Avoidance behaviour of birds around offshore wind farms

Overview of knowledge including effects of configuration

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Commissioned by: Rijjkswaterstaat Sea and Delta

21 July 2014
Report nr 13-268

Status:	final report
Report nr.:	13-268
Date of publication:	21 juli 2014
Title:	Avoidance behaviour of birds around offshore wind farms
Subtitle:	Overview of knowledge including effects of configuration
Author:	dr. K.L. Krijgsveld
Photo credits cover page:	Ruben Fijn / Bureau Waardenburg
Number of pages incl. appendices:	30
Project nr:	12-064
Project manager:	dr. K.L. Krijgsveld
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Reference client:	Orderbon met kostenplaats/kostenactiviteit: 4077291 - 0020 / t.n.v Q Duivestein / 5 December 2013
Signed for publication:	team leader bird ecology Bureau Waardenburg bv drs. J. van der Winden
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Preface

To obtain more clarity regarding the location and configuration of future offshore wind farms with respect to effects on birds, Rijkswaterstaat Sea and Delta of the Ministry of Infrastructure and the Environment wants to gain insight in the expected number of collisions of birds with offshore wind turbines as well as in the avoidance behaviour of birds around offshore wind farms. Rijkswaterstaat has therefore asked Bureau Waardenburg to provide a brief overview both aspects, based on available research.

The report at hand provides a concise review of available knowledge on avoidance behaviour, in which general patterns in avoidance behaviour are identified and presented. An overview of the collision risk models that are used to estimate the number of collision victims offshore is provided in a separate publication and supporting short note by Kleyheeg-Hartman *et al.* (2014a and b).

This review was written by Karen Krijgsveld, in cooperation with Martin Poot and Jan van der Winden (all Bureau Waardenburg).

The project was coordinated by Martine Graafland at Rijkswaterstaat Sea and Delta. We thank her for her cooperation.

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1 Introduction

1.1 Background

The numbers of birds that collide with wind turbines offshore is one of the major unknowns concerning the ecological effects of offshore wind energy. This number is very much dependent on the avoidance behaviour of birds around the wind farm and around the individual turbines. Birds that strongly avoid wind farms will have a far lower risk of colliding with the turbines than birds that are indifferent to the wind farms or that are even attracted to them. On the other hand, birds that show strong avoidance of wind farms will have a higher risk of suffering barrier effects and displacement effects, which can result in habitat loss and potentially a lowered carrying capacity for local populations.

Because bird collisions with offshore turbines cannot be measured directly yet, impact assessments are currently based on collision risk models (CRM's) such as the SOSS Band model (Band 2012). These CRM's are heavily reliant on avoidance rates, and therefore it is crucial to have accurate figures for avoidance rates of the different individual bird species flying at offshore wind farm sites. CRM's do not take into account the effect of the wind farm configuration, such as spacing between the turbines, orientation in relation to the coast and the size of the wind farm, mainly because it is unknown how wind farm configuration affects avoidance behaviour. The number of collision victims among birds as well as potential barrier effects can possibly be reduced by accounting for the local species composition and the main flight paths of these birds in the planning phase, and by adjusting the configuration of the wind farm to this.

Since the first offshore wind farms became operational, several studies have been carried out internationally to measure their effects on birds. Some of these have focussed on flight paths of individual bird species, while others aimed to determine displacement effects on local populations. Combined, these studies may provide insight in general behaviour patterns of individual bird species around offshore wind farms. In addition, because wind farms vary in size and configuration, the results we have obtained thus far may shed some light on how these factors affect avoidance behaviour.

In this overview we distinguish two types of avoidance, being micro- and macro-avoidance. Macro-avoidance is avoidance of the entire wind farm, micro-avoidance is when a bird does fly into the wind farm, but avoids flying into the rotor-swept zone of the individual turbines.

1.2 Aim

In this review report, we provide the following information:

1. We give an overview of the results on avoidance behaviour that were measured at different offshore wind farms internationally, as far as this is currently known from publicly available research.
2. Based on this overview, we will evaluate whether similarities can be found in the avoidance behaviour of individual species at the different wind farm areas, or whether behaviour of species varies between wind farms.
3. In addition, we evaluate whether wind farm features such as size and turbine spacing can be recognized as factors that affect the behavioural response of birds towards the wind farms.
4. Based on the results of this review, we define the major areas where knowledge is insufficient and which require further research to realize a further increase in the number of offshore wind farms in harmony with birds offshore.

1.3 Birds and offshore wind farms

Offshore wind farms can have three quintessential types of effects on birds:

1. *Collisions* with the turbines, where birds suffer lethal injury and disappear in the sea;
2. *Barrier effects,* where feeding, resting or breeding areas may become inaccessible to the birds due to the presence of a large wind farm in their flight path; and
3. *Displacement effects,* where birds are displaced from their feeding, resting or breeding areas through the presence of a wind farm in these areas.

Collision risk models are used to predict the number of collision victims, and are based on the theoretical risk that a bird that flies through a wind farms, collides with a turbine, in combination with the avoidance rate of that bird in response to the wind farm (Kleyheeg-Hartman 2014a,b). This avoidance behaviour includes both horizontal behaviour (flight routes) and vertical behaviour (flight heights). As long as actual measurements of collisions offshore are unavailable, CRM's continue to be the only way to quantify the number of collisions offshore. Both barrier effects and displacement effects are closely related to avoidance behaviour as well. The stronger the avoidance of a wind farm, the larger the potential barrier and displacement effects of these wind farms. This will be reflected in the minimum distance between two wind farms (a special case of 'macro-avoidance') or between adjacent turbines within a wind farm that a bird will accept as safe to fly between.

1.4 Approach

For this review, we made an inventory of the currently available studies on responses of birds to offshore wind farms, with respect to the following subjects:

- macro-avoidance behaviour
- micro-avoidance behaviour
- effects of wind farm configuration on avoidance behaviour

The inventory is based on publicly available research from Denmark, Germany, Belgium, the UK and the Netherlands. We provide an overview of the avoidance behaviour of the different species of seabirds as measured in the different studies. We evaluate whether similarities and dissimilarities within species can be observed between the various studies. Subsequently, we assess whether avoidance behaviour can be related to the configuration of the various wind farms that were studied, with respect to distance between turbines, number of turbines, and the presence and use of flight corridors. This leads to an overview of patterns in bird avoidance behaviour, of essential gaps in our knowledge, and of future challenges.

