From: Dominika Phillips
To: Hornsea Project Three; KJ Johansson; Kay Sully
Cc: Andrew Guyton; Stuart Livesey
Subject: Hornsea Project Three (UK) Ltd response to Deadline 4 (Part 5)
Date: 15 January 2019 23:03:34
Attachments: image001.png
D4_HOW03_Appendix 12_Scheidat et al 2011.pdf
D4_HOW03_Appendix 13_Wisniewska et al 2016.pdf
D4_HOW03_Appendix 14_Bowgen_Cook 2018.pdf
D4_HOW03_Appendix 15_Furness 2015.pdf
D4_HOW03_Appendix 16_Cook et al 2014.pdf
D4_HOW03_Appendix 17_Dierschke and Garthe 2006.pdf
D4_HOW03_Appendix 18_Garthe and Huppop 2004.pdf

Dear Kay, K-J

Please find attached the 5th instalment of documents.

Best regards,
Dr Dominika Chalder PIEMA
Environment and Consent Manager

[redacted]

Environmental Management UK│ Wind Power
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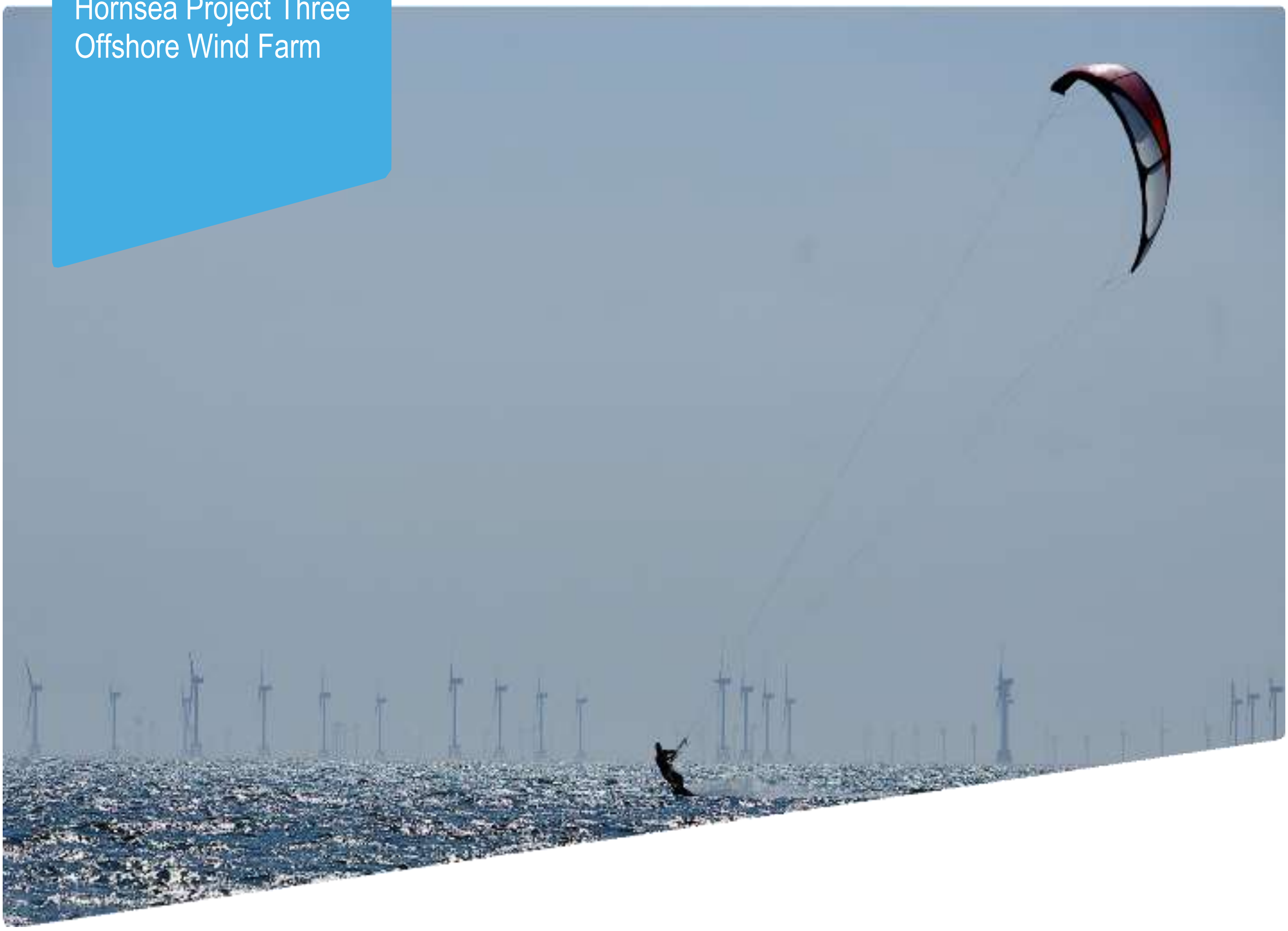
Hornsea Project Three
Offshore Wind Farm



Hornsea Project Three

Offshore Wind Farm

Appendix 18 to Deadline 4 Submission – Garthe and Huppop 2004

Date: 15th January 2019

Hornsea 3
Offshore Wind Farm

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Document Control			
Document Properties			
Organisation	Ørsted Hornsea Project Three		
Author	Garthe and Huppop 2004		
Checked by	n/a		
Approved by	n/a		
Title	Appendix 18 to Deadline 4 Submission – Garthe and Huppop 2004		
PINS Document Number	n/a		
Version History			
Date	Version	Status	Description / Changes
15/01/2019	A	Final	Submitted at Deadline 4 (15/01/2019)

