Cumulative effects of the wind parks could have regional consequences for the benthic communities. The prohibition of bottom and beam trawling in the parks, for safety reasons would have a definite effect on the fauna in these areas, since the wind parks would represent retreats for species (fish and benthic invertebrates) subjected to extreme pressure through fishing. This assumption is, however, neither qualifiable nor quantifiable due to a lack of hard data. Currently the project BeoFino (BMU, Projektträger Jülich) covers the requirements of research on the North Sea invertebrate benthos. Further reliable information on these effects, particularly on the effects for the fish fauna, is only expected from research accompanying the first wind park construction.

Information on the potential effects of electromagnetic fields on the marine fauna, resulting from the discharge of electricity, is still very speculative. First steps with regard to the required research are being undertaken within the BeoFino project. Current technology enables the deployment of cables with very low emission characteristics (natural ambient levels).

Resting and migratory birds

The potential dangers concerning the impact assessment of offshore wind energy plants on avifauna are: The danger of collision with WEP (bird strike), short term loss of habitat during the construction and or maintenance work, long term loss of habitat due to fright caused by the plants, barrier effects for migrants and disruption of ecologically connected cohorts of local bird communities.

Technical recommendations for the mitigation of collision risk can only be given to a limited extent due to a lack of experience in the offshore area and in the illumination of turbines on land. Recommendations made for land turbines can, however, be applied for the offshore plants as well. It is recommended that the turbine rows are constructed in line with the major flight direction, that interference free “migratory corridors” of several kilometres width between the wind parks be established as well as to refrain from large scale illumination and introduce flashing instead of continuous illumination and to use reflectors and signal colours on the plants. These measures do not require a large technical effort. It should be considered to adjust the illumination to the behavioural reaction to different weather conditions. To what extent the measures regarding illumination, as described in Chapter B-II-13, can be realized from a nautical perspective (ship safety), needs to be verified. A compromise may be required in the framework of the maritime law. A further measure to reduce the dangers of bird strike is a radar supported early warning system similar to the “bird strike warning system” applied by the armed forces.

There are no technical or logistical measures available to avoid or reduce the disruption of linked ecological units (e.g. resting or feeding grounds), nor the displacement of sensitive species. Spatial planning measures such as those discussed in Chapters B-II and C-3 are required in this case.

The local impact described above, are likely to have a wider regional or even national impact resulting from cumulative effects of several wind parks. This is particularly the case if wind parks in close proximity to each other create a barrier against bird migration, resulting in the fact that internationally important bird resting zones are no longer accessible to the birds. Apart from the technical and logistical measure to reduce bird strike, mentioned above, it is essential that exclusive measures, at the planning level, be introduced to reduce and avoid bird strike. These are described below in Chapter C-3.

A significant research input is required to determine further preventative or reductive measures of the impact of wind energy plants in the offshore zone, particularly regarding the characterisation of migration (corridors, seasonal and climatic changes in migratory patterns e.g. flight behaviour under different weather conditions) These are currently covered by the BeoFino project (BMU, project coordinator Jülich). Studies on bird strike should be initiated immediately after the first pilot plants have been constructed, as discussed in Chapter B-II-12.2The project MINOS (BMU, project co-ordinator Jülich) covers the research on potential impact on resting birds in relation to geographical distribution and utilization of specific areas. In this case, the first pilot plants should also be used by extensive mapping and behavioural observations, to determine the extent of the fright effects. Modelling should then be applied to determine to what extent areal loss has an effect on the bird stocks. It is imperative that bat migration patterns over the sea and potential collision risks be studied.