1.5 Limitations of this report

By request of the client, the purpose of this report is to provide a concise and qualitative overview of information on avoidance behaviour. Should a more quantitative and detailed analysis of avoidance rates from the various studies prove feasible, based on the results found in this report, then such an analysis could potentially be carried out subsequently. The studies that have been carried out vary considerably in approach and field methodologies, ranging from displacement studies carried out by means of standard ESAS-counts or aerial surveys to visual observations on flight behaviour and radar studies to determine flight paths. The resulting data (listed in appendix 1) therefore vary a great deal as well, reporting either effects on local populations (changes in densities) or different aspects of behaviour (distance maintained from wind farms, fraction of flight paths through wind farm or not, number of birds seen within wind farm versus outside). Trying to capture these results in quantifiable and comparable measures requires a careful approach.

Subsequently, we related the results on avoidance behaviour to wind farm configuration. This analysis is also limited to a crude evaluation whether results point into a specific direction. A more quantitative and statistically substantiated analysis can only be carried out when the results permit this. In the results at hand, too much variation existed in the manner in which data were obtained to allow for such an analysis. In addition, effects of confounding factors, such as weather and changes in local populations due to factors unrelated to the wind farm, were too big to allow such an analysis.

2 Materials and methods

2.1 Available literature

With only a limited number of offshore wind farms worldwide, the number of studies carried out to date is also limited. We contacted several companies and institutions internationally, in order to obtain the relevant information, and to investigate whether any additional studies might be available which we were unaware of (table 2.1). This resulted in a list of wind farms for which relevant data were available and that are discussed in this review (table 2.2). Results are publicly available from offshore wind farms in Denmark, the Netherlands and Belgium. In addition, studies on the German offshore wind farm Alpha Ventus were in the process of being published, and the authors were so kind to provide us with the main conclusions (pers. comm. Stefan Garthe, University of Kiel). In the UK, ample research has been carried out to determine bird densities at future wind farms sites. It proved difficult to obtain results from actual UK wind farm sites, either because the studies have not been finalized yet or because results are not publicly available. In addition, UK studies focus on bird densities rather than flight behaviour, providing insight only in displacement effects.

2.2 Presentation of results

We summarized the results on avoidance and displacement behaviour in a table, where observed behaviours are listed per species and species group, as well as per country, and including information on wind farm configuration and type of research. This overview allowed us to identify similarities and dissimilarities in avoidance behaviour within the various species, as evident from the different studies. We present and discuss the overview of avoidance behaviour in chapter 3 of this report, while the underlying table with the summary of original observations is included in appendix 1.

Interpretation of behaviour (avoidance, attraction or indifference) is based on conclusions drawn in each of the reports. This is mostly textual information, substantiated with figures presented in text, tables or figures.

Table 2.1 Overview of parties that were approached for information on avoidance behaviour of birds around offshore wind farms, and/or of which reported results were used. Results indicated per country. Shown as well is the type of research carried out and the availability for this review.

country / affiliation / person	**type of observations**	**availability/relevance**
Denmark		
DMU; I.-K. Petersen	ship surveys Horns R/Nysted	displacement
	radar research Horns R/Nysted	avoidance
BioConsult SH, J. Blew (Germany)	radar research Horns R/Nysted	avoidance
Germany		
FTZ, Uni. Kiel; S. Garthe	ship surveys Alpha Ventus	displacement
	aerial surveys Alpha Ventus	displacement
Avitec; R. Aumüller / R. Hill	radar research Alpha Ventus	not applicable (flux+flight heights)
	visual obs. Alpha Ventus	not available (exp. summer 2014)
IBL Umweltplanung; H. Wendeln	radar research	not applicable (baseline)
IfAÖ, T. Coppack	radar research	not available
Norway		
NINA; R. May	no offshore wind farms and no data	
Belgium		
INBO; N. Vanermen	ship surveys	displacement
MUMM; R. Brabant	radar research	avoidance, not available
Netherlands		
IMARES; M. Leopold	ship surveys OWEZ	displacement
	ship surveys PAWP	displacement
Bureau Waardenburg; K. Krijgsveld	radar research OWEZ	avoidance
M.J.M Poot	aerial surveys NTW	not applicable (crude distribution)
United Kingdom		
BTO; A. Cook		
ECON; M. Perrow	observations Sheringham Shoals	not available (avoid. beh. terns)
USA		
West Inc. Env & Stat Consultants, C. Gordon; no data available		

Table 2.2 Overview of offshore wind farms that are discussed in this review report, listed by country.

country	wind farm	reference
Denmark	Horns Rev	Petersen *et al.* 2006
		Blew *et al.* 2008
	Nysted	Petersen *et al.* 2006
		Blew *et al.* 2008
Germany	Alpha Ventus	Mendel *et al.* 2014
Netherlands	OWEZ (Offshore Wind Egmond aan Zee)	Krijgsveld *et al.* 2011
		Leopold *et al.* 2011
	PAWP (Princess Amalia Wind Park)	Leopold *et al.* 2011
Belgium	Blighbank	Vanermen *et al.* 2013
	Thorntonbank	Vanermen *et al.* 2013
UK	Robin Rigg	Walls *et al.* 2013
	Kentish Flats	Percival 2010

3 Results

Information on whether species show avoidance or not could be obtained fairly easily from published documents. Data on the actual extent of avoidance (*i.e.* actual avoidance rates), however, was almost absent. Below we present an overview of avoidance behaviour of bird species at sea, as found in the literature. These data are then compared to show similarities and differences between studies.

3.1 General patterns in avoidance behaviour

Avoidance was measured using highly varying methodologies. Examples of these methods and the resulting information on avoidance are given in figures 3.1 (OWEZ) and 3.2 (Belgian offshore wind farms).