Ørsted

5 Howick Place,

London, SW1P 1WG

Journal of Applied Ecology 2004
41, 724–734

Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index

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Summary

1. Marine wind farms have attracted substantial public interest. The construction of wind facilities offshore may become Europe's most extensive technical development in marine habitats. Due to political pressure to complete construction soon, assessments of possible wind farm locations, for example in the German sectors of the North Sea and Baltic Sea, have to be based on existing knowledge.
2. In this study, we developed a wind farm sensitivity index (WSI) for seabirds. We applied this index to the Exclusive Economic Zone and the national waters of Germany in the North Sea. We chose nine factors, derived from species' attributes, to be included in the WSI: flight manoeuvrability; flight altitude; percentage of time flying; nocturnal flight activity; sensitivity towards disturbance by ship and helicopter traffic; flexibility in habitat use; biogeographical population size; adult survival rate; and European threat and conservation status. Each factor was scored on a 5-point scale from 1 (low vulnerability of seabirds) to 5 (high vulnerability of seabirds). Five of these factors could be dealt with by real data but four could only be assessed by subjective considerations based on at-sea experience; in the latter cases, suggestions of the first author were independently modulated by experts.
3. Species differed greatly in their sensitivity index (SSI). Black-throated diver *Gavia arctica* and red-throated diver *Gavia stellata* ranked highest (= most sensitive), followed by velvet scoter *Melanitta fusca*, sandwich tern *Sterna sandvicensis* and great cormorant *Phalacrocorax carbo*. The lowest values were recorded for black-legged kittiwake *Rissa tridactyla*, black-headed gull *Larus ridibundus* and northern fulmar *Fulmarus glacialis*.
4. A WSI score for areas of the North Sea and Baltic Sea was calculated from the species-specific sensitivity index values. Coastal waters in the south-eastern North Sea had values indicating greater vulnerability than waters further offshore throughout the whole year.
5. Derived from the frequency distribution of the WSI, we suggest a 'level of concern' and a 'level of major concern' that are visualized spatially and could act as a basis for the selection of marine wind farm locations.
6. *Synthesis and applications.* The wind farm sensitivity index might be useful in strategic environmental impact assessments (EIA). Results of small-scale EIA from wind installations should be considered within a more global perspective, provided, for example, by large mapping projects and detailed behavioural studies. This is difficult in normal EIA, particularly in highly dynamic coastal/marine habitats, and the results of this study fill an important gap by providing information on the potential sensitivity of seabirds and the importance of locations of wind installations.

Key-words: birds, conservation, management, sensitivity analysis, wind energy

Journal of Applied Ecology (2004) **41**, 724–734

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Introduction

The first wind farms at sea were established in the early 1990s, off Denmark and Sweden (Larsson 1994). There are now at least nine operational marine wind farms in Europe, as well as proposals to build many more around the UK and off Germany and Denmark (Anonymous 2000a,b, 2001, 2002; ICES 2003). Plans for marine wind farms indicate that each may consist of up to 1000 turbines, extending as far offshore as 100 km, and in waters up to 40 m deep (Anonymous 2002). Within north-west Europe, there are in total about 260–270 turbines in existing marine wind farms (as of December 2003, http://www.offshorewindenergy.org/) but many thousands are planned for construction in the next few years (Hüppop, Exo & Garthe 2002; ICES 2002). According to the current development plan for the German parts of the North and Baltic Seas, marine wind farms will require an area of 13 000 km^2 between 2002 and 2030 (BMU 2001). The UK has recently issued licenses for the development of about 40 marine wind farms in its waters. Thus, erection of wind facilities offshore may become Europe's most extensive technical development in marine habitats (Merck & von Nordheim 2000).

With so few wind farms established in the sea to date, there is very limited information on their effects on the marine environment (Merck & von Nordheim 2000; ICES 2002) and none on marine sites located more than 10–20 km from the coast. As applications for offshore wind farm construction will be decided in many locations before comprehensive, medium- to large-scale, ecological studies on the status of marine wildlife are completed, predicted effects have to be based on limited current knowledge. This should include conclusions from studies of wind farms on land, from the few inshore wind farms and from knowledge of the spatiotemporal patterns of abundance of organisms at sea that might be at risk.

Birds are assumed to be among the taxa affected most heavily by wind farms. Studies on land, and the first results from marine sites, suggest that both birds on migration and those resting or foraging locally may be affected (Barrios & Rodríguez 2004). At sea, this therefore includes both migrating birds, from the smallest songbirds to large birds such as cranes and birds of prey, and seabirds during their local movements (Anonymous 2000b; Garthe 2000; Exo, Hüppop & Garthe 2003; Hüppop, Exo & Garthe 2002). From extensive studies of seabirds at sea over the past 20 years, the distribution and abundance of seabirds in the North Sea is well-known over large and medium scales. Available data can therefore advise the site selection of wind farm locations. However, different habits and activities of birds at sea have to be taken into account. For example, species flying frequently at altitudes of 50–200 m a.s.l. are much more vulnerable to wind turbines than species that swim most of the time. However, there are many effects to be considered in addition to direct collisions.

In order to assess the possible impacts on seabirds of a range of factors, several indices have been applied in recent years, for example with regard to oil pollution (King & Sanger 1979; Williams *et al*. 1994) and the sandeel fishery (Furness & Tasker 2000). One of the indices of vulnerability to oil pollution has been applied to the whole North Sea, separating areas of high and low vulnerability for seabirds over the year (Carter *et al*. 1993). While the lack of long-term data, the inability to infer causality from monitoring studies and the limited spatial and temporal scales of experimental studies make such indices difficult to derive with confidence, more are required (Forde 2002). Debate on the effects of human activities on wildlife necessitates risk and impact assessments (Stillman *et al*. 2001) even where the database might be poor (Tuck *et al*. 2001).

In this study, we developed a wind farm sensitivity index (WSI) for seabirds. In terms of rationale and methodology, this index follows those of Williams *et al*. (1994) and Furness & Tasker (2000). We applied this index to the Exclusive Economic Zone and national waters of Germany in the North Sea. This area was selected for three reasons. First, there has not been any governmental advice prior to the beginning of the planning process (as was the case in Denmark, for example; Anonymous 1996) so site selection by the applicants might not have taken into account all of the important environmental issues. Secondly, there is an urgent need to evaluate risks in this area, in which 24 project applications comprising more than 11 000 single turbines were in place as of January 2003 (in the Exclusive Economic Zone). Thirdly, due to the complex geomorphology and hydrography under the existing intensive human usage (e.g. shipping lanes), a small- and medium-scale environmental assessment is urgently needed as a solid basis for future licensing.