Sound impacts

The statements concerning sound emanating from the construction and operation of off shore wind energy plants are based on existing measurements from Sweden and Denmark as well as on model calculations and measurements of ambient sound. Wind energy plants built on steel foundations have not yet been tested in the marine environment. That is why model calculations were carried out using data obtained on land-based plants. These results revealed that the estimated sound level produced by the plants falls below the ambient levels at a distance of between 700 and 1500 meters away from the plants. The sound spectrum only differs from the ambient spectrum within the range below 1kHz and thus lies in the range of typical wind energy plant engine noise (gearboxes, generators) The interpretation of audibility, under consideration of the currently known auditory thresholds, revealed that harbour seals and some fish did react to relevant auditory radii. No concrete observations were made for the Grey seal due to a lack of data. The calculations did not reveal any audibility of sound emission outside the immediate range of individual foundations.

Measures for the prevention or mitigation of sound emission during the operation of wind energy plants, particularly the mitigation in radiation of single tones, are extremely cost intensive and need to be considered in the initial construction plans. In this regard, the assessment of the relevance particularly of tonal emission for marine organisms is of particular importance. Urgent research is required, particularly concerning the actual radiation by wind energy plants as well as on the potential consequences for marine fauna. The available data on the hearing, habitat utilization and migratory behaviour as well as the spatial distribution (particularly of marine mammals) for both the North and Baltic Seas are insufficient to enable significant statements on the effects of sound emission during the operation of wind energy plants. Conditional statements can be made on local effects (see above). However, no statements can be made regarding regional or national impacts. Currently the research requirements regarding the habitat utilization, spatial distribution and hearing capacity are covered by the MINOS project (BMU, project co-ordinator Jülich). The first pilot plants should urgently be used to determine actual real sound emission.

Considerable sound emission will result from ramming during construction. This will be of major significance, particularly for marine mammals. Measures of prevention and mitigation of these sound emissions are of technical and logistical nature. Technically, the ramming of foundation anchors should be replaced by vibration and drilling. However, very little engineering experience has so far been gained in offshore technology, with the result that it is difficult to assess whether this technology can be applied nor whether additional expenses will be incurred during construction. Also not yet thoroughly tested, technically, in offshore technology, is the damping of sound emission with air bubble curtains or combined bubble and fabric curtains. Experience is also required here, particularly with regard to the efficiency and feasibility in both the North and Baltic Seas. A further preventative measure, is the active deterring of animals from the construction site, taking into consideration the important closed seasons such as reproductive seasons. These measure need to be constantly monitored, as discussed in Chapter B-III-7.

Collision risk

The North and Baltic Seas are regarded as having amongst the highest ship traffic in the world. However, the traffic data varies considerably, depending on the source and statistical methods applied. This results in a series of uncertainties regarding the ship traffic statistics. In order to facilitate a comparison of risk analyses for individual wind parks, standardized methods and comparable data are essential. The verified data should become available for the required risk analyses.

Off shore wind energy plants constitute a hindrance to shipping and as a consequence represent a potential accident risk. The major approach of collision risk analyses between ships and wind energy plants are the scenarios: " Collision of manoeuvrable ships with WEPs" and "collision of disabled vessels with WEPs". Different methods were tested and their advantages and disadvantages described. From the point of view of this project community there are sufficient accurate approaches available (see B-IV). However, no adequate methods are available to assess the potential effects on the ships themselves by enabling accurate analysis of the damage due to parameters such as construction of vessels and WEPs as well as environmental conditions. This research requirement is currently being covered by the project "Computational analysis of offshore wind energy plant foundations in collisions with ships" by the Technical University Hamburg-Hamburg (BMU, project co-ordinator Jülich).

The spatial treatment of accident probability for the traffic separation zone in the German Bight as well in the Kadetrenden and areas north east of the Baltic Sea has revealed a high accident probability for these areas. The geographical distribution of the overall accident risk in the North Sea could be determined using a grid based model and the inclusion of biological data on the occurrence and sensitivity of the marine environment. The model showed that there were high to very high risk potentials in the traffic separation zones. Sea areas with comparatively high to very high risk potential were also identified for wind energy plants in the North East to North West of the east Frisian coastline and the Elbe River mouth since under such conditions discharged harmful substances will drift towards the coast and therefore onto highly sensitive areas. It was not possible to make similar model calculations for the Baltic Sea.