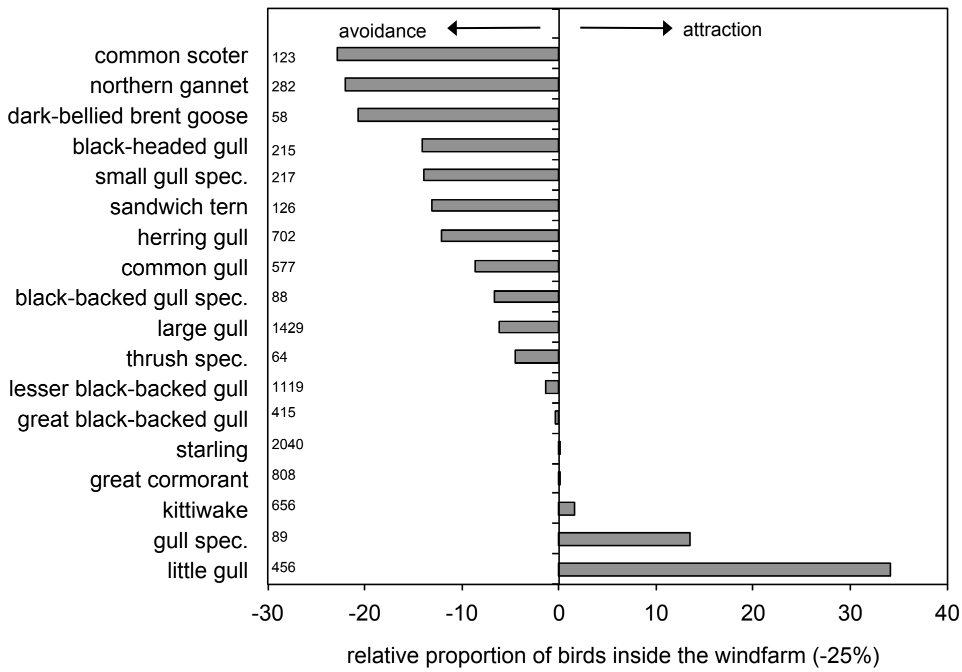

Figure 3.1 Overview of macro-avoidance per species, as measured at the Dutch Offshore Wind Farm Egmond aan Zee (OWEZ) by Krijgsveld et al. (2011, fig. 9.25 therein). Data reflect individual flight paths of birds, and were obtained through standardized visual observation techniques in combination with radar observations.

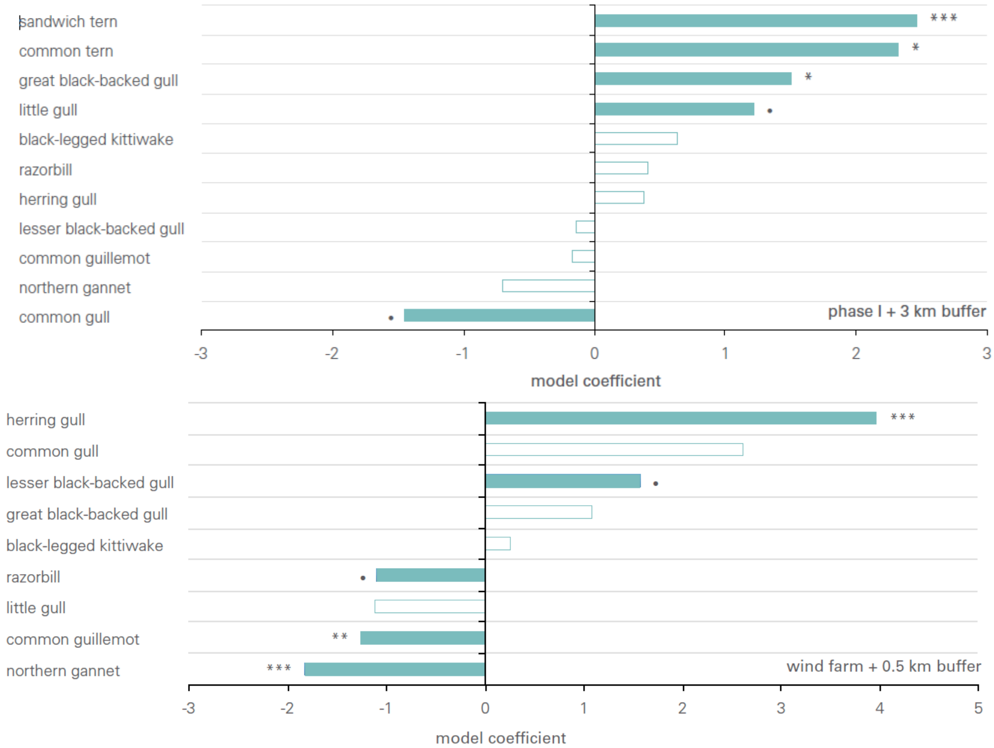

Figure 2.2 Overview of macro avoidance per species, as measured at Belgian offshore wind farms Thorntonbank (top) and Blighbank (bottom). Negative bars reflect avoidance, positive bars attraction; filled bars reflect significant results. (Figs 5 and 9 in ch. 5 by Vanermen et al.; in DeGraer et al. 2013.) Data reflect differences in densities, and were obtained through ship-based surveys.

Avoidance behaviour of the various species tends to be remarkably similar between studies. Overall, when grouping birds into the major species groups that have been observed at wind farms in the North Sea, the data reveal several fairly robust patterns (table 3.1). Seabirds such as divers, alcids, gannets and seaducks show avoidance of wind farms with very little exception. The four studies that report on cormorant behaviour report either attraction or indifference to wind farms. Gulls are mostly reported to be indifferent to wind farms or be attracted to them. The pattern in terns is less consistent (but see following paragraph). Migrating waterbirds and land birds varied in behaviour, showing both strong avoidance (geese) and indifference (raptors).

Table 3.1 Overview of avoidance behaviour for the main species groups encountered offshore. For each group the number of studies is shown that report avoidance (AV), attraction (ATT) or indifferent (I) behaviour (or mixes thereof) when passing offshore wind farms. Colour reflects the majority of studies, to lead the eye and show general trends; it does not reflect significance in any way. 'Other seabirds' concerns pelagic seabirds other than gulls, terns and cormorants.

	number of studies					
	AV	**AV/I**	**I**	**ATT/AV**	**ATT**	total
other seabirds	27	3	0	1	2	33
cormorants	0	0	1	0	3	4
gulls	5	0	21	1	11	38
terns	1	4	0	0	2	7
migrating landbirds	4	0	8	0	0	12

