Seabirds? What seabirds?

An exploratory study into the origin of seabirds visiting the SE North Sea and their survival bottlenecks

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Contents

Summary

This report summarises existing data on seabird tracking devices: classic steel rings, which mostly only get read at deployment and once the bird is found dead; colour rings, which can be read and reported more often, but which are rarely read at sea; and telemetric tracking devices such as GPS loggers, which enable following birds in great detail, also at sea. Seabirds, being long-lived, numerous and easily accessible (in breeding colonies) have long been popular for ringing studies. For most species relevant to offshore wind farm development, ringing data exist that can be used to learn more about yearly and age-related survival. However, it will be difficult, with only two data points per ring (date and place of deployment and of the bird's death) to relate these to offshore wind farms, which do not cause many birds to die in sharply defined incidents (such as major oil spills do). Colour ringing schemes, such as already used in large gulls for many years, and in Sandwich Tern for a shorter, but growing number of years, yield more possibilities to learn more about the survival (or mortality) of within-species groups of birds. GPS loggers provide the best data of seabirds' usage of the open sea, including offshore wind farm areas. Many birds have already been equipped with such loggers, but mostly at relatively large distances from offshore wind farms. Specific tagging programmes related to offshore wind farms are rare, the best data probably are now collected on Helgoland.

Several possible next steps forward are identified. Detailed analyses of existing colour ringing data would be a first logical step. Colour ringing and GPS-tracking of birds in colonies closest to existing and planned offshore wind farms is advisable, as this will increase the probability that the most relevant birds (those that actually make use of offshore wind farm areas) are being tagged, rather than random birds, of which many will go elsewhere. A final and, for the Netherlands new, approach would be to catch birds directly at sea for tagging, in or near wind farm areas. This would greatly increase the usefulness of tagging data and our understanding of seabird movement around and through our offshore wind farms.

1 Background

The North Sea is crucial for the survival of a range of seabirds, that breed on its shorelines or further away, feed here, go through their annual moult(s) here, use it as a migration corridor or refuelling station and/or winter here. While the North Sea comprises vast wild and open spaces, the seabirds are far from alone at sea, and must share this habitat with other species, including man. Human usage of the marine environment has been increasing. Over the centuries, seabirds have suffered from interference with several forms of human usage of the seas and the coastlines, such as direct harvesting of eggs, chicks and breeders in colonies, habitat destruction (mostly on land and in wetlands), (over)fishing, fisheries bycatches, debris (entanglement, plastic ingestion), marine pollution (oil, mostly, but also other substances discharged directly at sea or running off from land), shipping (disturbance), and recently, the development of offshore wind harvesting. On the other hand, seabirds have also benefitted from human activities, such as protective measures, both in colonies and in MPAs, extra food in the form of fisheries discards and removal of competition for forage fish by larger predatory fish, the targets of many fisheries.

The Dutch government is committed to a large-scale development of renewable energy sources, including offshore wind energy. Several offshore wind farms are already operational, and many more such wind farms are under construction or will be built in the years and decades to come (Leopold *et al*. 2014). Tall, rotating, man-made structures are new in the marine environment and marine wildlife, such as seabirds, will need to cope with these. As seabirds are protected animals, it is important to understand the nature and magnitude of impacts that offshore wind farms might have and how seabirds respond to them. It is also important to know how, when and where seabird population sizes might be limited. If population sizes are limited by e.g. the available breeding space, or by survival in wintering quarters outside the North Sea, offshore wind farms are less likely to play a crucial role in population development. If on the other hand, survival in the southern North Sea, where offshore wind farms will be developed in large numbers in the coming decades, is crucial, extra pressures within this realm may have far-reaching effects on populations of seabirds from a wide geographical range in terms of breeding distribution. Knowledge of the importance of the southern North Sea for seabird populations is therefore important for governments in charge of regulating this development.

In the Netherlands, the Ministry of Economic Affairs and the Ministry of Infrastructure and Environment (represented by "Rijkswaterstaat") are responsible for the spatial planning and the conditions for construction (through licencing), as well as for the management of the man-made infrastructure facilities in the Dutch part of the North Sea. The economic development, including transition of the economy into a more sustainable modus, as well as nature protection, are the responsibility of the Ministry of Economic Affairs. These two ministries have taken the initiative to conduct effect studies of offshore wind farms on marine life, including seabirds, from the onset of offshore wind farm development in the country. This has now led to a wider "Wind Op Zee Ecologisch Programma (WOZEP, translated: *Wind At Sea Ecological Programme*) that will run from 2016 to 2021. One of the preliminary studies within this programme is a review of the knowledge of spatio-temporal survival of seabirds in relation to offshore wind farm development. In this desk study, we aim to identify ways and means to examine seabird survival throughout their yearly cycle, in order to understand better if and how offshore wind farms might interfere with this and try to identify the crucial parameters of habitat use and population dynamics that can enable us to make reliable predictions.

2 Introduction

Seabirds are typically long-lived, slowly reproducing (k-selected) species, with low adult mortality and with population sizes that respond only slowly to detrimental developments (Lack 1954, 1966, 1967; Cairns 1992). In fact, a human pressure such as oil pollution, which has caused large numbers of casualties among North Sea seabirds for decades and significantly decreased adult winter survival (Votier *et al*. 2005), was counteracted by better protection of colonies and a better food supply at sea and the net result was a significant growth of population sizes of many North Sea seabirds in the second half of the last century (Lloyd *et al*. 1991; Mitchell *et al.* 2004). Therefore, there is always a balance between factors that enhance breeding output or survival and factors that do the opposite, but population development may be slow to respond and affected populations may breed far away from the single pressure one might be interested in. This makes it hard to evaluate the effect of a single human-induced pressure, because other, e.g. environmental factors may be more important; or because non-breeders may recruit into the population at a higher rate, buffering adult mortality; or because the majority of birds killed may be immature (which will not immediately affect numbers of breeding pairs); or simply because available census data are inadequate to detect population changes (Votier *et al*. 2005).

The most directly measurable effects of a specific pressure are probably those that affect a particular, local part of the population. For instance, mortality from drowning in fishing gear may have significant effects on a given colony of seabirds, if the nets are set in close proximity of that colony (Zydelis *et al*. 2013). Wind turbines, placed in the immediate vicinity of breeding seabirds, may cause significant colony-specific mortality of breeders (Stienen *et al.* 2008). In contrast, mortality from offshore oil spills, offshore gill-netting or offshore wind farms may affect birds stemming from a large geographical breeding area and effects on any one specific breeding colony within that area may be small and will not be readily detected.

If we consider offshore wind farms in this light, it becomes clear that a wind farm is most likely to affect seabirds in a significant manner if it either affects many seabirds from a large geographical area, or fewer birds from a smaller area, such as one particular colony. A wind farm placed within the feeding range of a seabird colony might impact the birds operating from that colony but not others from neighbouring colonies, if inter-colony feeding ranges do not overlap. In the non-breeding season birds from different colonies may mix more freely at the high seas, but little is yet known about colony-specific dispersal and migration patterns outside the breeding season. The aim of this study is to identify data or promising research possibilities to shed some light on these dispersal patterns of seabirds and, linked to these, survival bottlenecks.

In this report, three main research questions are addressed, regarding seabird species considered most at risk from offshore wind farm development:

1. What is the origin (breeding colony) of birds present in specific offshore wind farms or in broader areas designated for offshore wind development?
2. How do birds behave in response to offshore wind farms?
3. What are survival bottlenecks of seabirds commonly occurring in areas designated for offshore wind development? Are these bottlenecks geographically and temporarily linked to their usage of these areas and if so, what population segment is most affected?