Methods

VULNERABILITY FACTORS

We chose nine different factors, derived from species' attributes, to be included in the WSI, all taking into account the risks of seabirds colliding with wind turbines and/or being disturbed by wind farms. Each factor was scored on a 5-point scale from 1 (low vulnerability to seabirds) to 5 (high vulnerability to seabirds). Five of these factors could be based on real data, four could only be assessed by subjective considerations based on at-sea experience. In the latter cases, our suggestions were sent for independent evaluation by 10 experts per factor. The experts were chosen according to their experience (e.g. in ship-based and aerial seabird surveys) from a total of eight national and five international experts (listed in the Acknowledgements). Following Furness & Tasker (2000), we made changes if two or more experts suggested alterations to the original categorization in the same direction. The nine factors included are outlined below.

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(a) Flight manoeuvrability

This factor took into account flight properties with regard to the potential to avoid collision with wind farms at sea. It was assessed subjectively, based on extensive field experience, and was modulated by experts as described above. Species were ranked from a very high flight manoeuvrability (score 1) to low flight manoeuvrability (score 5). A fast-flying, relatively heavy species such as the common guillemot *Uria aalge* (Pontoppidan) is thus considered much more vulnerable compared with a very agile species such as the Arctic tern *Sterna paradisaea* Pontoppidan, which is assumed to be able to escape wind turbines much better.

(b) Flight altitude

This factor was based on flight altitude assessments made during regular seabirds at sea surveys (see Distributional data). Flight altitudes were estimated using binoculars, distance meters and comparative height measures on the ships according to the following height classes: 1, 0–5 m; 2, 5–10 m; 3, 10–20 m; 4, 20–50 m; 5, 50–100 m; 6, > 100 m. A further separation of high flight altitudes was not useful. Flight altitude data were converted to a 5-point scale by using two different percentiles of the flight altitude data distributions, the median (= 50 percentile) and 90 percentile. The 90 percentile was chosen in addition to the median to take into account the few birds that flew high (i.e. 90% of the birds flew in the same or lower height classes, 10% of the birds flew in the same or upper height classes). The scores were classified as follows: 1, height class 1 for the median; 2, height class 2 for the median; 3–5, height class 3 for the median but the 90 percentile differed, score 3 had height classes < 5 for the 90 percentile, score 4 height class 5 for the 90 percentile and score 5 height class 6 for the 90 percentile.

(c) Percentage of time flying

The percentage of time flying was obtained from seabirds at sea counts, with numbers of swimming birds corrected for individuals overlooked at larger distances (see below). Species were scored 1 if 0–20% of the individuals in the transect were flying, 2 if 21–40% in the transect were flying, 3 if 41–60%, 4 if 61–80% and 5 if 81–100% of the individuals in the transect were flying.

(d) Nocturnal flight activity

Nocturnal flight activity could not be quantified by real data and was thus classified subjectively from 1 (hardly any flight activity at night) to 5 (much flight activity at night). Information for this classification was taken from comprehensive handbooks such as Glutz von Blotzheim & Bauer (1982) and Cramp & Simmons (1983). Field experience as well as personal observations were also used (Garthe & Hüppop 1996). Our classification was subsequently modulated by experts as indicated above.

(e) Disturbance by ship and helicopter traffic

Species react differently to the ship and helicopter traffic that occurs during the construction and maintenance of wind farms. Such behaviour might also give an indication of the general behaviour of birds towards disturbances. Due to the paucity of data, this factor was scored subjectively from 1 (hardly any escape/avoidance behaviour and/or none/very low fleeing distance) to 5 (strong escape/avoidance behaviour and/or large fleeing distance) and classifications were modulated by experts. Our scores resulted from extensive surveys at sea from boats, where the reactions of birds to the approaching platform were experienced constantly. Also, species' reactions to counts from aerial surveys (low-flying aeroplanes) as well as to over-flying aeroplanes and helicopters in coastal areas were used.

(f) Flexibility in habitat use

Habitats at sea are often defined by hydrographic characteristics. Because these hydrographic characteristics, e.g. water masses and fronts, depend on wind direction and speed as well as tidal stage, they often vary in location and may shift over many tens of kilometres. This factor scored the flexibility in habitat use of the different species. It could only partially be based on real data, such as published in Garthe (1997) and Skov & Prins (2001). Thus, in addition, unpublished data on seabird–habitat relationships were analysed. We scored this factor from 1 (very flexible in habitat use) to 5 (reliant on specific habitat characteristics) based on the information sources listed above. Species scored low were those occupying large sea areas with no specific habitat preference (e.g. lesser black-backed gull *Larus fuscus* Linnaeus), while species that scored high were those relying on specific habitat features (e.g. sea ducks occurring over bivalve banks on shallow grounds). Our classifications were again modulated by experts.

(g) Biogeographical population size

This factor was scored according to the respective biogeographical population size of each species. Population sizes were taken, if available, from either Rose & Scott (1997) or by collating area-specific data species by species from Lloyd, Tasker & Partridge (1991). Score 1 was given for population sizes exceeding 3 million individuals; score 2 for > 1 million up to 3 million individuals; score 3 for > 500 000 up to 1 million individuals; score 4 for > 100 000 up to 500 000 individuals; and score 5 for less than 100 000 individuals.

(h) Adult survival rate

As additional mortality due to collisions affects species with high annual survival rates more than species with low survival rates, we included this factor. A score of 1 was given if the annual survival rate ≤ 0·75; 2, > 0·75–0·80;