3.2 Observed patterns in individual species

Pelagic seabirds other than gulls

Within species groups, the similarity in behaviour towards wind farms was higher in some groups than in others (table 3.2). For example, most species in the group of 'other seabirds' consistently show avoidance of wind farms. All seven studies that present results on **divers** (mostly Red-throated Divers), report that these birds all strongly avoided flying into wind farms. The same is true for **Northern Gannets** (7 out of 7 studies report avoidance). For **Common Scoters**, three studies report that the species avoided flying into the wind farm (Nysted, OWEZ, Robin Rigg). In the fourth study, at Horns Rev, the same strong avoidance was observed, but here the scoters changed behaviour in later years due to food availability patterns, and at that time entered the wind farm area where food was abundant (Petersen *et al.* 2006, Petersen & Fox 2007). **Auks** strongly avoided wind farms as well in the majority of studies (8 studies out of 10 studies). Only at Thorntonbank in Belgium, Razorbills and Guillemots respectively either were attracted to or were indifferent to / avoided the wind farm, although these results were not significant. This concerned behaviour of birds foraging in the area, and may reflect birds drifting into the wind farm rather than their flight paths. Wintering Razorbills and Guillemots occurred in this area in medium densities and results thus reflect a considerable number of observations. At Blighbank, further offshore and in deeper Belgian waters, auks avoided the wind farm. The authors hypothesise that, similar to the scoters at Horns Rev, behaviour of the auks may well have been related to food availability in the area more than to wind farm presence (Vanermen *et al.* 2013). At OWEZ, despite overall avoidance, foraging guillemots on the water were regularly seen within the wind farm, and the observers suggest that avoidance at OWEZ may be relaxed compared to Horns Rev due to the relatively large spacing between turbines (Krijgsveld *et al.* 2011, Leopold *et al.* 2011).

Cormorants

Four studies report on the behaviour of **Great Cormorants**, three of which (OWEZ, PAWP, Robin Rigg) report attraction to wind farms (table 3.2), reflecting birds using the turbines as an outpost at sea, which they use to rest and dry their wings, and thus extend their foraging grounds further away from the shore. At Horns Rev Cormorants are reported to be indifferent to the wind farm. This is based on both foraging and migrating birds. At Horns Rev, flocks of migrating Cormorants tended to show a stronger response to wind farms than foraging birds, in that they were regularly seen to 'panic' before entering the wind farm (Petersen *et al.* 2006). This behaviour has not been reported from other sites.

Table 3.2 Overview for individual bird species of avoidance behaviour. Table similar to table 3.1 and based on the same data. For each species the number of studies is shown that report avoidance (AV), attraction (ATT) or indifferent (I) behaviour (or mixes thereof) when passing offshore wind farms. Colour reflects the majority of studies, to lead the eye and show general trends; it does not reflect significance in any way (shown only for species for which more than 1 study showed same type of behaviour). 'Other seabirds' concerns pelagic seabirds other than gulls, terns and cormorants.

			number of studies					
main group	**species group**	**species**	**AV**	**AV/I**	**I**	**ATT/AV**	**ATT**	**total**
other seabirds	divers	Red-throated Diver	2					2
		diver spec.	5					5
	tubenoses	Manx Shearwater	1					1
	gannets	Northern Gannet	7					7
	sea ducks	Eider		1				1
		Common Scoter	3			1		4
	other ducks	Long-Tailed Duck	1					1
		Red-breasted Merganser					1	1
	skuas	Arctic Skua		1				1
	alcids	Guillemot	3	1				4
		Razorbill	2				1	3
		Razorbill/Guillemot	3					3
cormorant	cormorants	Great Cormorant			1		3	4
gulls	large gulls	Herring Gull			4		2	6
		Lesser Black-backed Gull	1		3		1	5
		Great Black-backed Gull			3		3	6
		Black-backed Gull spec.			1			1
		large gull spec.			1		1	2
	smaller gulls	Black-headed Gull			1			1
		Common Gull	1		2		1	4
		Kittiwake	1		3		1	5
		small gull spec.			1			1
		Little Gull	2		1	1	2	6
	gulls	gull spec.			1			1
terns		Sandwich Tern	1	1			1	3
		Common Tern					1	1
		Common/Arctic Tern		1				1
		tern spec.		2				2
landbirds	geese	goose spec.	2					2
		Dark-bellied Brent Goose	1					1
	waders	wader spec.	1		1			2
	raptors & owls	Sparrowhawk			1			1
		raptors & owls			1			1
		Wood Pigeon			1			1
		songbird spec.			2			2
		thrush spec.			1			1
		Starling			1			1
		total	37	6	31	2	18	94

Larger gulls

In **gulls**, the response to wind farms is more diverse, although strong avoidance has not been reported from any site. The **larger gull species** tend to be indifferent to the wind farm, or even show increased densities at the wind farm sites, indicating attraction (table 3.2). The behaviour of this group of species around wind farms seems to be directed more by food availability than by the presence of the wind farm. They show little or no reluctance to enter the wind farm, based on flight behaviour (Horns Rev, OWEZ). Krijgsveld *et al.* 2005 showed that flight behaviour and abundance of gulls around the Dutch OWEZ wind farm were strongly associated with fishing vessels (70-80% of birds). This was true for both smaller and larger species, although results suggested that larger gulls were more often associated to fishing vessels than smaller species. Little Gulls were associated with fishing vessels to a far lesser extent. Only in one out of 18 studies was a species of larger gull shown to avoid the wind farm. This was the case for the Lesser Black-backed Gull, occurring in high densities at the German Alpha Ventus wind farm. Here, density of this species was significantly lower within the wind farm than in the control area outside the wind farm, although the number of actively feeding birds was similar within and outside the wind farm, while outside the wind farm most birds were resting and many were associated with fishing vessels.

Smaller gulls

The **smaller gull species** show more variation in behaviour towards the wind farms (table 3.2). Especially for Common Gull, Kittiwake and Little Gull, results vary between studies, showing both avoidance of, indifference and attraction to wind farms. The reason for the difference for Common Gulls between studies is unclear.

For **Kittiwakes**, three out of 5 studies reported kittiwakes being indifferent to the wind farms, and readily entering them (OWEZ, PAWP, Blighbank). At Thorntonbank (B) attraction was observed, in contrast to observations at Blighbank where densities were much higher (Vanermen *et al.* 2013). At Alpha Ventus, where kittiwakes are numerous, a strong decline in numbers was reported, suggesting possible avoidance (Mendel *et al.* 2014). However, only results reported by Leopold *et al.* (2011) were significant for this species.