Practical ways and means to address these questions in the context of WOZEP are explored for all species considered relevant in this context.

2.1 Not all seabirds are equal

Different species of seabirds tend to have different at-sea distributions and local pressures may thus affect species in various ways. Differences in geographical or spatio-temporal habitat use may also exist within species. Systematic seawatching for instance, has indicated that male Common Scoters *Melanitta nigra* arrive earlier in Dutch coastal waters than the females that first must attend their fledglings in the breeding areas (Camphuysen & van Dijk 1983). Black-legged Kittiwakes *Rissa tridactyla* that were unsuccessful as breeders, were found to leave the colony earlier than successful breeders and move to more distant wintering grounds (Bogdanova *et al*. 2011). Male Lesser Black-backed Gulls *Larus fuscus* breeding on Texel tend to forage much more in the North Sea than their female conspecifics (Camphuysen *et al*. 2015) and more so on week-days than in weekends (Tyson *et al*. 2015). Common Guillemots *Uria aalge* breeding in different colonies around the British Isles tend to winter in different areas of sea, and the same applies to birds of different age classes. In many such cases, however, there is a considerable overlap of wintering ranges of the various groups of birds (Wernham *et al*. 2002; Grantham 2004). Even at the scale of the Dutch coastline, a cline in the ratio adult:juvenile birds was found among oiled, stranded Common Guillemots from north to south (Camphuysen & Leopold 2004; see Figure 1), with higher proportions of adults in the south. As it is generally believed that a mass mortality event affecting mostly adults within a population will have a more severe effect on the population than an event affecting mostly juveniles (that tend to have a higher mortality in any case), the same pressure (e.g. from an oil spill or from an offshore wind farm) may have different population effects in different locations. Effects on the population size are probably largest, if the most "valuable" part of the population is affected, i.e. the adult, breeding birds. In general, effects of human pressures at sea may thus be most severe if these act close to breeding colonies in the breeding season, or in areas where large numbers of adult birds concentrate in the non-breeding season.

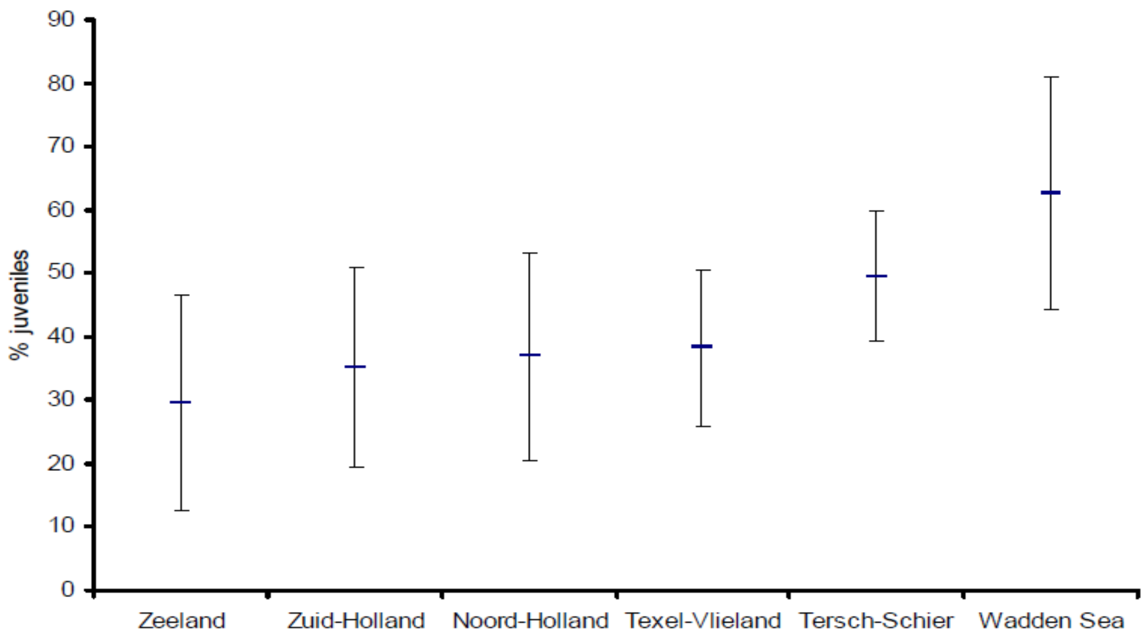

Figure 1 *Mean (± SD) proportion of juvenile (first winter) Common Guillemots among birds found dead in winter (Nov-Apr) along different sections of the Dutch coastline (from S➔N: left to right along the X-axis).*

3 Methods

For the seabird species considered most relevant to offshore wind farms in the southern North Sea (as identified by Leopold *et al*. 2014), the existing scientific literature was reviewed. More specifically, studies on survival, dispersal and migration, using a variety of techniques such as ringing, colour ringing, and telemetric tracking, were reviewed. "Migration Atlases" from all North Sea countries were screened for relevant information on presumed source populations of seabirds wintering in, or migrating through, the southern North Sea. For species for which currently a lot of relevant studies are under way, i.e. not yet published, two principal investigators in the eastern North Sea (Prof Dr Stefan Garthe and Dr Kees Camphuysen) were interviewed to learn more on the most recent avenues of research. The possibilities of using colour ringing programmes, which typically only yield sightings (records) of seabirds while these are on land, were discussed with another expert in the field, Dr Tamar Lok. The possibilities of catching seabirds at sea, in wind farm areas, in order to be able to conduct telemetric tagging studies of the birds most relevant, have been discussed with Dr Ib Krag Petersen and with Dr Ramunas Zydelis.

3.1 Ways and means to study seabird movement and survival

The effects of a specific human-induced mortality, such as the effects of an oil spill (Votier *et al*. (2005), or of habitat degradation in a specific part of their range (Lok *et al*. 2015; Piersma *et al*. (2015) can be modelled if sufficient data are available for the impacted population. Ideally, large numbers of individually marked birds are followed over their entire life, either through electronic tagging or by applying permanent marks that can be read from a distance, such as colour rings, or by standard, steel rings. Electronic tags give the highest resolution on the level of the individual, but numbers of individuals that can be tagged are usually comparatively low. Colour rings have been used on larger numbers of individuals, but "recaptures" are mainly made by observers on land and therefore have relatively little bearing on the marine distribution of seabirds. Classic steel rings have been used on the largest numbers of birds, but these give even less information at the individual level, as recoveries are mostly made only once, after the bird has died and, in the case of seabirds, after their corpses have washed ashore somewhere.

3.1.1 Classic ringing

Seabirds have been ringed in large numbers for many decades. Colonial seabirds in particular, have been ringed in large numbers, often early in life, as chicks, which makes it possible to follow these birds over their entire life, provided that rings are used that are as long-lived as the birds themselves. Overviews of ringing results have recently been published in many countries around the North Sea (UK, Norway, Denmark, Helgoland, Germany) and beyond (Sweden, Finland, Faroe Islands, the Barents Sea region, Greenland): places of origin of many seabirds that move through the southern North Sea in the non-breeding season. The Netherlands are somewhat lagging behind in this respect, with the most recent ringing atlas being published in 1984, by Speek & Speek. However, work on a new, up to date atlas is currently under way and analyses of ringing (and of colour-ringing and electronical tagging) of seabirds have also been published recently on relevant species.