Table 1. Annual adult survival rates of the bird species involved in the index

Species name (English)	Species name (scientific)	Annual adult survival	Source
Red-throated diver	*Gavia stellata*	0·84	Hemmingsson & Eriksson (2002)
Black-throated diver	*Gavia arctica*	0·85	Nilsson (1977), Hemmingss on & Eriksson (2002)
Great crested grebe	*Podiceps cristatus*	0·7	Fuchs (1982)
Red-necked grebe	*Podiceps grisegena*	0·7	Estimate
Northern fulmar	*Fulmarus glacialis*	0·986	del Hoyo, Elliott & Sargatal (1992)
Northern gannet	*Morus bassanus*	0·94	del Hoyo, Elliott & Sargatal (1992)
Great cormorant	*Phalacrocorax carbo*	0·84	Krementz, Sauer & Nichols (1989)
Common eider	*Somateria mollissima*	0·895	Krementz, Barker & Nichols (1997)
Black scoter	*Melanitta nigra*	0·773	Krementz , Barker & Nichols (1997)
Velvet scoter	*Melanitta fusca*	0·77	Estimate
Arctic skua	*Stercorarius parasiticus*	0·84	del Hoyo, Elliott & Sargatal (1996)
Great skua	*Catharacta skua*	0·90	del Hoyo, Elliott & Sargatal (1996)
Little gull	*Larus minutus*	0·80	Estimate
Black-headed gull	*Larus ridibundus*	0·825	Glutz von Blotzheim & Bauer (1982)
Mew gull	*Larus canus*	0·80	Glutz von Blotzheim & Bauer (1982)
Lesser black-backed gull	*Larus fuscus*	0·93	Wanless *et al*. (1996)
Herring gull	*Larus argentatus*	0·93	Glutz von Blotzheim & Bauer (1982)
Great black-backed gull	*Larus marinus*	0·93	Glutz von Blotzheim & Bauer (1982)
Black-legged kittiwake	*Rissa tridactyla*	0·81	del Hoyo, Elliott & Sargatal (1996)
Sandwich tern	*Sterna sandvicensis*	0·88	Estimate
Common tern	*Sterna hirundo*	0·88	del Hoyo, Elliott & Sargatal (1996)
Arctic tern	*Sterna paradiasea*	0·875	del Hoyo, Elliott & Sargatal (1996)
Black tern	*Chlidonias niger*	0·88	Estimate
Common guillemot	*Uria aalge*	0·885	del Hoyo, Elliott & Sargatal (1996)
Razorbill	*Alca torda*	0·905	del Hoyo, Elliott & Sargatal (1996)
Atlantic puffin	*Fratercula arctica*	0·95	del Hoyo, Elliott & Sargatal (1996)

3, > 0·80–0·85; 4, > 0·85–0·90; 5, > 0·90. For survival rates see Table 1. Due to a lack of data, for red-necked grebe *Podiceps grisegena* (Boddaert), velvet scoter *Melanitta fusca* (Linnaeus), little gull *Larus minutus* Pallas, sandwich tern *Sterna sandvicensis* Latham and black tern *Chlidonias niger* (Linnaeus), values from closely related species had to be taken.

(i) European threat and conservation status

This factor reflected both threat and conservation status of the species in Europe as given by Tucker & Heath (1994). Species were scored 1 if the threat status was 'secure' and no species of European concern (SPEC) status given. A score of 2 was given for species with a threat status of 'secure' but a SPEC status of 4 (species whose global populations are concentrated in Europe). Species judged 'localized' for threat status were scored 3, those listed as 'declining' 4 and those judged 'vulnerable' 5.

SENSITIVITY INDEX CALCULATION

We organized the nine vulnerability factors into three groups, comprising (A) flight behaviour (factors a–d), (B) general behaviour (factors e–f) and (C) status (factors g–i). For each group, an average score of the respective factors was calculated. These average scores were subsequently multiplied by each other to give the species-specific sensitivity index (SSI) for each species:

$$\mathrm{SSI} = \frac{(a+b+c+d)}{4} \times \frac{(e+f)}{2} \times \frac{(g+h+i)}{3}$$

DISTRIBUTIONAL DATA

Distribution at sea was assessed by counts from boats following the methods of Tasker *et al*. (1984), Webb & Durinck (1992) and Garthe, Hüppop & Weichler (2002). Transects were always 300 m wide and were set to one or both sides of the vessels. Because some birds were overlooked in the outer areas of the transect, the density of swimming birds was corrected using the values provided by Stone *et al*. (1995). For grebes, being quite rare in North Sea waters and not dealt with by Stone *et al*. (1995), we used a correction factor of 1·3 based on our own, more extensive, data sets from the western Baltic Sea. The density of flying birds was not corrected, assuming that flying birds were recorded more or less completely within the transects (Stone *et al*. 1995; Garthe 1997). Data originated from the European Seabirds at Sea Database version 3.0 (July 2002) and the German Seabirds at Sea Database version 3.06 (April 2003). Databases are described in Stone *et al*. (1995) and Garthe, Hüppop & Weichler (2002).

VULNERABILITY MAPS

Seabird vulnerability to offshore wind farms is presented in maps with grids of 6′ latitude × 10′ longitude each, amounting to a total grid size of *c*. 120 km^2. Only data collected under good detectability conditions (in

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sea states 0–4; Garthe, Hüppop & Weichler 2002) from January 1993 to May 2003 were used for analyses. Data were summarized per season: summer = June–August, autumn = September–November, winter = December–February, spring = March–May. Coverage was not equal across the study area. Thus, data were corrected for different survey effort: for each species, the density per grid cell was obtained by dividing the sum of individuals recorded in the transect by the total transect area covered by cruises. To reduce bias due to only short visits to some grid cells, all grid cells with less than 1 km^2 covered were excluded. For each grid cell with sufficient data, the vulnerability was determined as:

$$WSI = \sum_{species} (\ln (density_{species} + 1) \times SSI_{species})$$

Thus, for each species, the respective SSI value was multiplied with the natural logarithm of its density (+1, to avoid undefined values) and subsequently summed over all species.

We also defined three levels for a final evaluation of the area under investigation. The levels were established with the following considerations. The median divides the whole sample into two equally large parts, i.e. half of the grid cells have a WSI larger than the 'average'. By definition these are the areas with a wind farm vulnerability higher than the average. To end up with a more conservative estimate for areas of 'concern' we decided to use the 60 percentile rather than the 50 percentile (= median). Accordingly we assumed a 'level of major concern' for the fifth of all grid cells with the highest WSI indices.

SENSITIVITY ANALYSIS FOR THE WSI

In order to verify how the WSI might be affected by inaccurate scores for any of the nine factors listed above, a sensitivity analysis was carried out. We chose three species, one with a high SSI, one with a medium SSI and one with a low SSI. Randomly, each score for any of the eight factors was altered. In a first run, the scores were altered either by upgrading or downgrading them by 1 (determined by random and only if applicable, e.g. score 5 could not be increased and thus remained). In a second run, the scores were altered either by upgrading or downgrading them by 2 (again determined randomly and only to the extent possible).