For **Little Gull**, results are very dissimilar between studies. At all wind farm sites the species occurs as a migrant, passing the areas mainly in the spring months. Avoidance (non-significant) was observed in bird densities at Blighbank and at OWEZ and PAWP. At PAWP and OWEZ little gulls were not observed inside the wind farm (PAWP), or only at the fringes of it (OWEZ) during ship surveys (Leopold *et al.* 2011). Directed observations however of flight behaviour inside versus outside the OWEZ wind farm revealed that large flocks of little gulls would forage inside the wind farm (77% of birds seen inside the wind farm versus outside; 456 individuals in 66 flocks; Krijgsveld *et al.* 2011). The latter results suggest that little gulls were indifferent to the presence of the wind farm or were even attracted to it, and that low abundances of species in the area may easily lead to false interpretations of avoidance behaviour. At Horns Rev in Denmark, results were inconclusive. The percentage of little gulls inside the wind farm was lowest of all gulls (5%; Petersen *et al*. 2006), suggesting avoidance (not significant). Similarly, focal observations here showed that of over 1000 individuals, ca 30% flew inside Horns Rev wind farm, which was interpreted as significant avoidance (Blew *et al.* 2008). On the contrary, however, densities of little gulls in the wind farm area increased from the pre- to post-construction phase, suggesting preference for the wind farm area (non-significant due to low numbers; Petersen *et al.* 2006). Highest abundances of little gulls were observed at Alpha Ventus in Germany. Results for this site show no clear preference for or avoidance of the wind farm area (Mendel *et al.* 2014). Little gulls were regularly seen foraging inside the wind farm, and (large-scale) densities increased from pre- to post-construction phase, although highest densities were always observed at several kilometers distance from the wind farm.

Terns

Terns that were seen in the various wind farm areas are either sandwich terns, common terns or arctic terns, and occasionally black terns and little terns. Information on avoidance behaviour is available only for the more commonly occurring species. The patterns on tern behaviour is fairly consistent between sites. The birds seem to avoid the wind farm itself, but they do forage near the outer fringes of the wind farms. Such behaviour was observed both at Horns Rev, and at OWEZ (Petersen *et al.* 2006, Krijgsveld *et al.* 2011). Blew *et al.* (2008) report terns migrating close to but not inside the Horns Rev wind farm, Vanermen *et al*. (2013) report a significant relative increase in tern densities post-construction. Here, sandwich terns were regularly seen inside the Thorntonbank wind farm. At Blighbank, further offshore, terns were hardly seen at all. In conclusion, the terns generally tend to avoid offshore wind farms, but not strongly, and food availability inside the wind farm seems to lead them into the wind farm for foraging trips.

Migrating coastal birds and landbirds

Observations on avoidance behaviour of migrating species of coastal birds and landbirds mostly originate from radar studies (Blew *et al.* 2008, Krijgsveld *et al.* 2011). This is because these species are not accounted for in density surveys from vessels or aircraft, and occur in too low numbers to draw conclusions regarding differences in densities within versus outside wind farms. Individual flight paths as recorded with radar and/or visual observations do however reveal behavioural responses of this group to the wind farms.

Geese (greylag and brent) flying past OWEZ and Horns Rev all showed strong avoidance behaviour; with birds generally flying well around the wind farm, and above it when entering the wind farm area. Migrating flocks approaching the wind farm often 'panicked', losing formation and flying up and around in circles before regrouping and reorienting on a new route. This is a normal behaviour that is also regularly seen on land in relation to e.g., busy roads and highways. Occasional **swans** that were observed near the wind farms flew outside the wind farm and/or above turbine height.

Waders generally flew well above turbine height both at OWEZ and at Horns Rev. This was observed for a variety of species. Birds that did fly at turbine height, showed little or no deflection (e.g., Curlews increasing altitude; Blew *et al*. 2008, birds entering wind farm where turbines were standing still; Krijgsveld *et al.* 2011)

Raptors that were observed in the OWEZ and Horns Rev wind farms, showed little behavioural response to the wind farms, showing flight paths into the wind farms at turbine height. Species observed were Sparrowhawk, Goshawk, Marsh Harrier, Hen Harrier, Kestrel, Merlin, and Peregrine Falcon. At OWEZ, a Peregrine Falcon was repeatedly seen perched on the metmast and on the turbines, from where it hunted migrating songbirds.

The majority of **passerines** flew above turbine height. Under adverse weather conditions birds would fly at lower altitudes. Among birds flying at turbine height, birds avoiding the wind farm were observed as well as birds showing no (macro-) avoidance. No clear patterns were distinguishable, but overall, avoidance seemed less explicit than in other species such as seabirds and geese. Avoidance was higher at night than during daytime, both at OWEZ and at Horns Rev, and strong micro-avoidance was regularly observed.

3.2 Effect of configuration

Information on flight behaviour of birds around offshore wind farms is obtained through highly varying methods. Although this has yielded useful information on avoidance behaviour for each wind farm, the variation in methods means that it is difficult if not impossible to compare results between wind farms. This is because avoidance is quantified in different ways in all wind farms. The largest difference is between changes in densities through ship surveys and changes in flight routes through radar and visual observations. Changes in flight paths cannot be compared quantitatively with changed in densities. In addition, the effect a wind farm has on distribution of birds often is difficult to interpret, because density changes are related to a myriad of factors (e.g., weather, population changes unrelated to the presence of the wind farm) and often show too much fluctuation to define an effect of the presence of the wind farm. On top of this, the number of studies that report on avoidance behaviour is still very limited, and hence few data are available from wind farms with substantially different configurations, in otherwise similar circumstances and observation protocols. All of this means that an effect of configuration of a wind farm on behavioural responses of birds cannot be obtained from the information presented above, at least not in the sense of a quantitative analysis of avoidance rates with respect to factors such as wind farm size or turbine spacing. What is possible is an anecdotal comparison of observations that relate to wind farm configuration. These observations are provided below.

With respect to wind farm configuration, no differences are evident between the wind farms in avoidance behaviour. At the wind farms where turbines are spaced most closely together (see table 3.3), avoidance behaviour is not reported to be stronger or more significant than at wind farms where turbine spacing is larger.