3.1.2 Colour ringing

Most of the species of seabirds that breed in The Netherlands which are relevant to offshore wind farms have been colour ringed in some coastal colonies. Migration and dispersal patterns, as far as these can be followed from land-based re-sightings of colour rings, and parameters such as annual survival, site-fidelity and recruitment are thus becoming increasingly better known. Lesser Black-backed Gulls and Herring Gulls *Larus argentatus* have been colour-ringed in various colonies in The Netherlands since 1986 (Camphuysen 2008; Camphuysen *et al*. 2011). More recently, large colour ringing programmes have focussed on colonies in NW and SW Netherlands, and in IJmuiden. Hundreds of Sandwich Terns *Sterna sandvicensis* have been colour ringed in the Dutch Delta area each year since 2012 (www.cr-birding.org) and similar programmes have commenced on Texel and Ameland in 2014 and on Griend in the Dutch Wadden Sea in 2015. Common Terns *Sterna hirundo* and Arctic Terns *S. paradisaea* are being colour ringed in the Dutch Delta area, in the river Eems estuary and on Griend. Great Cormorant *Phalacrocorax carbo* research has long focussed on freshwater colonies (van Eerden & Zijlstra 1988), but colour ringing commenced on more seaward situated colonies in 1992 (Ventjagersplaten, Haringvliet) and on Vlieland and the islet De Hond (Eems estuary) in 1997 (van Rijn & Zijlstra 2002), but regrettably not in colonies closest to the offshore wind farms OWEZ, PAWP and Luchterduinen, i.e. not in colonies in the dunes of Noord-Holland.

Colour ringing data may allow an analysis of (added) mortality from human pressures, if these act on the colony studied and if the effects are large enough to be detected against the background of variance in the census data. Sufficient numbers of birds need to be ringed and re-sighted for a mark-recapture analysis. In such analyses, it "helps" if mortality events are distinct and significant. It also helps if the seabird species is studied in detail in the relevant colonies and over a long period. Long-term studies of any kind are rare, but several seabirds have been studied for decades. An example is provided by Votier *et al*. (2005), who studied the (added) mortality on Common Guillemots breeding on the well-studied colony on Skomer Island, Wales, from a series of major oil spills. There was a long-term increase in breeding colonies, that was not interrupted by any of the oil spills, even though adult survival was depressed by each incident (Figure 2). Note that the Common Guillemot is a typical k-selected seabird, with high adult survival and low fecundity, and that each of the oils spills studied caused massive die-offs of Guillemots. This situation is generally less favourable if wind farm related mortality is to be studied, as this mortality will be less concentrated in space with wind farms being built all over the North Sea and with numbers of turbines gradually increasing: a situation quite different from typical oil spills, that occur suddenly and can cause tens of thousands of victims per event.

However elegant the analysis of Votier *et al*. (2005) might be, they could incorporate data from known spills. These events had a sudden, localised and drastic impact on seabirds, with thousands or even tens of thousands of casualties per event. Offshore wind farms are not known to kill off such vast numbers of seabirds quickly and effects will be much less sudden. Moreover, rather than a situation with subsequent major events (oil spills), the situation with wind farms is one of a steady increase of the number of operational wind farms, with the effects of each new one adding up to the effects of wind farms already in existence, and to other effects. If there is a population effect on seabirds of offshore wind farms, it is likely to be a gradual one, but the magnitude of the effect is likely to increase with time, as more wind farms become operational. Population effects may become involved if at-sea mortality rises with increasing numbers of offshore wind farms, or if birds gradually show a gradual range shift, away from wind farm areas to less favourable habitats, with decreased fitness as a result. Note that such effects will be difficult to pinpoint directly to wind farm development, as other factors, both on land and at sea, are likely to impact seabird populations simultaneously.

Colour rings are usually only re-sighted on land, in the case of Common Guillemots in the colony, allowing only for year-to-year survival assessments. Colour rings on other species (cormorants, gulls, terns) can also be seen outside their colonies, but will hardly ever be seen at sea, i.e. in the impact area. This contrasts to the situation in e.g. birds of intertidal habitats, that can be followed throughout their yearly cycle, even if they are long-distant migrants (Lok *et al*. 2015), allowing detailed analyses of survival bottlenecks in space and time. However, if birds habitually rest in wind farms, on the monopiles or on other wind farm related structures such as measuring devices (e.g. the OWEZ meteo-mast) or transformer stations, recovery rates could probably be increased through dedicated ring-reading (e.g. with camera's), particularly if birds in nearby colonies will be colour ringed.

3.1.3 Electronic tagging

Electronic tagging yields the highest resolution in data on where birds go, also at sea. Relevant tagging projects are the tagging of Herring and Lesser Black-backed Gulls on Texel (Kees Camphuysen, NIOZ) and of Great Cormorants, Common and Sandwich Terns in SW Netherlands (Ruben Fijn, Bureau Waardenburg). Many more seabird colonies in other countries have received decades of scrutiny from seabirds biologists and, increasingly, birds are being tagged electronically. Results are now increasingly being published and critical population parameters for such colonies are often rather well known. One of the added values of electronic tagging is that the whereabouts of seabirds at sea, from a given colony, are becoming clear. Conversely, if birds are marked in more colonies, the origin of birds in any part of the North Sea, such as a (future) offshore wind farm area, may be assessed. Currently, however, birds are only tagged in a few selected colonies, providing only a partial picture and numbers of tagged birds are low in comparison to population sizes.

Another option than tagging birds in colonies would be to catch and tag them at sea, in wind farm areas. This was long considered impossible, but at-sea catching of seaduck and divers, both in North America and in the Baltic (http://www.pwrc.usgs.gov/resshow/perry/scoters/capturetechniques.htm and Dr Ramunas Zydelis, *pers. comm*), has changed this perception. Red-throated Divers *Gavia stellata* have been successfully caught and tagged at sea (German Bight: see, www.divertracking.com (fieldwork tab)).