Results

SENSITIVITY INDEX

The species had strongly differing sensitivity index values (Table 2). Black-throated diver *Gavia arctica* (Linnaeus) and red-throated diver *Gavia stellata* (Pontoppidan) ranked highest (i.e. were most sensitive), followed by velvet scoter, sandwich tern and great cormorant *Phalacrocorax carbo* (Linnaeus). The lowest SSI values were

Table 2. Score of the nine vulnerability factors and the resulting species sensitivity index (SSI) values for each of the 26 seabird species. For details see text

Bird species	Flight manoeuvrability	Flight altitude	% flying	Nocturnal flight activity	Disturbance by ship and helicopter traffic	Habitat use flexibility	Biogeographical population size	Adult survival rate	European threat and conservation status	SSI
Black-throated diver	5	2	3	1	4	4	4	3	5	44·0
Red-throated diver	5	2	2	1	4	4	5	3	5	43·3
Velvet scoter	3	1	2	3	5	4	3	2	3	27·0
Sandwich tern	1	3	5	1	2	3	4	4	4	25·0
Great cormorant	4	1	4	1	4	3	4	3	1	23·3
Common eider	4	1	2	3	3	4	2	4	1	20·4
Great crested grebe	4	2	3	2	3	4	4	1	1	19·3
Red-necked grebe	4	2	1	1	3	5	5	1	1	18·7
Great black-backed gull	2	3	2	3	2	2	4	5	2	18·3
Black tern	1	1	4	1	2	3	4	4	4	17·5
Common scoter	3	1	2	3	5	4	2	2	1	16·9
Northern gannet	3	3	3	2	2	1	4	5	3	16·5
Razorbill	4	1	1	1	3	3	2	5	2	15·8
Atlantic puffin	3	1	1	1	2	3	2	5	5	15·0
Common tern	1	2	5	1	2	3	3	4	1	15·0
Lesser black-backed gull	1	4	2	3	2	1	4	5	2	13·8
Arctic tern	1	1	5	1	2	3	3	4	1	13·3
Little gull	1	1	3	2	1	3	5	2	4	12·8
Great skua	1	3	4	1	1	2	5	4	2	12·4
Common guillemot	4	1	1	2	3	3	1	4	1	12·0
Mew gull	1	3	2	3	2	2	2	2	4	12·0
Herring gull	2	4	2	3	2	1	2	5	1	11·0
Arctic skua	1	3	5	1	1	2	4	3	1	10·0
Black-headed gull	1	5	1	2	2	2	1	3	1	7·5
Black-legged kittiwake	1	2	3	3	2	2	1	3	1	7·5
Northern fulmar	3	1	2	4	1	1	1	5	1	5·8

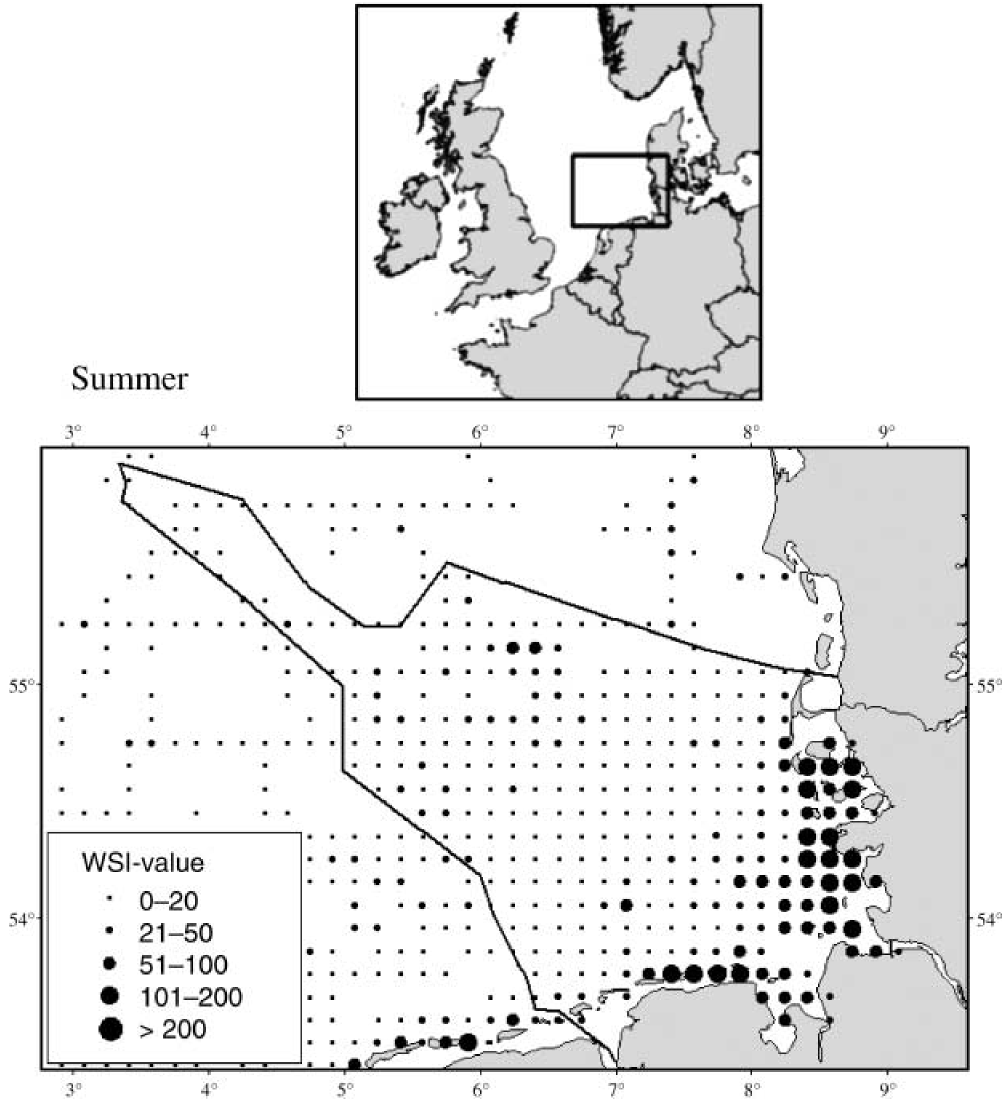

Fig. 1. Spatial distribution of the wind farm sensitivity index (WSI) values (all seabird species combined) in the south-eastern North Sea in summer (June–August) 1993–2002. For assumptions and calculations see text.

calculated for black-legged kittiwake *Rissa tridactyla* (Linnaeus), black-headed gull *Larus ridibundus* Linnaeus and northern fulmar *Fulmarus glacialis* (Linnaeus).