Table 3.3 Configuration of offshore wind farms for which avoidance information is available. Wind farms ordered by increasing distance between turbines. Two distance values represent distance within versus between turbine rows.

country	wind farm	distance turbines (m)	nr turbines	surface covered (km^2)	total height turbine (m)
UK	Robin Rigg	500	60	18	125
NL	PAWP	550	60	14	99
DK	Horns Rev	560	80	20	110
BE	Blighbank	450/650	55	18	134
UK	Kentish Flats	700	30	10	115
DK	Nysted	480/850	72	24	110
BE	Thorntonbank	600/850	54	20	157
D	Alpha Ventus	800	12	4	153
NL	OWEZ	650/1000	36	27	115

At both Horns Rev and OWEZ behavioural responses of individual birds were recorded. Despite a considerable difference in turbine spacing, general patterns on avoidance behaviour are the same between the two wind farms. The percentage of birds that was seen inside the wind farm however was higher in OWEZ than in Horns Rev for eight species, while this percentage was higher in Horns Rev for only two species (Common Scoter and Herring Gull; Scoters entered the Horns Rev wind farm driven by high local availability of food, while at OWEZ Scoters were present in low abundancies and the wind farm was not suitable as foraging area). The fact that for eight out of ten bird species the proportion of birds avoiding Horns Rev was higher, could suggest that the avoidance rate was higher in Horns Rev, where turbines were spaced more closely together, than in OWEZ. The comparison however would have to be expanded with information from other wind farms and the data would have to be made more comparable (e.g. calculation of percentage inside), before solid conclusions can be drawn.

Other comparisons on the effect of wind farm configuration all originate from the observations on OWEZ and nearby PAWP in the Netherlands. Ship surveys by Leopold *et al.* (2011) covered both PAWP and OWEZ, allowing comparisons between the two wind farms. In general, relative densities in PAWP were lower than in OWEZ. This could well be related to configuration effects. For instance, although divers were occasionally seen flying through OWEZ, only one observation was made of divers flying through PAWP. This concerned two birds that entered the wind farm after some hesitation, there where turbines were spaced somewhat further apart from their flight perspective. For guillemots, an analysis of the distribution of birds sitting on the water suggested that PAWP (as well as the anchorage area of IJmuiden) had a larger deterring effect on the birds than OWEZ. For kittiwakes, results suggest that the number of birds observed within PAWP may possibly have been slightly lower than the number observed within OWEZ, which could reflect an effect of turbine density. Similarly, at PAWP Little Gulls were never seen feeding inside the wind farm during ship surveys. At OWEZ Little Gulls were seen inside the wind farm although always only at the fringes (contrary to visual focal observations, see §3.2).

Table 3.4 Percentage of birds observed within Horns Rev (HR) and OWEZ wind farms (WF). Shown as well are the total numbers of individuals or flocks observed. Percentages are corrected for differences in observed surface volume inside and outside the wind farm area.

			% inside WF		nr flocks		nr individuals	
main group	**species group**	**species**	**HR**	**OWEZ**	**HR**	**OWEZ**	**HR**	**OWEZ**
seabirds	divers	diver spec.	0		16		61	
	gannets	Northern Gannet	0	7	126		268	282
	sea ducks	Common Scoter	11	5	288		2379	123
	skuas	Arctic Skua	24		150			
	alcids	Razorbill/Guillemot	4		82			
cormorant	cormorants	Great Cormorant	30	48	20			808
gulls	large gulls	Herring Gull	53	35			1851	702
		Lesser Bl-b Gull	38	49				1119
		Great Bl-b Gull	38	48			1160	415
		Bl-b Gull spec.		41				88
		large gull spec.		35				1429
	smaller gulls	Black-headed Gull		31				215
		Common Gull	38	44				577
		Kittiwake	31	56			1002	656
		Little Gull	5	77			1196	456
		small gull spec.		21				217
	gulls	gull spec.	24	69	461		1254	89
terns	terns	Sandwich Tern		33				126
		tern spec.	42		104			
landbirds	geese & swans	goose spec.	21		19			
		Brent Goose		19				58
	other ducks	other ducks						
	waders	wader spec.	11		87			
	landbirds	Wood Pigeon	29		7		1145	
		thrush spec.		38				64
		Starling		52				2040
overall %			23	35				

Krijgsveld *et al*. (2011) observed differences in avoidance behaviour within the OWEZ wind farm. They analysed that the number of bird tracks was significantly higher in the area of the wind farm where turbine spacing was largest. In addition, birds were sensitive to the turbines being operational or idle. The number of tracks was two to three times higher when the nearest turbine was idling than when it was operational. Similarly, birds showed less avoidance of the single line of turbines in the northwestern corner of the wind farm than of the main body of the wind farm.

These results suggest that spacing of the turbines within a wind farm likely has a considerable effect on avoidance behaviour of birds, and that through careful design of wind farms birds can for instance be led along flight paths through a wind farm or held away from a wind farm.

4 Conclusions and recommendations

4.1 Conclusions

Similarities and differences in avoidance behaviour
The available studies on bird densities or bird behaviour at offshore wind farms show fairly strong consistencies within species groups or species in avoidance behaviour towards the wind farms or turbines. Pelagic seabirds such as gannets, divers and alcids flying in the vicinity of offshore wind farms consistently show strong avoidance behaviour, with only a few exceptions. These exceptions seem to occur when food availability in the specific wind farm is high, and birds enter the wind farm to exploit those food resources. The gulls show more variation in avoidance behaviour. The larger gulls species show indifference or even attraction almost without exception, but results for the smaller species show more variation, and no consistent patterns were observed for the individual species in this group. The variation may originate from differences in study methods in combination with low bird abundancies.

Effects of wind farm configuration
No research has been done regarding effects of wind farm configuration on avoidance behaviour, and therefore no solid interpretations can be made. Information on this topic is anecdotal and based on simultaneous density surveys in PAWP and OWEZ by Leopold *et al.* (2011), on analysis of flight path distribution in OWEZ by Krijgsveld *et al.* (2011) and on a qualitative comparison between Horns Rev and OWEZ wind farms carried out in the report at hand. The results indicate that spacing of turbines within a wind farm likely has a considerable effect on avoidance behaviour of birds. Avoidance seems to be lower in wind farms where turbines are spaced more widely, and birds flying within wind farms seem to prefer flying in areas where spacing between turbines is larger or where rotors are idle. This means that through careful design of wind farms effects on birds can potentially be reduced. For instance, a major flight route of a bird species can potentially be maintained by designing a corridor through a wind farm with the right orientation, and barrier effects can be prevented by allowing sufficient spacing between wind farms. Whether spacing can effectively reduce collision rates will remain unknown until actual numbers of victims can be measured and until an effect of turbine position and spacing can be analysed. Similarly, more insight in species-specific avoidance rates is required to assess (cumulative) barrier effects and the extent to which corridors can prevent these.