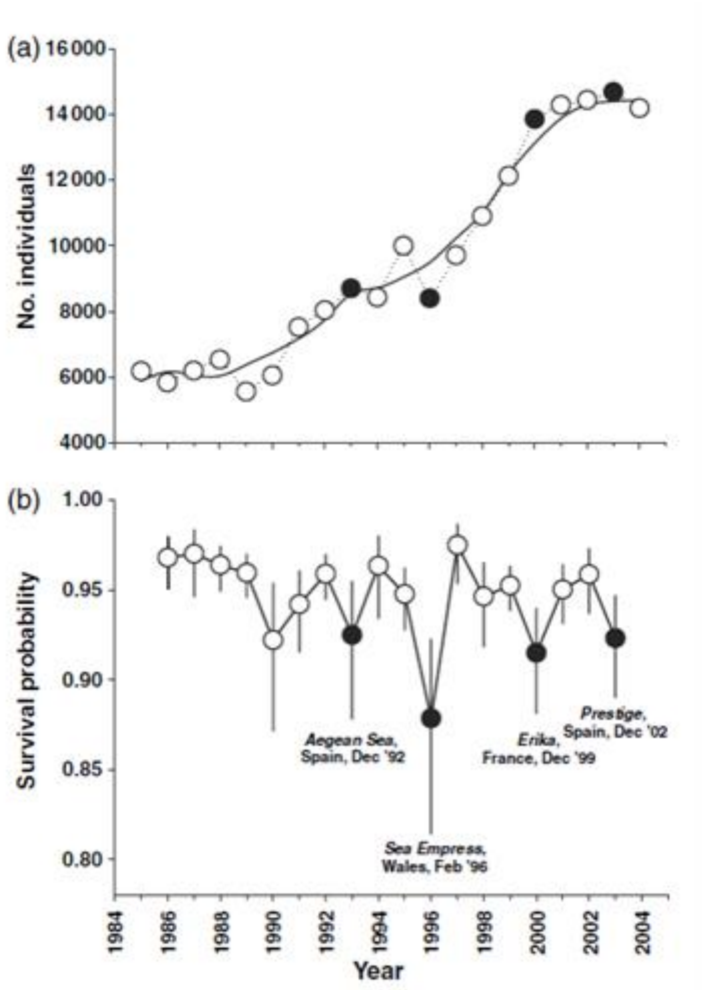

Figure 2 *Population development (whole island counts) of Common Guillemots on Skomer Island, Wales (upper panel). Deviations from the general trend were not found to be significant in any of the years with a major oil spill (filled symbols). In contrast, over-winter survival, was clearly lower in years with a major oil spill (lower panel). Years following winter oil spills are labelled with the name of the tanker, date and location of the spill. Taken from: Votier* et al*. (2005).*

4 Population effects of offshore wind farms?

4.1.1 Bird species at risk

Seabirds may be killed directly in offshore wind farms, through collisions with the rotor blades. Seabirds may also suffer habitat loss and through that, reduced fitness, if they avoid the footprint of the wind farm. Leopold *et al*. (2014) have argued, that while collision mortality clearly reduces seabird numbers directly: one bird less after each hit, these losses may be quickly replaced by recruitment and density dependent survival of the remaining population. Habitat loss resulting from seabirds avoiding offshore wind farms may have a more permanent impact on seabird populations, if this habitat loss reduces the carrying capacity of the sea for e.g. winter survival or the amount of space available for feeding around a seabird colony. In the case of collisions, only birds that fly through the offshore wind farm might be hit: individuals that either live elsewhere or avoid wind farms within their home range run no such risk. Conversely, individuals that let themselves be displaced by an offshore wind farm may suffer fitness loss, as do individuals living in the vicinity of the wind farm, through increased competition from the displaced birds. In either case, effects on the population level are only likely to occur if fitness loss from offshore wind farm impacts is not quickly balanced by new recruitment or density dependent changes in survival. Fitness loss through displacement from offshore wind farms is not likely to occur if the wind farm has no effect on the carrying capacity for the bird species considered. If birds can easily move to other parts of their range, for instance because their numbers are regulated elsewhere or in other parts of their yearly cycle, population effects are unlikely to occur. In general, birds considered susceptible to colliding with turbine rotors are those that spend a lot of time flying, at rotor height, and fly also at night when visibility is reduced, and do not avoid flying through an offshore wind farm, while birds that potentially suffer from habitat loss through displacement might suffer reduced fitness through increased competition with conspecifics (e.g. Garthe & Hüppop 2004; Krijgsveld *et al*. 2011; Band 2012; Cook *et al*. 2012; Wright *et al*. 2012a,b; Furness *et al*. 2013; Bradbury *et al*. 2014; Johnston *et al*. 2014; Krijgsveld 2014; Leopold *et al*. 2014). Dierschke *et al*. (2016) have reviewed the behavioural responses of seabirds to offshore wind farms and they have grouped the various species into five behavioural categories:

1. Species which are strongly attracted by offshore wind farms and used these sites as new opportunities for resting and feeding: Great Cormorant and European Shag *Phalacrocorax aristotelis*;
2. Species which are only weakly attracted by offshore wind farms, which they use for opportunistic feeding and resting: Common Gull *Larus canus*, Black-headed Gull (*Chroicocephalus ridibundus*), Great Black-backed Gull *L. marinus*, Herring Gull, Lesser Black-backed Gull *L. fuscus* and Red-breasted Merganser *Mergus serrator*;
3. Species which are hardly affected by offshore wind farms or which seem to show some attraction in some cases and some avoidance in others: Common Eider *Somateria mollissima*, Black-legged Kittiwake, Common Tern and Arctic Tern;
4. Species which weakly avoid offshore wind farms: Long-tailed Duck *Clangula hyemalis*, Common Scoter, Northern Fulmar *Fulmarus glacialis*, Manx Shearwater *Puffinus puffinus*, Razorbill *Alca torda*, Common Guillemot, Little Gull *Hydrocoloeus minutus* and Sandwich Tern;
5. Species which strongly or (nearly) completely avoid offshore wind farms: Great Crested Grebe *Podiceps cristatus*, Red-throated Diver, Black-throated Diver *Gavia arctica* and Northern Gannet *Morus bassanus*.

Leopold *et al*. (2014) considered the cumulative effects of 100 existing and yet to be built offshore wind farms in the southern North Sea and suggested a top-10 of seabird species likely to be impacted most, from the combined direct collision mortality and inferred mortality from habitat loss (displacement): Figure 3.

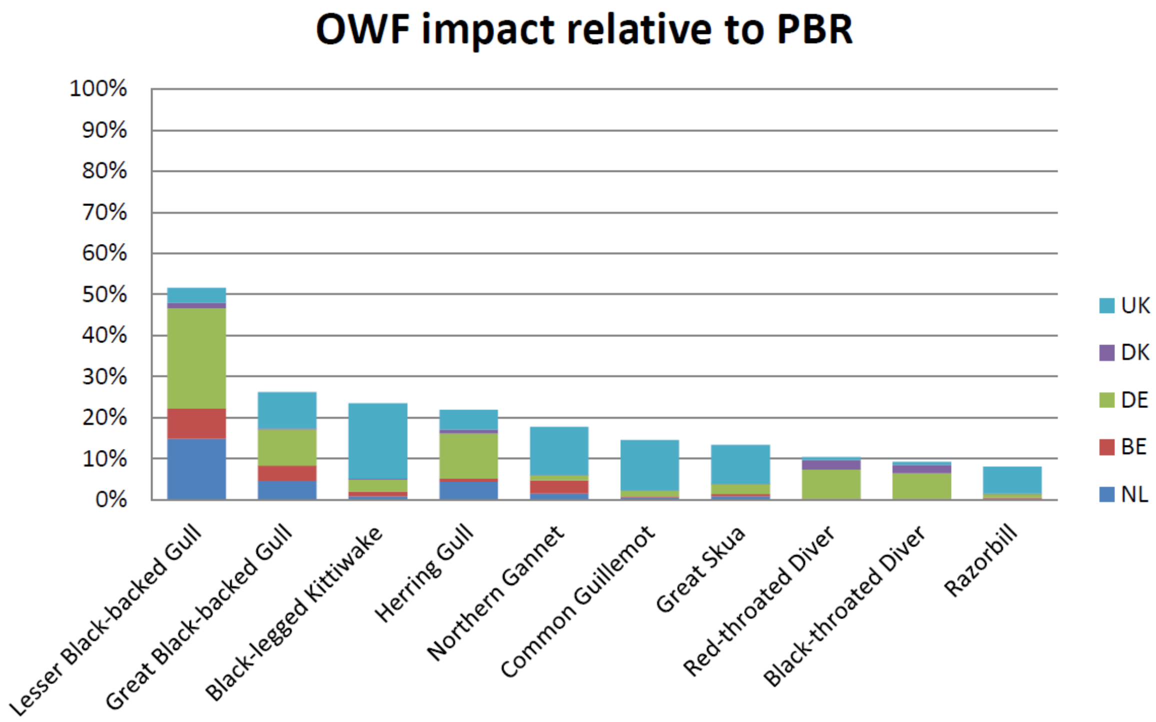

Figure 3 *The presumed top-ten of seabird species likely to be negatively affected from offshore wind farm development (projection for 2023). Estimated cumulative added mortality is scaled against the specific PBR (Potential Biological Removal) values. Colours represent national sections of the southern North Sea where the mortality will take place. Taken from Leopold* et al*. (2014).*