Sensitivity analyses for the three species selected resulted in moderate deviation when the scores where randomly altered by 1 (mean of 10 runs per species). The SSI for red-throated diver changed from 43·3 to 44·8, the SSI for common eider *Somateria mollissima* (Linnaeus) from 20·4 to 23·0 and that for black-headed gull from 7·5 to 10·0. When the scores were randomly altered by 2, the changes were more pronounced (mean of 10 runs per species). The SSI for red-throated diver was reduced from 43·3 to 24·4, the SSI for common eider increased from 20·4 to 30·3 and that for black-headed gull from 7·5 to 16·4.

AREAS OF VULNERABILITY

Throughout the whole year, WSI values in coastal waters of the south-eastern North Sea were considerably higher than those of waters further offshore. Focusing on the German sector, the coastal zone had consistently moderate to high WSI values in summer (Fig. 1). The area around Helgoland showed some moderate values whereas vulnerabilities further offshore were low. In autumn, WSI values were generally lower than in summer, but a number of coastal sites reached moderate to high vulnerabilities (Fig. 2). Some offshore areas gained importance compared with summer because species' distributions were less confined to breeding sites so that they were more widely distributed. Also, autumn migration certainly created higher densities in areas far away from the coast. In winter, the south-easternmost part of the German Bight was less vulnerable than in summer and autumn (Fig. 3). Nevertheless, it was obvious that WSI values in the coastal zone in winter were usually moderate to high whereas the values far away from the coast were low or very low. In spring, vulnerabilities were again quite high in most areas of the coastal zone but were also moderate to high in areas up to 70–80 km off the northern part of the German coast (Fig. 4).

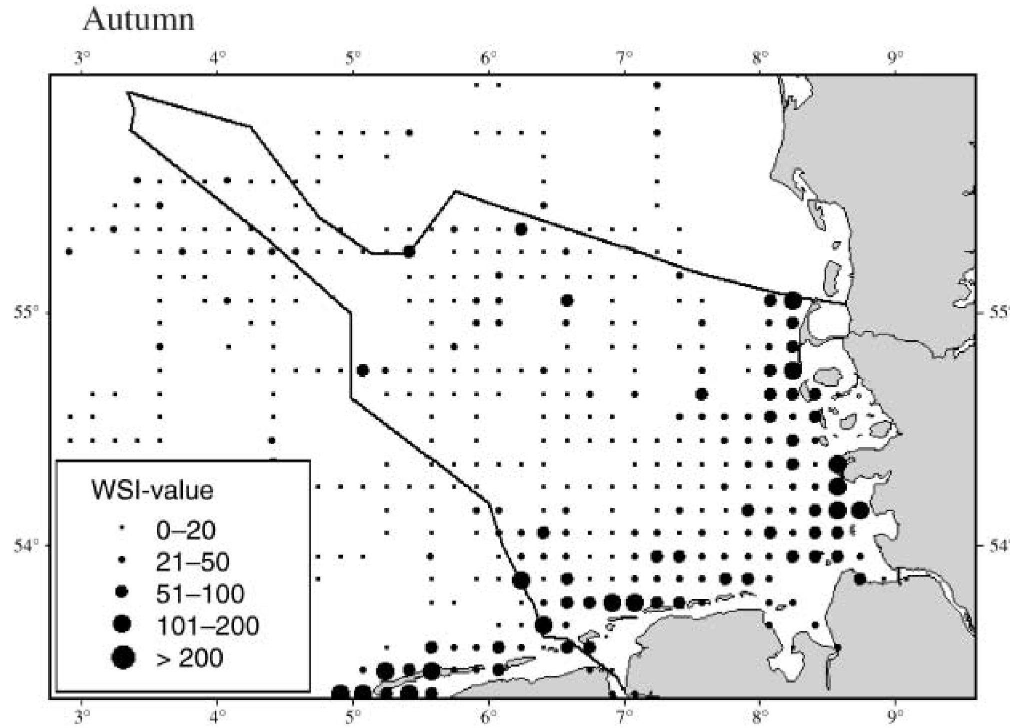

Fig. 2. Spatial distribution of the wind farm sensitivity index (WSI) values (all seabird species combined) in the south-eastern North Sea in autumn (September–November) 1993–2002. For assumptions and calculations see text.

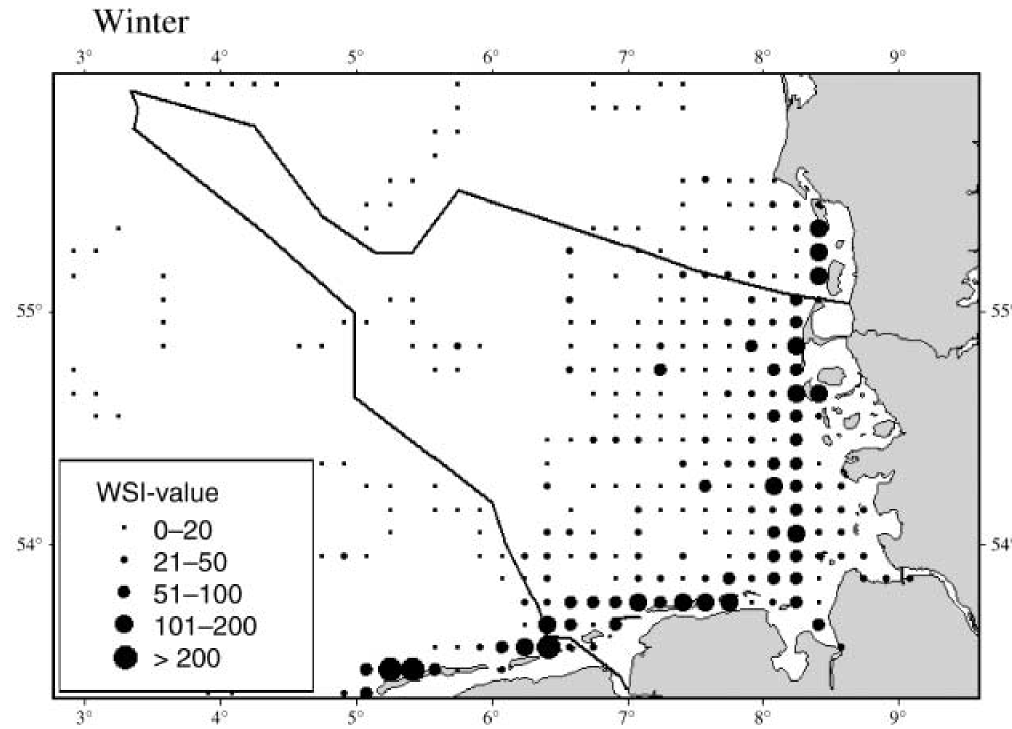

Fig. 3. Spatial distribution of the wind farm sensitivity index (WSI) values (all seabird species combined) in the south-eastern North Sea in winter (December–February) 1993–2003. For assumptions and calculations see text.