Measures to avoid or minimize collision risk have to be implemented at different organisational levels (Measures on ships, measures on wind parks and measures in the sea area) as described in detail in chapter B-IV-8.

The project community is of the opinion that, under the condition that all technical measures of accident prevention were applied according to latest technology, (see Chapter B-IV), the marine environment is not endangered by the plant, but rather by the safety of ship traffic and that appropriate measures should be developed in this sector. These range from ship technological measures (e.g. redundant navigational, engine and steering mechanisms) to risk minimizing measures in the sea area (e.g. provision of salvage tugs) (see list in chapter. B-IV-8.2 / 8.3). These technical and logistical measures would simultaneously also improve the general traffic safety in German waters, a stipulation which for a long time has been recommended by experts, independently of the construction of wind energy plants

Tabular overview

Table C1 shows the major impact pathways as well as potential ecological consequences. The table also provides an overview of possible suggestions on minimisation and avoidance of impacts. These are both technical (Dimensioning of construction and function of entire plants and methods of construction) as well as logistic (e.g. operation and servicing). Comments on research needs are also given. The compilation is to be regarded as source of key words and thus only provide a broad overview. The designation of chapters in the keywords refers to detailed discussion in the report.

TableC-1: Overview of potential impact pathways, possible effects, technical and logistic measures of prevention and mitigation, research needs

Impact pathways	Potential impacts	Technical and logistical measures of prevention and reduction	Research needs	Reference
Construction of foundations on the sea floor>> Changes in habitat structure on the sea floor.	Depending on the foundation type and construction method, it is expected that sediment will be moved during construction with corresponding effects on the macro zoo benthos and demersal fish fauna (displacement, burial, mortality). The impact is temporary with a recovery phase of 2-5 years.	Driving of monopiles (anchor-pylons) by ramming and vibration	Covered by concomitant research during construction and operation	B-I-4.1 B-I-4.2.1 B-I-6.2
	Changes in the species composition of benthic communities: Settlement of "atypical" species due to supply of hard substrata (foundations, monopiles, anchor-pylons). Changes in the small-scale hydrography and sediment characteristics in proximity to the foundations. Changes in food availability for sea birds Loss of sea bird habitat due to interference	No large volume gravity foundations, instead, monopiles, tripods, Jacket - construction.	Research needs on processes in immediate proximity to the foundations are currently being covered by the BMU - project BeoFino. The meso-scale area (within and in vicinity of wind parks) for the period during construction and 3 year period of operation is covered by concurrent research. Prolonged monitoring is required to study long-term changes.	B-I-4.1 B-I-4.2.2 B-I.4.6 B-I-6

Table C-1: Continued

Impact pathways	Potential impacts	Technical and logistical measures of prevention and reduction	Research needs	Reference
Impact of the WEP on bird migration	Danger of collision with wind energy plants during flight movements. Barrier effects on migration routes	- Orientation of plants parallel to main migratory direction - Migratory interference free corridors of several kilometres between wind parks -Avoid construction of wind parks in areas of high migration density - Refrain from large scale illumination - Use of flash instead of constant illumination - Use of reflectors and signal colours on the plants	- Investigations on the aerial extent of bird migration - Investigations on the intensity of bird migration - Additional information on the altitude distribution relative to the weather - Investigations on the spatial / temporal distribution of bird migration - Studies in the actual off shore zone to validate the measurements on bird migration done on land - Studies on collision risk and on the effectivity of avoidance measures The research requirements are currently covered by the BeoFino (BMU) project.	B-II-3.2 B-II-7.3 B-II-13 B-II-14.2
Impact of the WEP on resting birds	Danger of collision with WEP during flights from feeding and resting grounds. Short-term loss of resting and feeding grounds during the construction phase Long-term loss of resting and feeding grounds due to the fright effect of WEPs.	- No construction in areas with high density of sensitive species - The above mentioned measures of minimization of collision risks	- Continued charting in the Baltic area - Investigations on the fright distances of sea birds at sea Research needs currently covered by the MINOS (BMU) project	B-II-3.2 B-II-11 B-II-13 B-II-14.2