Note that the two seabirds labelled by Dierschke *et al*. (2016) as category 1 species (strongly attracted by offshore wind farms): Great Cormorant and European Shag are not in this top ten. These birds are likely to learn how to exploit offshore wind farms for feeding and resting, and might be well able to deal with the rotors (i.e. avoid these while still exploiting the wind farms). Note also that some other species, mentioned by Dierschke *et al*. (2016) do not occur in the top ten of Leopold *et al*. (2014). These species are mostly too coastal to be impacted by offshore wind farms or do not have their main distribution range within the southern North Sea to be impacted much by offshore wind farms in these parts. The top-four: Lesser and Great Black-backed Gulls, Herring Gull and Black-legged Kittiwake all do not avoid offshore wind farms (much), while their current at-sea distribution shows much overlap with (future) wind farms in the southern North Sea. These species are likely to suffer direct (collision) mortality mostly, as opposed to Northern Gannet, Common Guillemot, Red- and Black-throated Divers and Razorbill, which will suffer most from habitat loss as these birds all tend to avoid wind farms. The Great Skua *Stercorarius skua* has only a small global population size and thus even small numerical losses would be comparatively high.

Note also that the estimates for PBR used by Leopold *et al.* (2014) were based on rather coarse population estimates of seabirds. Should impacted birds stem from much more limited populations, such as Dutch, or eastern UK coast colonies only, impacts on these specific populations might be much higher than currently projected. For this reason, it is important to find ways to assess the origin of birds likely to be impacted by specific offshore wind farms. For the breeding season this is rather obvious: only wind farms situated within the foraging range of adjacent colonies may have an impact. For instance, the wind farm located on the Scroby Sands sandbank, 2.5 kilometres off the coast of Great Yarmouth, Norfolk, eastern England, United Kingdom, has been implicated to impact Little Terns *Sternula albifrons* breeding nearby through a local reduction of Herring *Clupea harengus* numbers

(Perrow *et al*. 2006, 2011), an important forage fish for this tern that cannot fly far offshore to get its food (Beijersbergen 2015). Other wind farms, situated further offshore, are unlikely to impact this particular species in the breeding season. During migration, however, birds from many colonies are likely to pass through the same area of sea and birds from other colonies may also pass through a wind farm that was out of range in the breeding season.

While birds may be tied to certain feeding ranges in the breeding season, the situation is less clear in the non-breeding season. Then, birds are not directly linked to breeding sites on land, but birds from certain colonies might still winter in specific areas, rather than show random mixing with conspecifics from other colonies. A specific wind farm may thus impact birds from a specific colony, or geographic area, much more than others. As most colonies are protected, it becomes increasingly important to know where these birds go in the non-breeding season and where human pressures may act on them, specifically.

5 Species of interest

For the top-ten species of Leopold *et al*. (2014) the available information on area of origin-specific at sea distribution will be reviewed.

5.1 Lesser Black-backed Gull *Larus fuscus*

Lesser Black-backed Gulls breed in many, often large colonies around the North Sea and breeding birds might venture tens of kilometres out to sea to forage for their offspring in the nest. A study with GPS loggers on Texel (Camphuysen *et al*. 2015) has revealed that the two sexes behave quite differently in the breeding season, with the larger males being more true seabirds than the females, which mostly fed on land or nearshore and in the Wadden Sea, where they had many foraging options and a varied diet. In the North Sea, the males were largely dependent on fisheries discards at offshore trawlers. This pattern yet needs to be established for birds breeding elsewhere, but this difference between males and females implies that the males would be mostly at risk of colliding with rotor blades in offshore wind farms. Both JNCC *et al*. (2014) and Furness (2016) consider that there is a need to improve data on both site-specific and generic flight height, and also on avoidance rates, of Lesser Black-backed Gulls to improve collision modelling. Should this mortality factor be, or become with future offshore wind farm development, significant, a sex-specific analysis of survival, comparing pre- and early years of offshore wind farm development with future years with many more such wind farms, should yield a growing difference in male and female mortality in this species. Also, colonies might exist that are situated too far from the nearest offshore wind farm to be impacted while wind farms on land should impact the females within the population, mostly. Note, however, that usage of the marine environment may change (quickly) if food supplies vary in time (Tyson *et al*. 2015) and that this may also differ across the southern North Sea, with birds in other colonies behaving quite differently from those breeding on Texel (Schwemmer & Garthe 2005; Gyimesi *et al*. 2011).

In the breeding season, when breeders are tied to their nesting site, breeders travel only within a certain range around it. At sea, they face competition from birds from neighbouring colonies. This results in rather fixed feeding ranges per colony. Kees Camphuysen (2013) commented on this phenomenon:

> "Few Lesser Black-backed Gulls [from Texel] foraged to the northwest of the breeding colony, a sea area that is actually packed with Lesser Black-backed Gulls in summer. Also the Frisian Front area was rarely utilised by tagged birds from Texel. The high densities of Lesser Black-backed Gulls in that area, and between the Frisian Front and the Wadden Sea islands, most likely comprised birds from colonies at Vlieland and Terschelling".

This "dividing up the sea between colonies" would imply that any one offshore wind farm will receive mainly birds from one, or at most, a few, geographically adjoining colonies. Birds breeding on Texel, for instance, only just reach the offshore wind farms OWEZ and PAWP off the Dutch mainland coast (Figure 4); birds in these two wind farms are probably more likely to stem from the colony in IJmuiden port, while birds in the (future) offshore wind farms Borssele very unlikely come from Texel, but rather from the large population breeding in Europoort/Maasvlakte. Any impact of an offshore wind farm on this species is thus likely to affect mainly birds from one specific colony, or a few such colonies. Note that this at-sea usage only refers to the breeding part of the population. Non-breeders, including juveniles and immatures, are likely to be less strictly tied to any particular colony and may range more freely, also at sea. However, decades of ship-based, at-sea observations of Lesser Black-backed Gulls have shown that the vast majority of birds at sea are in adult plumage. This does not exclude the possibility that non-breeding adults (birds that are already “adult” in plumage but that have not yet reached breeding status, or birds that skip a particular year for breeding) might also be at sea, but from these observations it would appear that immatures and juveniles at least venture out to sea much less than breeding adults. Furness (2016), however, reaches another conclusion: “*The southern North Sea may hold large numbers of immatures, especially during summer, and better understanding of migrations and origins of birds in the southern North Sea could reduce consenting risk*”. He also notes that the whereabouts of immatures are poorly known, also because tracking studies have focussed on adult birds (breeders). Away from the colonies and outside the breeding season, there is a general uncertainty about origins of Lesser Black-backed Gulls found in the southern North Sea, and a better understanding of origins of these individuals would help reduce uncertainty about the specific (segments of the) populations that might be impacted by offshore wind development (Furness 2016). Note, however, that population development is not influenced by offshore wind farms alone (far from it, in fact!). Changes to fisheries management in particular may affect gull population trends since these birds obtain a substantial amount of food from fishery discarding, a practice that is supposed to decrease in magnitude through new rules within the EU Common Fisheries Policy (the discards ban). Even though there is a wealth of data on Lesser Black-backed Gull vital rates, Furness (2016) still concluded that the amount, quality and geographical spread of these data are not yet adequate data to model the impacts of major drivers (including offshore wind development) on Lesser Black-backed Gull demographic parameters that would be required for predictive modelling.