Discussion

SUITABILITY OF THE WSI

Five factors incorporated into the WSI were based on real data but this was not possible for the remaining four factors. We therefore decided to assess these factors subjectively based on at-sea experience. Experts then evaluated our initial scores by reading and considering our values presented on a list, based on their own experiences related to that topic. Such a procedure, called the Delphi technique, has been applied broadly

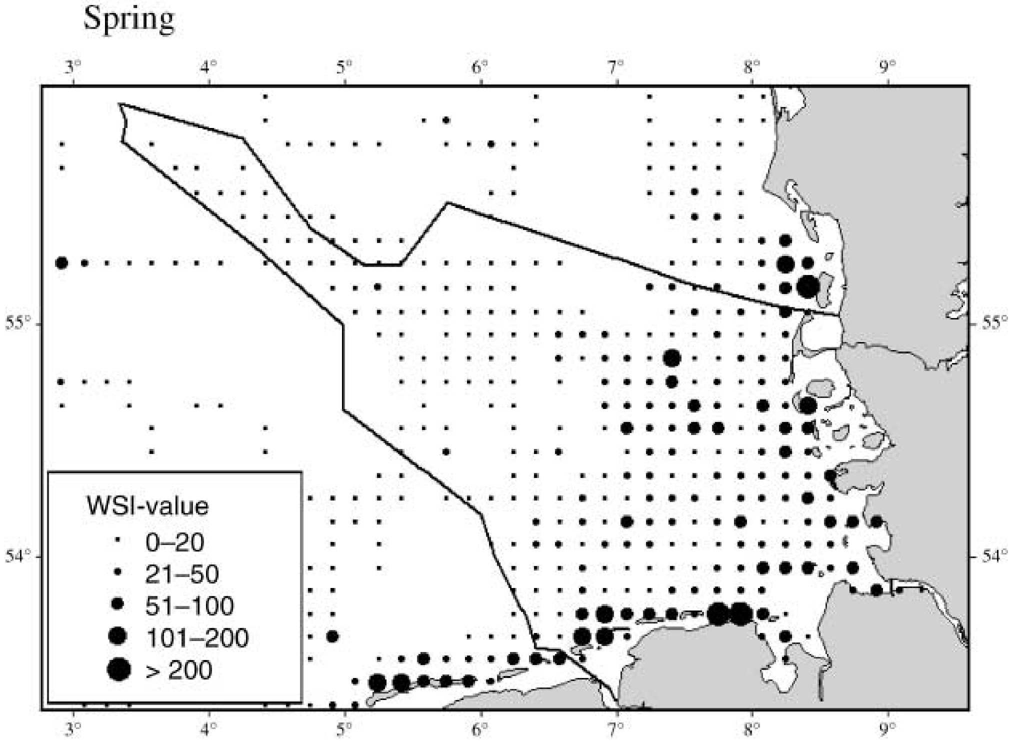

Fig. 4. Spatial distribution of the wind farm sensitivity index (WSI) values (all seabird species combined) in the south-eastern North Sea in spring (March–May) 1993–2003. For assumptions and calculations see text.

before, for example in habitat suitability indices of the US Fish and Wildlife Service (Crance 1987). Recently Cowling *et al*. (2003) compared an expert-based and a systematic algorithm-based approach to identifying priority areas for conservation in the Cape Floristic Region. They concluded that 'rather than emphasize the dichotomy between expert and systematic approaches, conservation planners should devise ways of integrating them'. Although not without difficulties, these data based on expert judgement are currently the best available.

In general, indices depend strongly on the factors selected and the way they are weighed against each other. The WSI proposed in this paper is no exception in this respect. Nevertheless, there are at least four reasons why this index seems to be well-suited to fulfil the urgent need to assess the vulnerability of all seabirds that occur in a large area. First, the final SSI values show substantial differences between the species. Hence, the WSI combines numerical abundance data with evaluations of the sensitivity and importance of the different species. Secondly, not too many alterations were required on the basis of the evaluations made by national and international experts (four changes for flight manoeuvrability, nine changes for nocturnal flight activity, 18 changes for disturbance by ship and helicopter traffic and 15 changes for habitat use flexibility), suggesting that the species-specific scores for each vulnerability factor were well chosen. Interestingly, it has been shown by morphometric measurements and behavioural observations in the literature (Verbeek 1977; Camphuysen 1995) that lesser black-backed gulls have a higher flight manoeuvrability than herring gulls *Larus argentatus* Pontoppidan, providing an example of how accurate our expert judgement system was. Thirdly, sensitivity analyses showed that minor changes in the scores did not affect the SSI much, although major changes may do so. Fourthly, the spatial representation of the WSI values fits well with previous evaluations of the location of important bird areas (Skov *et al*. 1995).

SUGGESTIONS FOR CONSERVATION AND MANAGEMENT

In the German Bight, seabird vulnerability towards wind farms seems to be a function of distance to the coast. The highest values were found relatively close to the coast and lowest values (very) far from the shore. However, there are differences between the two coasts. North of the East Frisian Islands (the southern part of the German sector), the values decrease at much shorter distances from the coast than they do west of the North Frisian Islands (in the eastern part of the German sector). These patterns originate from the density distribution of all species, with a bias towards those species that are ranked high in the SSI and with less emphasis towards species having a low SSI. However, in no case did high densities of a single species create very high WSI values. Thus, the vulnerability maps are more a summary of all species contributing to the final WSI value to a different degree. Species' attributes do not exhibit much variation over the study area so that they contribute primarily via the input factors for the SSI. Thus, spatial variation of the WSI values is basically a reflection of summarized species' density distributions.