Methods of measuring avoidance behaviour
Accurate quantification of species-specific avoidance rates is crucial for a reliable assessment of offshore wind energy on bird populations. This is especially the case because to date collision rates of birds with offshore wind turbines are determined not through actual measurements of collisions but through collision rate models, which rely heavily on avoidance rates. Given this importance of avoidance rates, it is remarkable that so few measurements of actual avoidance rates exist. The reason behind this seems to be that most bird studies on the effects of offshore wind farms

focus on bird densities and changes therein. The aim of these studies is to measure population effects, which is a valid aspect of potential effects. These displacement studies however do not provide quantitative data on avoidance rates, which are urgently needed in collision rate modelling. Secondly, the authors of the various studies on densities and displacement report that differences in observed densities are difficult to interpret, because they may reflect changes in large-scale patterns rather than effects of the wind farms. Few studies follow a well-designed BACI-protocol (Before-After-Control-Impact), which allows a separation between larger-scale population effects and wind farm effects. The Belgian study is a good example of how a BACI-design can help identify actual wind farm effects (Vanermen *et al.* 2013). But even when following a well-designed protocol, it has proven to be difficult to draw significant conclusions on wind farm effects. Variation in densities is large (seasonal and year-to-year variation, patchiness of bird distribution), making it difficult to assign changes in distribution patterns to wind farms.

Observations of individual flight paths of birds, by means of visual and/or radar observations, provide a more direct assessment of behavioural response of birds to wind farms, but such results are only available from three wind farms (Horns Rev, Nysted, OWEZ). Again, study design is important to enable unbiased collection of data on flight paths (c.f. proportion of birds entering wind farm, or adjusting flight paths). Issues with these types of studies are that visually, bird flight paths may not be traceable over long enough distances from the wind farm or underestimate the proportion of birds flying at higher altitudes (as shown by Hartman *et al* 2012) and that radar observations do not (yet) allow identification of flight paths to species level.

4.2 Recommendations

- To be able to assess the occurrence of barrier effects of offshore wind farms on birds, and the extent of these barrier effects, more information is required on species-specific avoidance rates. This is especially relevant in the light of potential North Sea-wide cumulative effects.
- To improve collision rate models and therewith provide a more accurate prediction of the number of collision victims among birds, more field data on avoidance rates (macro and micro) are required. Currently, information on avoidance rates is limited, and exact values are unavailable. A protocol with standardised visual observations would serve best to obtain these data. Obtaining such data is likely to result in a reduction of the estimated collision rates well below the currently estimated rates. This is due to the fact that the currently used worst case scenarios are based on rather crude estimates of avoidance rates. When more actual data on avoidance rates and collision risks are available, less worst case assumptions have to be made.
- Further quantitative analysis of existing data would improve estimates from collision rate models. This would be possible for instance for available data on flight heights in relation to wind farms.

- To allow effects of wind farm configuration to be included in collision risk models and in Environmental Impact Assessments, more quantitative information is needed on the relationship between avoidance rates and wind farm configuration. Whether spacing can effectively reduce the number of collision will remain unknown until actual collision victims can be measured, and until an effect of turbine position and spacing can be analysed.

5 Literature

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Appendix 1

Data underlying this report

country	wind farm	species	abundance in area	change abundance	general avoidance behaviour	significance	min distance to WF (km)	nr within WF	% within WF	nr observed (individuals)	nr observed (flocks)
UK	Robin Rigg	Red-throated Diver	low		AV	NS					
UK	Kentish Flats	Red-throated Diver	medium		AV		0,5				
Germany	Alpha Ventus	diver spec.	low	no change	AV		1,1	0	0		
Denmark	Horns Rev	diver spec.			AV	S	2	almost never	0	61	16
Denmark	Nysted	diver spec.	low	no change	AV	NS	2				
Netherlands	OWEZ	diver spec.	low		AV		0,6		0	?	
Netherlands	PAWP/OWEZ	diver spec.	low		AV	NS		occasionally			
Netherlands	PAWP/OWEZ	Great Crested Grebe	very low								
Netherlands	OWEZ	Northern Fulmar	very low				0,2			?	
Netherlands	PAWP/OWEZ	Northern Fulmar	very low								
Belgium	Thorntonbank	Northern Fulmar	low								
Belgium	Blighbank	Northern Fulmar	low								
UK	Robin Rigg	Manx Shearwater	low		AV	NS					
Germany	Alpha Ventus	Northern Gannet	very low	decrease	AV		1	0	0		
Denmark	Horns Rev	Northern Gannet	low	no change	AV	S/NS	4	almost never	0	268	126
Netherlands	OWEZ	Northern Gannet	medium		AV		0,5		7	282	
Netherlands	PAWP/OWEZ	Northern Gannet	medium		AV	NS					
Belgium	Thorntonbank	Northern Gannet	medium		AV	NS		2			
Belgium	Blighbank	Northern Gannet	low		AV	S		18			
UK	Robin Rigg	Northern Gannet	low	decrease	AV	NS					
Belgium	Thorntonbank	Great Cormorant	low					10			
Denmark	Nysted	Eider	high	no change	I/AV	S	2				
Denmark	Horns Rev	Common Scoter		increase	ATT/AV	NS		rarely	3	2379	288
Denmark	Nysted	Common Scoter	low		AV	NS	4				
Netherlands	OWEZ	Common Scoter	low		AV		0,6		5	123	
Netherlands	PAWP/OWEZ	Common Scoter	low								
UK	Robin Rigg	Common Scoter		no change	AV	NS					
Denmark	Nysted	Long-Tailed Duck	high	increase	AV	S	2				
Denmark	Nysted	Red-breasted Merganser		no change	ATT	S					
Belgium	Thorntonbank	Great Skua	low					2			
Belgium	Blighbank	Great Skua	low								
Denmark	Horns Rev	Arctic Skua			I/AV	NS		a few	24		150
Germany	Alpha Ventus	Guillemot	?	sign decrease	AV		0	a few	-		
Netherlands	PAWP/OWEZ	Guillemot	high		AV	S					
Belgium	Thorntonbank	Guillemot	medium		I/AV	NS		21			
Belgium	Blighbank	Guillemot	medium		AV	S		61			
Netherlands	PAWP/OWEZ	Razorbill	medium		AV	S					
Belgium	Thorntonbank	Razorbill	medium		ATT	NS		44			
Belgium	Blighbank	Razorbill	low		AV	S		59			
Denmark	Horns Rev	Razorbill/Guillemot	medium		AV		4		4		82
Netherlands	OWEZ	Razorbill/Guillemot	low		AV		0,4		0	?	
Belgium	Thorntonbank	Razorbill/Guillemot	medium					12			
Belgium	Blighbank	Razorbill/Guillemot	medium					18			
UK	Robin Rigg	Razorbill/Guillemot			AV	NS					
Denmark	Horns Rev	Great Cormorant			I				30		20
Denmark	Nysted	Great Cormorant									
Netherlands	OWEZ	Great Cormorant	high		ATT		0,2		48	808	
Netherlands	PAWP/OWEZ	Great Cormorant	high		ATT	S					
Belgium	Blighbank	Great Cormorant	low								
UK	Robin Rigg	Great Cormorant		increase	ATT	S					
Denmark	Horns Rev	Herring Gull		no change	I	S			53,3	1851	
Denmark	Nysted	Herring Gull	high	no change	I	S		regularly			
Netherlands	OWEZ	Herring Gull	high		I				35	702	
Netherlands	PAWP/OWEZ	Herring Gull	high		I	NS					
Belgium	Thorntonbank	Herring Gull	low		ATT	NS		11			
Belgium	Blighbank	Herring Gull	low		ATT	S		193			
Germany	Alpha Ventus	Lesser Black-backed Gull	high	sign decrease	AV		0	regularly	10,4		
Denmark	Horns Rev	Lesser Black-backed Gull							37,9		
Netherlands	OWEZ	Lesser Black-backed Gull	high		I				49	1119	
Netherlands	PAWP/OWEZ	Lesser Black-backed Gull	high		I	S					
Belgium	Thorntonbank	Lesser Black-backed Gull	high		I	NS		178			
Belgium	Blighbank	Lesser Black-backed Gull	low		ATT	S		278			
Denmark	Horns Rev	Great Black-backed Gull			I				37,6	1160	
Netherlands	OWEZ	Great Black-backed Gull	medium		I				48	415	
Netherlands	PAWP/OWEZ	Great Black-backed Gull	medium		I	NS					
Belgium	Thorntonbank	Great Black-backed Gull	medium		ATT	S		24			
Belgium	Blighbank	Great Black-backed Gull	low		ATT	NS		151			
UK	Robin Rigg	Great Black-backed Gull		increase	ATT	S					
Netherlands	OWEZ	Black-backed Gull spec.	medium		I				41	88	
Netherlands	OWEZ	large gull spec.	high		I				35	1429	
UK	Robin Rigg	large gull spec.			ATT	S					