Table C-1: continued

Impact pathways	Potential impacts	Technical and logistical measures of prevention and reduction	Research needs	Reference
Introduction of sound to the marine environment during construction and operation	Sound emission during construction could lead to habitat loss for invertebrates, fish and marine mammals by frightening the animals off. Lasting physiological damage from high sound levels is also possible Acoustic masking (e.g. communication signals), changes in reproductive success (e.g. increased stress), interference with important behaviour as well as lasting habitat loss due to long term displacement are possible during the construction phase.	The following needs to be considered during the construction of the plants: - Maintaining of closed seasons - Introduction of acoustic damping measures - Gradual increase in sound emission - Acoustic deterring measures - Acoustic surveillance - Visual surveillance	Marine mammals: - Determination of audiograms - Determination of TTS-values - Determination of action radius - Investigations on habitat utilization Fish: - Determination of auditory capacity - Investigations on sound related behavioural reactions in captivity and in the field Invertebrates: - Sound induced effects on the settlement of hard substrata - Reactions to the sound emission by WEPs General: - Actual sound emission by planned WEPs including various foundation types Research needs for marine mammals covered by the MINOS (BMU) project.	B-III-5.2 B-III-6 B-III-7 B-III-8
Impact of electro magnetic fields during discharge of electrical energy	Electro magnetic fields in proximity of cables could influence the orientation or migratory behaviour of invertebrates and demersal fish fauna It is also not possible to exclude possible injury to invertebrates in the immediate proximity of cables.	Deployment of best available technology (e.g. bipolar Flat-Type-cables), to minimize electro magnetic fields as far as possible.	There is an urgent research need to understand the effects of electro-magnetic fields which is currently being covered by the BMU-Project, BeoFino	B-I-4.4 B-I-6.4 B-I-8

Table C-1: continued

Impact pathways	Potential impacts	Technical and logistical measures of prevention and reduction	Research needs	Reference

Accidents between ships and wind energy plants and the ecological consequences	Discharge of harmful substances as a result of collision between ship and WEP and the effects on the marine environment.	Measures in Wind parks: - Denote Windpark as closed area - Permanent surveillance in the sea area of the Windpark - Collision “friendly” construction of WEP - Lightning according to IALA-guidelines Measures in the sea area: - Surveillance of the pilotage area - Accident management - Allocation of salvage tugs	Improvement of the statistical compilation of ship traffic and incorporation of the data in analytical methods. Further development in technology to carry out probabilistic analyses in an acceptable time frame. The research requirements with regard to impacts of ship collisions on the vessel structure are being fulfilled by the TU Hamburg Harburg: "Collision of ships and offshore wind energy plants"	B-IV-4.7.4.1 B-IV-4.7.3.2.5 B-IV-6.2.1 B-IV-8 B-IV-9

C-3 Measures to avoid and minimise the impact of land use planning actions on the marine environment.

Apart from making recommendation on technical and logistical measures of avoidance and minimisation, the project group also made suggestions on the geographical location of offshore wind energy plants. The recommendations are to be regarded uncoupled from the legal side, since the project group did not include a person of legal competence who was able to ascertain and present the scope for design in land use planning to the authorising agency (BSH) in its assessment of the laws of environmental protection (Bundesnaturschutzgesetz) and the marine facilities ordinance (Seeanlagenverordnung). However, there is consensus that the principle of "first come, first served" has lead to a situation, which must be regarded as sub optimal.