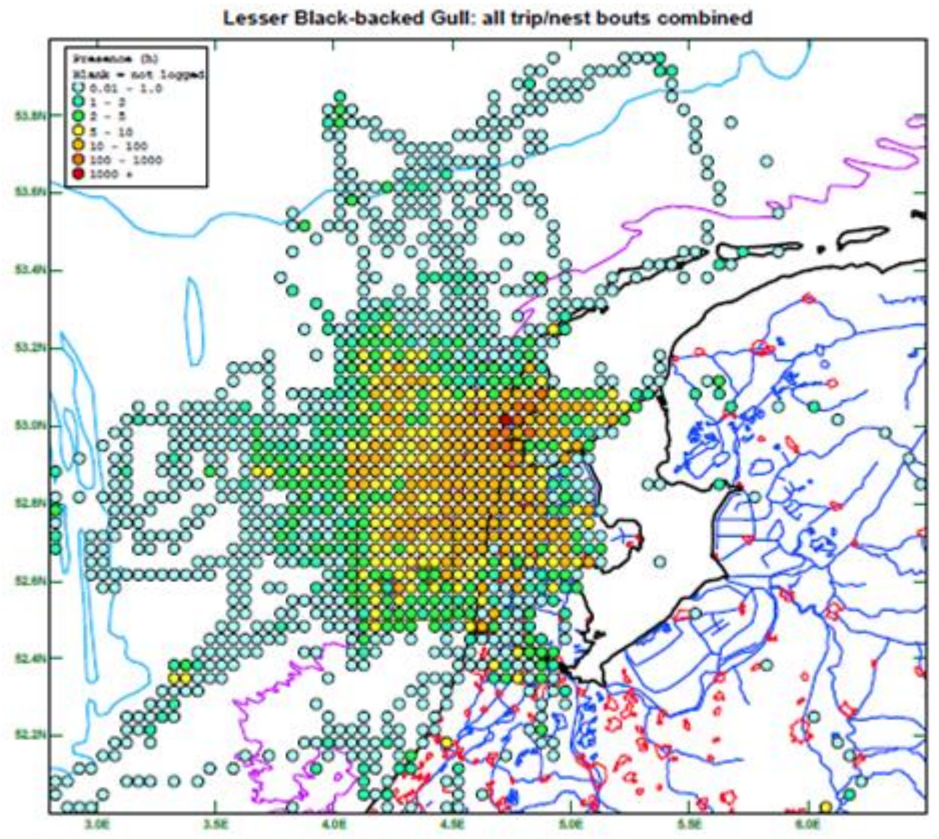

Figure 4 *The relative at-sea distribution of Lesser Black-backed Gulls fitted with GPS loggers in the breeding colony in southern Texel, 2008-2011. From: Camphuysen (2011).*

After the breeding season, Lesser Black-backed Gulls move south, to SW Europe and NW Africa, becoming much more “land birds” than they are in the breeding season (Camphuysen 2013). Birds from a much larger area, comprising Scotland, Norway, Sweden, Finland, Denmark and Germany, move through the southern North Sea (Bakken *et al*. 2003; Wernham *et al*. 2002; Valkama *et al*. 2014), while this is less clear for birds from Iceland and the Faroes (Hallgrimsson *et al*. 2012; Hammer *et al*. 2014). How exactly, male or female, or adult vs immature birds migrate through the North Sea is not yet clear, but these questions may be addressed in the near future, using GPS-tracking data.

Yearly adult survival in Lesser Black-backed Gulls on Texel was found to be 0.91 (Camphuysen & Gronert 2012), the same value as found earlier for Lesser Black-backed Gulls in the United Kingdom (Wanless *et al*. 1996). Adult annual survival in Lesser Black-backed Gulls on Texel showed considerable variation between years (ranging from 0.81-1.0) and might be declining due to increasing food shortage. Adult mortality appears to peak at the end of the breeding season (Camphuysen & Gronert 2012), i.e. when birds still are present at North Sea latitudes. High food stress also results in poor breeding output in this species, through low chick survival caused by starvation, predation and even cannibalism (Camphuysen 2013).

Implications for WOZEP*: Should offshore wind farms have a significant negative impact on Lesser Black-backed Gulls breeding in The Netherlands, this effect should be most severe on the adult males, in colonies that are within foraging range. Therefore, a sex-specific analysis of adult survival, on birds from colonies at various distances from operational offshore wind farms would be a first important step. Note that the birds breeding at Texel, which are extensively studied, are rather far removed from current operational offshore wind farms; studies in more nearby colonies, e.g. in IJmuiden and in the near future, Maasvlakte-Europoort, need more scrutiny. Electronic tagging, of birds in the latter two regions, will be needed to gain more insight of the at-sea terrain usage of these birds, and the relative importance that wind farm areas might have in the food provisioning of nestlings. It is thus advised to intensify studies, and particularly data analyses, on birds in IJmuiden and Maasvlakte-Europoort. During migration, birds from a large area may pass through North Sea offshore wind farms. These birds face a collision risk but flight paths of birds from different colonies are likely to overlap, which will make it impossible to link collision risks of individual wind farms, or the cumulative effects of all wind farms, to specific colonies until migration flight paths become better known.*

5.2 Great Black-backed Gull *Larus marinus*

The opening statement of Furness (2016), in his review of Great Black-backed Gull literature is: "Great black-backed gull has received remarkably little attention from seabird ecologists and is one of our least well known breeding seabirds".

Only few Great Black-backed Gulls breed around the southern North Sea, the species is mainly a visitor here in the non-breeding season. The species may occur in all parts of the southern North Sea, including all sites assigned to offshore wind farm areas (Leopold *et al*. 2014). As the largest of the gulls, it is a strong competitor around fishing vessels (Camphuysen *et al*. 1995) or any other site it might wish to go, including sites offering resting opportunities in offshore wind farms.

Most Great Black-backed Gulls in the southern North Sea probably come from the northern and western coasts of the British Isles, Iceland, Faroes, Denmark and Fenno-Scandia (Leopold *et al.* 2014). Both classic ringing schemes, and colour ringing data seem to suggest that Norway could be the main region of origin of birds wintering in the southern North Sea (Bakken *et al*. 2003; Wernham *et al*. 2002; Valkama *et al*. 2014). However, differences between the numbers (colour) ringed in the various countries make such an assessment difficult. It is also unknown if birds of a particular source population tend to winter in certain areas within the North Sea, although some colour ringed birds show site fidelity to wintering areas (Figure 4). Migration routes and wintering areas of Great Black-backed Gulls are only known from ring recovery data, colour-ringing studies, and counts of birds at sea and onshore, and without tracking data our understanding of their migrations is limited.