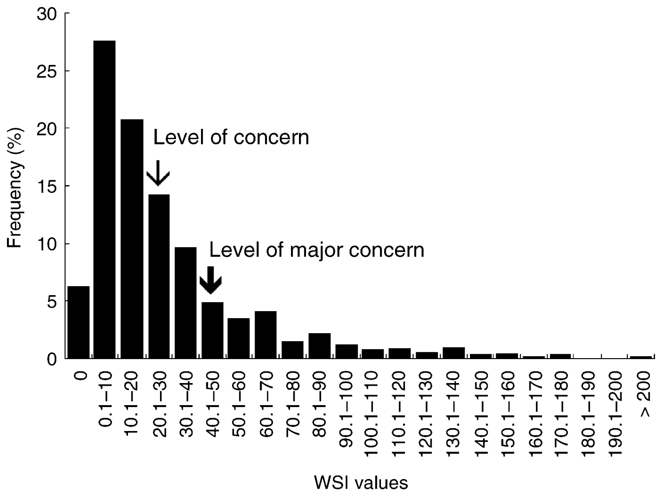

Fig. 5. Average frequency distribution (in percentage) of the WSI values in the German sector of the North Sea. The values were obtained by calculating means per size class over the fours seasons presented in Figs 1–4.

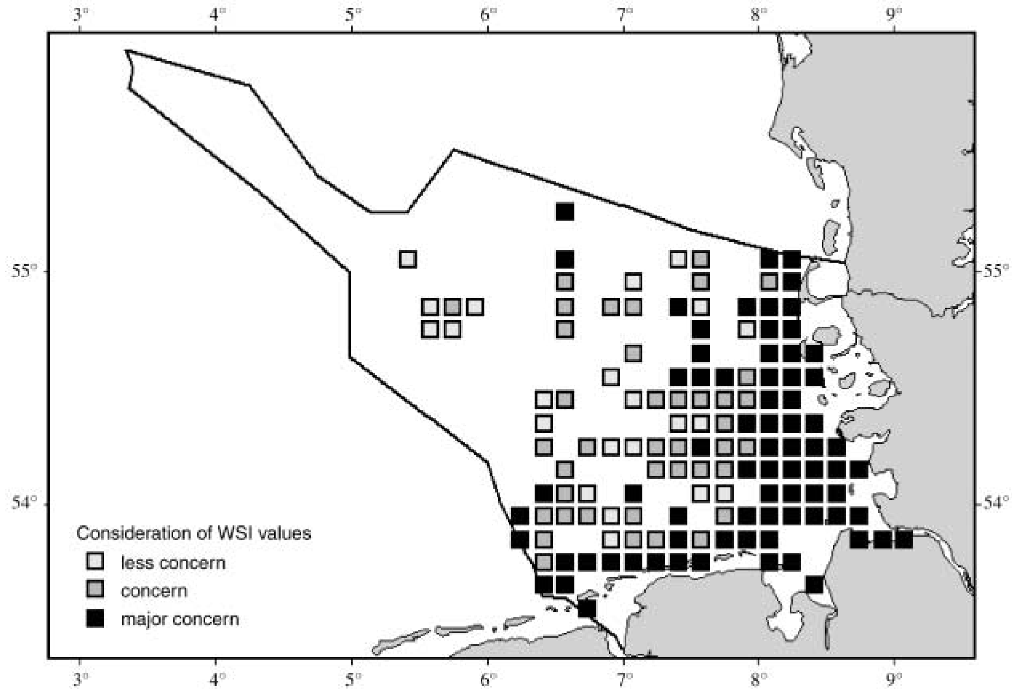

Fig. 6. Areas in the German sector of the North Sea where wind energy utilization is considered to be of 'no (less) concern', 'concern' or 'major concern'. Areas not studied in at least one of the seasons are left blank.

From the average frequency distribution of the WSI values over the four seasons (Fig. 5) it is apparent that most areas do not hold important concentrations of seabirds and thus do not appear particularly vulnerable to marine wind farm construction. However, there is no doubt that some areas have high to very high WSI values and hence are unsuited for such constructions. We suggest a level of concern set at the 60 percentile of the average frequency distribution (= WSI of 24) and a level of major concern set at the 80 percentile (= WSI of 43).

Wind farms operate the whole year round. Threats might therefore also be important even if they only affect species in a single season. Thus, spatial information from Figs 1–4 has been compiled for the whole year. The values of the most important season per grid cell are visualized spatially in Fig. 6 in relation to the levels of concern discussed above.

SYNTHESIS AND APPLICATIONS

This index has been developed primarily for marine wind farm site selection purposes and comparative area assessments. It might be a useful tool for strategic environmental impact assessments (EIA). However, it cannot substitute for proper, detailed EIA, which usually only cover small areas over a limited time period

(BSH 2003). Results from such small-scale EIA should therefore be set into a more global perspective, provided, for example, by large mapping projects and detailed behavioural studies. Because this is without doubt difficult in normal EIA, particularly in highly dynamic coastal/marine habitats, this study aims to fill this gap by providing comprehensive and up-to-date background information.

Acknowledgements

Kees Camphuysen, Volker Dierschke, Jan Durinck, Nils Guse, Thorsten Krüger, Mardik Leopold, Nele Markones, Ib Krag Petersen, Philipp Schwemmer, Henrik Skov, Nicole Sonntag, Niklas Ullrich and Tanja Weichler evaluated our preliminary subjective assessments for the four vulnerability factors for which no hard data existed. Nicole Sonntag helped with compilation of the data. The European Seabirds at Sea (ESAS) Coordinating Group improved this index through very stimulating discussions and by providing data from the ESAS database. F. Bairlein, P. Boye, C.J. Camphuysen, M. Exo, T. Merck and C. Zucco, two anonymous referees and the editors made valuable comments on earlier versions of this manuscript. R.W. Furness corrected our English.

This study was supported financially by projects funded by the following institutions: Federal Agency for Nature Conservation, Federal Agency for the Environment, Ministry for the Environment, Nature Conservation and Nuclear Safety, Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer (project MINOS within the ZIP programme), Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein und Hamburg e.V. and Freunde und Förderer der Inselstation der Vogelwarte Helgoland e.V. These studies could not have been realized without the help of numerous observers (often volunteers!) and usually free access to a variety of different governmental and private ships.

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Received 28 November 2002; final copy received 24 March 2004