Figure C-1 shows the ecologically particularly valuable areas in the German North and Baltic Seas, as a published by the German Federal Agency of Nature Conservation (BFN) (Version 01/2001). The areas partially cover those, which were accounted for by the individual sub projects in this report (see Chapter B. These areas, such as for example "Borkum Riffgrund" and other recommended marine benthic areas in the North and Baltic Seas, particularly worthy of protection (see chapter B-I-5) as well as areas with a relatively high wind energy sensitivity index (see chapter B-II-11, Figure II-66ff) for birds, do not necessarily preclude a criterion for exclusion. However, it is essential that the construction of offshore wind energy plants in these areas be critically assessed and evaluated. There is too little information on the distribution and habitat utilisation of marine mammals (with the exception of the harbour porpoise protected zone off Sylt) to enable a statement on the aerial extent of the EEZ in the North and Baltic Sea. The research requirements with regard to this point are covered by the MINOS project (BMU).

The aspect of a potential collision (ship- wind energy plant) and the ecological risks are discussed extensively in the sub project IV. A relatively high collision potential was identified for the North Sea traffic separation zones compared to other possible sites. However, the traffic separation zones were obviously already excluded during the preliminary planning phase. The installation of a wind park in the immediate proximity of major traffic areas needs to be individually verified.

A further important aspect in the consideration of measures to minimise and avoid possible ecological consequences are potential cumulative effects which will not be observed during a survey of single wind park. Thus a single wind park may have little effect on migration; however, a series of wind parks (e.g. by different operators forming a closed chain from Baltrum to Wangerooge along the east Frisian coast) could represent a barrier, which appears to be unacceptable. Since it is known for many species that they fly close above the sea it is essential to retain appropriately wide migration corridors to reduce the danger of bird strike and a barrier effect (see chapter B-II-13). Similar considerations are valid for the area of the North Frisian coast and the Baltic Sea. The project group sees an urgent need for action with regard to the observance of cumulative effects (also in the course of the approval procedure).

An integrated concept on land management in the German EEZ (and its legal regulation) is also urgently needed with regard to other utilization (fisheries, mining, environmental protection) The allocation of potential areas of utilization for the installation of wind energy plants could be the first step, whereby the progressive development of wind energy, as is currently followed in Germany, is a helpful manner of avoiding and minimising of potential effects, if the first pilot plants will also be used to address open questions itemised in this report.