Figure 5 *Adult Great Black-backed Gull JY77 (Texel 19 Aug 2014; Mardik Leopold), colour ringed in southern Norway as a chick in 2007. This bird has been sighted in the northern parts of The Netherlands (Terschelling-Texel) sixteen times since it was ringed.*

Despite large numbers of ringed birds in the general population, relatively little research on the population dynamics of this species has been done (Mitchell *et al*. 2004) and critical life history parameters (vital rates) are not known for Great Black-backed Gulls. The species is doing well, however, due to better protection and enhanced food availability and is increasing its range. Electronic tagging of this species has commenced in the German Bight, but tagged birds were found to be exclusively feeding in the Wadden Sea here (Stefan Garthe, *pers. comm*.). Likewise, 11 breeding birds tracked by Bogdanova *et al*. (2015) at East Caithness Cliffs SPA (UK) also foraged almost exclusively coastally, with a maximum range from nests of only 20 km. Breeding birds thus seem to face little risk from offshore wind farms, but migrating and wintering individuals, generally from unknown origin, may face collision risks. As in the other gulls, there is a need to improve data on both site-specific and generic flight height, and also on avoidance rates, of Lesser Black-backed Gulls to improve collision modelling (Furness 2016).

Implications for WOZEP*: The fact that most Great Black-backed Gulls that visit the southern North Sea originate from the Nordic countries makes that studying at sea-movements and survival will be difficult to organise from the Netherlands. At best, joint research might be set up with researchers in e.g. southern Norway, a region likely to provide a high proportion of birds wintering in the southern North Sea. WOZEP could, for instance, invest in a PhD project on the usage of the North Sea of birds stemming from southern Norway, in a way similar to current research on seabirds breeding even much further northward (see e.g. van Bemmelen et al. (2017) for a similar Dutch-Nordic study on remote seabirds). It would also be advisable to develop methods of catching these birds at sea, as this would greatly enhance possibilities of gps logger deployment on the most relevant birds.*

5.3 Black-legged Kittiwake *Rissa tridactyla*

Black-legged Kittiwakes (further: Kittiwakes) breed on rocky cliffs, all around the British Isles, the Nordic countries and Helgoland, Germany (Mitchell *et al*. 2004). Even birds from Greenland may reach the North Sea (Lyngs 2003) and over one million birds supposedly winter in the North Sea (Skov *et al*. 2007). In the southern North Sea, the largest numbers are found in the UK, at Bempton Cliffs and Flamborough Head (42 659 pairs counted around the year 2000, representing a sharp decline, from 85 000 pairs in 1985-88; Mitchell *et al*. 2004). The species also breeds at Helgoland (7000-9000 pairs; Markones *et al*. 2009) and on several offshore platforms in the Dutch sector of the North Sea (probably around 100 pairs altogether (Camphuysen & De Vreeze 2005, Camphuysen & Leopold 2007; Geelhoed *et al*. 2011). Concerns have been raised that offshore wind farms such as Hornsea, in the broad vicinity of Flamborough, could negatively impact the breeding birds, but such claims have been dismissed based on the rather large distance between colonies and wind farm (SMartWind Limited 2015). However, as for Northern Gannets, Furness (2016) warns there is still much uncertainty in collision risk modelling of this species, due to uncertainties about flying heights and avoidance, while future changes in behaviour (habituation) cannot be predicted. Furness (2016) thus argues for better monitoring of flight altitudes and avoidance rates of Kittiwakes.

Offshore wind farms in relatively close proximity of breeding colonies are considered to be potentially most harmful to Kittiwakes. Searle *et al*. (2014) modelled added mortality of wind farms for the east Scotland colonies (i.e. in a region north of the southern North Sea, where, as in Furness (2016), several biological input parameters required by the model are different from the situation at e.g. Flamborough). Therefore, while Furness (2016) considers this modelling approach valuable, he also considers that a model developed for NE Scotland cannot be extrapolated directly to colonies such as Flamborough, which are far more relevant to the situation in the southern North Sea. He also warns, that important components of the model such as prey distribution, behaviour of seabirds in response to offshore wind farms (including habituation), and effects of adult body mass change on subsequent survival are poorly known. A modelling approach may thus be a good way forward, but a lot of work still has to be done in colonies in the southern North Sea.

The Kittiwake has long been a popular species for study and was among the first seabird species to be radio-tracked (e.g. Gabrielsen & Mehlum 1989; Ostrand *et al*. 1998). Robertson *et al*. (2014) found a feeding range around a colony in the western North Sea of some 50 km, but such figures are dependent on colony size, location, feeding conditions and numbers of birds followed (Soanes *et al*. 2013). However, such a range would be similar to that found in Lesser Black-backed Gulls. The species thus ranges rather widely, even in the breeding season, and occurs throughout the North Sea in the non-breeding season. Despite large numbers of ringed birds, recoveries in the non-breeding season are relatively few (Speek & Speek 1984; Bakken *et al*. 2003; Wernham *et al*. 2002). Recoveries on Dutch beaches include relatively many birds from SE Scotland and Norway, a few from Denmark and France, and one from western Greenland. There are no winter-telemetry studies that shed any light on the movements and origins of Kittiwakes in winter in the southern North Sea. In the breeding season, much of the offshore wind farms within the southern North Sea are distant from breeding colonies, and Furness (2016) considers that it is highly likely that most Kittiwakes summering here are in fact immature birds from colonies further north, including Norwegian Sea and Barents Sea colonies. This would mean that any impact from offshore wind farms in the southern North Sea most likely would affect these northern colonies most, but also that these colonies would be affected through a lower survival of immatures, rather than the more "valuable" breeders and that effects would thus be slight at most. Furness (2016) warns, that despite an abundance of Kittiwake population studies, that have produced good quality demographic data, Population Viability Analysis (PVA) models are still far from producing meaningful predictions of added wind farm mortality effects.

Conditions in the North Sea for Kittiwakes are currently unfavourable, resulting in halving of the breeding population since 1990 (Frederiksen *et al*. 2004a,b). This decline has been attributed to prolonged poor breeding success and poor survival of adult birds, due to food shortages, resulting from changes in oceanographic conditions. In a colony of Kittiwakes on Fair Isle, Rothery *et al*. (2002) found breeding success to be extremely variable between years, but averaging 0.81 young reared per completed nest. Adult survival between 1986 and 1996 was 86.0% and stable, but this figure dropped to 51.6% in 1997 and was probably low again in 1998. Survival from fledging to recruitment was in the order of 20%. Such vital rates are insufficient to sustain the population. More recent studies found a productivity over the UK as a whole to be 0.69 chicks per pair (Horswill & Robinson 2015); or 0.672 chicks per pair (Furness 2015). However, Furness (2016) indicates that productivity differs considerably between regions and years, and is strongly influenced by food (sandeel) abundance closely around the colony studied.