country	wind farm	species	abundance in area	change abundance	general avoidance behaviour	significance	min distance to WF (km)	nr within WF	% within WF	nr observed (individuals)	nr observed (flocks)
Netherlands	OWEZ	Black-headed Gull	low		I				31	215	
Netherlands	PAWP/OWEZ	Black-headed Gull	low								
Denmark	Horns Rev	Common Gull							37,7		
Netherlands	OWEZ	Common Gull	medium		I				44	577	
Netherlands	PAWP/OWEZ	Common Gull	medium		I	NS					
Belgium	Thorntonbank	Common Gull	medium		AV	S		40			
Belgium	Blighbank	Common Gull	low		ATT	NS		1564			
Germany	Alpha Ventus	Kittiwake		decrease	AV		0	a few	-		
Denmark	Horns Rev	Kittiwake							31	1002	
Netherlands	OWEZ	Kittiwake	low		I				56	656	
Netherlands	PAWP/OWEZ	Kittiwake	low		I	S					
Belgium	Thorntonbank	Kittiwake	medium		ATT	NS		25			
Belgium	Blighbank	Kittiwake	medium		I	NS		711			
UK	Robin Rigg	Kittiwake									
Germany	Alpha Ventus	Little Gull	high	increase	I		0	regularly	-		
Denmark	Horns Rev	Little Gull		increase	ATT/AV				5	1196	
Netherlands	OWEZ	Little Gull	low		ATT				77	456	
Netherlands	PAWP/OWEZ	Little Gull	low		AV	NS					
Belgium	Thorntonbank	Little Gull	low		ATT	S		14			
Belgium	Blighbank	Little Gull	low		AV	NS					
Netherlands	OWEZ	small gull spec.	medium		I				21	217	
Denmark	Horns Rev	gull spec.							24	1254	461
Netherlands	OWEZ	gull spec.	medium		I		0,3		69	89	
Netherlands	OWEZ	Sandwich Tern	low		I/AV				33	126	
Netherlands	PAWP/OWEZ	Sandwich Tern	low		AV	NS					
Belgium	Thorntonbank	Sandwich Tern	low		ATT	S		75			
Belgium	Blighbank	Sandwich Tern	low					4			
Belgium	Thorntonbank	Common Tern	low		ATT	S					
Denmark	Horns Rev	Common/Arctic Tern			I/AV	NS	0	edges only			
Netherlands	PAWP/OWEZ	Common/Arctic Tern	low								
Belgium	Blighbank	Common/Arctic Tern	low								
Denmark	Horns Rev	tern spec.			I/AV				24-42	855	104
Netherlands	OWEZ	tern spec.	low		I/AV		0,3				
Denmark	Horns Rev	goose spec.			AV				21		19
Netherlands	OWEZ	goose spec.	low		AV		0,5				
Netherlands	OWEZ	Dark-bellied Brent Goose	low		AV				19	58	
Netherlands	OWEZ	other ducks					0,4				
Denmark	Horns Rev	wader spec.			I				11		87
Netherlands	OWEZ	wader spec.			AV	NS	0,3				
Denmark	Nysted	Sparrowhawk			I			43	80	54	
Netherlands	OWEZ	raptors & owls			I	NS	0,5				
Denmark	Horns Rev	Wood Pigeon			I	NS			29	1145	7
Netherlands	OWEZ	large landbirds					0,3				
Netherlands	OWEZ	thrush spec.	medum		I				38	64	
Netherlands	OWEZ	Starling	medium		I				52	2040	
Denmark	Horns Rev	songbird spec.			I						
Denmark	Horns Rev	songbird spec.			I						

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