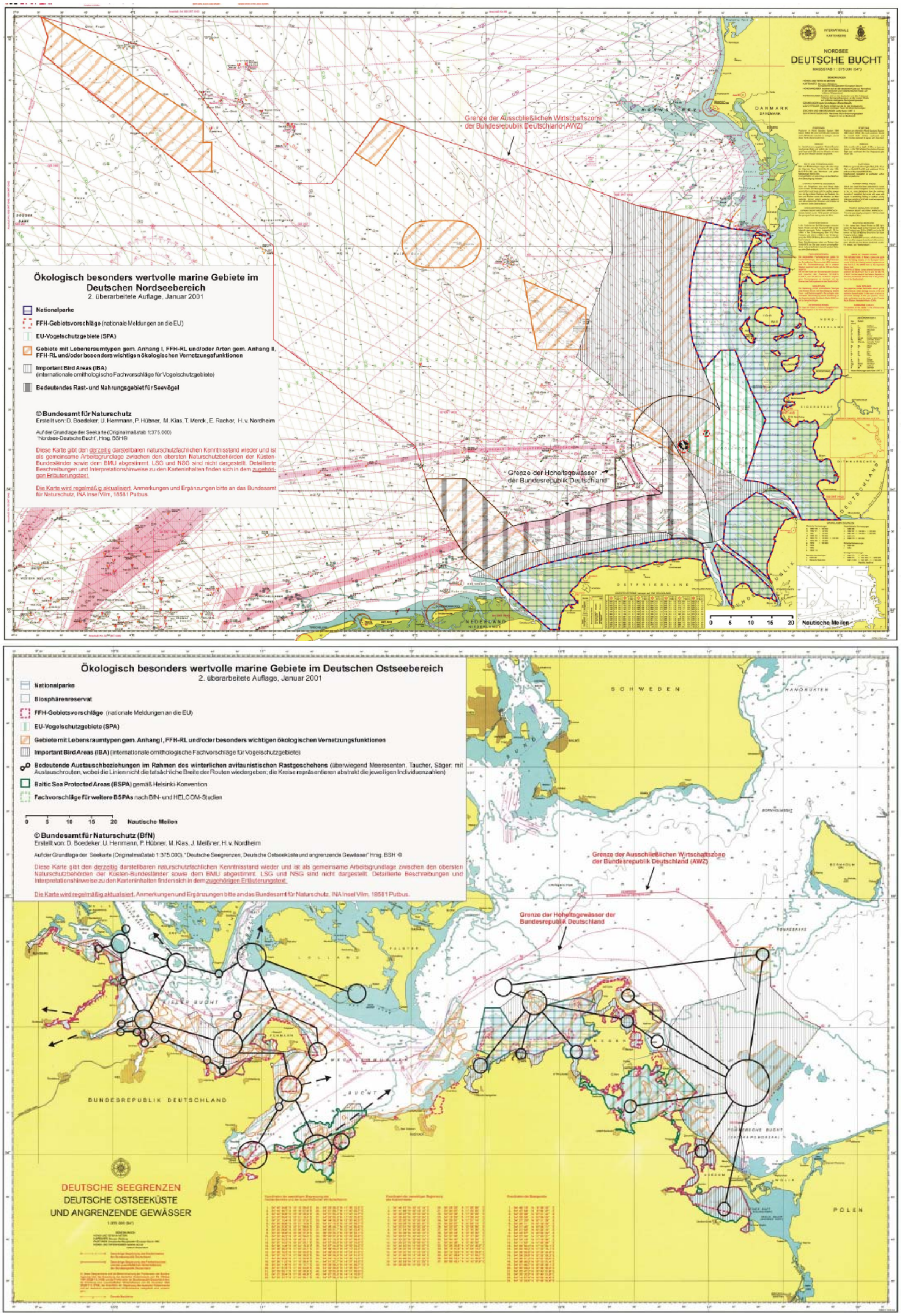


Figure C-1: **Ecologically particularly valuable areas in the German areas of the North and Baltic Seas**
Source : Federal Nature Conservation Agency
Status : January 2001

C-4 Recommendations for the minimum requirements of project related investigations on potential construction and operational impacts of offshore wind energy plants on the marine environment of the North and Baltic Seas.

In the spring of 2001 the project group regarded it as essential to establish recommendations on minimum requirements for project specific investigations. These were to be applied in the framework of the approval process for offshore wind energy plants to establish potential effects on the benthos, birds and marine mammals, since no standards were available to harmonise investigations and qualifications with regard to extent and quality. Particularly the general framework or as the case may be, the scheme of procedures and also the determination of the investigation areas was laid down in close co-operation with the Federal Environmental Agency and the Federal Government Department of Nature Conservation. These minimum requirements would allow the assessment of appropriateness of a requested site and the approbation of a project and permit the recommendation of alternative measures, (also of a technical nature) on a scientifically sound basis. Standards were to be developed to enable the comparison of data derived from studies by the different applicants. These recommendations were completed in the summer of 2001, after discussions with experts, and served as a basis for the "Standarduntersuchungskonzeptes für Genehmigungsverfahren nach Seeanlagenverordnung" published by the authorising agency (BSH) in December 2001.

The original version of the recommendations on minimum requirements of the project group "OffshoreWEP" version 2001 can be found under E-1 in the annex of the German version of this report. Since then Hüppop et al. (2002b) have published revised recommendations on resting and migratory birds. The “Standarduntersuchungskonzept für Genehmigungsverfahren nach Seeanlagenverordnung” was revised in Spring 2003 by the Bundesamt für Seeschifffahrt und Hydrographie (BSH 2003).

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