Even though breeding comes with substantial energetic costs, adult mortality is thought to peak in winter (Wernham *et al*. 2002). Interestingly, winter mortality and ways and means to try to reduce this, appear to be linked to the breeding success in the previous summer in Kittiwakes. Individuals that were unsuccessful as breeders, were found to leave the colony earlier than successful breeders and move to more distant wintering grounds (Bogdanova *et al*. 2011). Birds tagged on the Isle of May, western North Sea, moved far into the Atlantic, rather than wintering in the North Sea (Figure 6), which would take them out of harm's way, at least as far as offshore wind farms are concerned. 94% of the tagged unsuccessful breeders travelled over 3000 km to the West Atlantic against 53% of the birds that had bred successfully, whereas fewer unsuccessful bird remained within 1000 km of the colony, in the East Atlantic (31% versus 80% successful). Recent geolocator studies on breeding Kittiwakes in Svalbard, Barents Sea, Norwegian Sea, North Sea, Celtic-Biscay Shelf, Faroe, Iceland, Greenland and Canada indicate that some of the northern birds winter in the North Sea (Frederiksen *et al*. 2012; Furness 2016)

Note that Figure 6 also illustrates the point made by Soanes *et al*. (2013) that sufficient numbers of birds should be tagged to see the entire distribution pattern of the species. Birds from the British Isles indeed tend to winter west of their breeding sites, apparently with little difference in this respect between colonies, but some do venture far into the North Sea, much beyond the ranges shown in Figure 6, as is illustrated by ringing recoveries (Wernham *et al*. 2002). The origin of the large numbers of Kittiwakes wintering in the North Sea, given the westerly wintering orientation of many UK birds, and the northwesterly orientation of Norwegian birds (Bakken *et al*. 2003), therefore remains unclear. Note, however, that the Southern Bight of the North Sea is not a very important area for Kittiwakes at large: within the North Sea much higher densities are found further north. Ties to specific colonies are probably weak in the Southern North Sea, and birds from a vast number of colonies might visit the region, on occasion. Residence times of such birds are unknown.

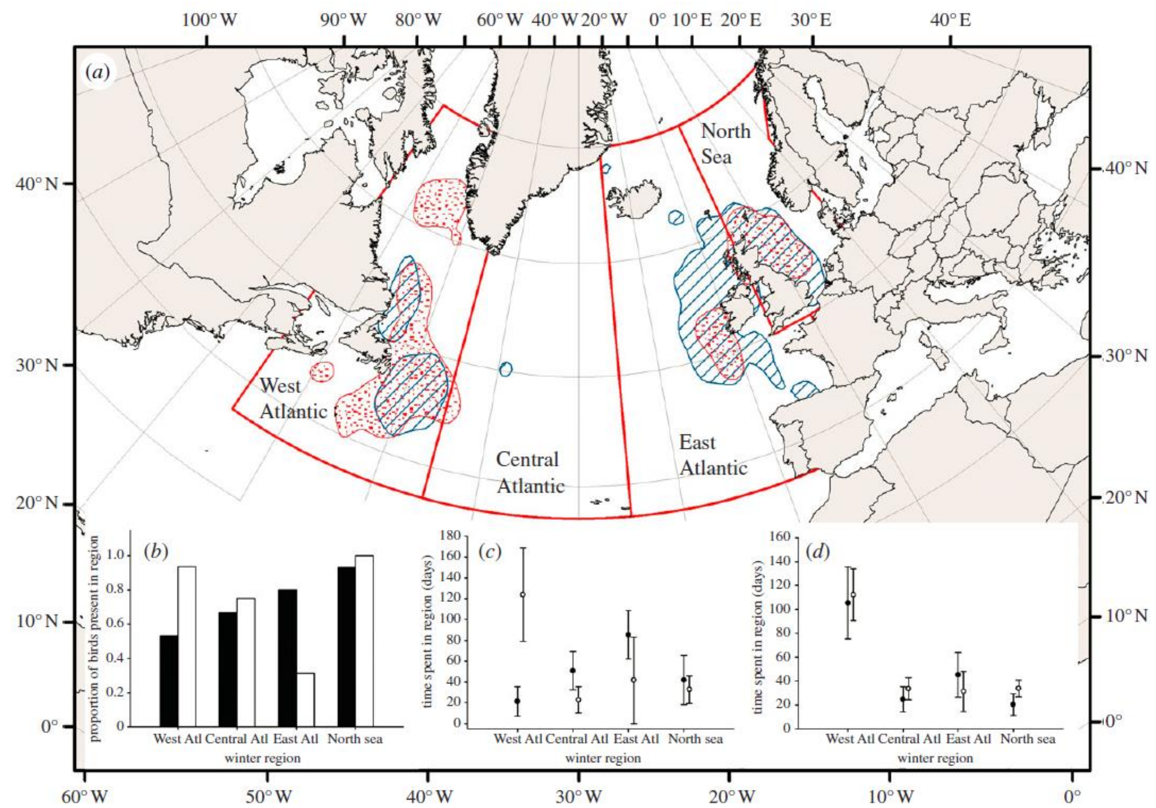

Figure 6 *(a) Fifty percent density Kernels of wintering Black-legged Kittiwakes tagged on the Isle of May (SE Scotland). Blue polygons: successful breeders (n=15), Red: unsuccessful (n=16). (b) Proportions of successful (black bars) and unsuccessful (open bars) individuals in each region. (c) Time spent in each region by successful (filled circles) and unsuccessful (open circles) females, and (d) the same for males. Both (c) and (d): mean± s.e. From: Bogdanova* et al. *(2011).*

***Implications for WOZEP**: The southern North Sea holds large numbers of Kittiwakes throughout the year. The Flamborough Head colony has the largest numbers of breeding birds in the region and a second, but much smaller colony is situated on Helgoland. There is scope for modelling added wind farm related mortality, but existing models still need to be parameterised better and this can only be done by researchers with access to the birds in those colonies. With only a few small colonies present in the Dutch sector of the North Sea, the Dutch are probably not the most obvious Kittiwake researchers. However, if access could be arranged to such a colony, e.g. on a derelict gas production platform, the Dutch could certainly take this on. At present, only the colony on Helgoland in the southern North Sea appears to receive intensive scrutiny regarding risks of offshore wind farms through dedicated research with electronically tagged birds. For the larger southern North Sea, and for much of the year, it remains unknown where most visiting birds originate from, making the added value of tagging studies questionable for WOZEP related issues in Dutch waters. There is an urgent need for more wind farm related work in the Flamborough area, but this would be up to the UK authorities to organise, not the Dutch. However, this species will be rather intensively studied at and around Helgoland; it is advised to wait and see what results of these studies will be. Alternatively, the Dutch could liaise with the Garthe group working on Helgoland and start their own line of research on a (new) study colony on a derelict gas production platform and by doing so, gain a position in this field. Residence times, as well as at-sea usage could be studied by tagging birds in such a colony, or, alternatively through catching birds at sea and equipping them with tagging devices (which should be relatively easy for this species, known to follow e.g. fishing vessels at very close range (Camphuysen 1993)).*

5.4 Herring Gull *Larus argentatus*

Herring Gulls have a breeding distribution around the North Sea that is similar to that of the Lesser Black-backed Gull, but in the breeding season, this species is far less orientated to the North Sea than the Lesser Black-backed Gull, which probably results from competition with this species. The feeding range of Herring Gulls in the North Sea in the breeding season was found to be considerably smaller than that of Lesser Black-backed Gulls. 95% of all Herring Gulls at sea were seen within a 54 km range of the colony, while this was 135 km for 95% of all Lesser Black-backed Gulls (Camphuysen 1995).

Mean apparent (as inferred from colour rings) annual adult survival was calculated to be 79% in females and 86% in males for the birds breeding on Texel (Camphuysen 2013), which was considerably lower than the values for Lesser Black-backed Gull. Herring Gull numbers have reached a plateau of circa 90,000 pairs in the mid-1980s in The Netherlands, but have since significantly declined to 52,000 pairs in 2009 (a 42.5% reduction in just about two decades), while numbers of Lesser Black-backed Gulls have continued to increase at least until the early 2000s (Figure 7).

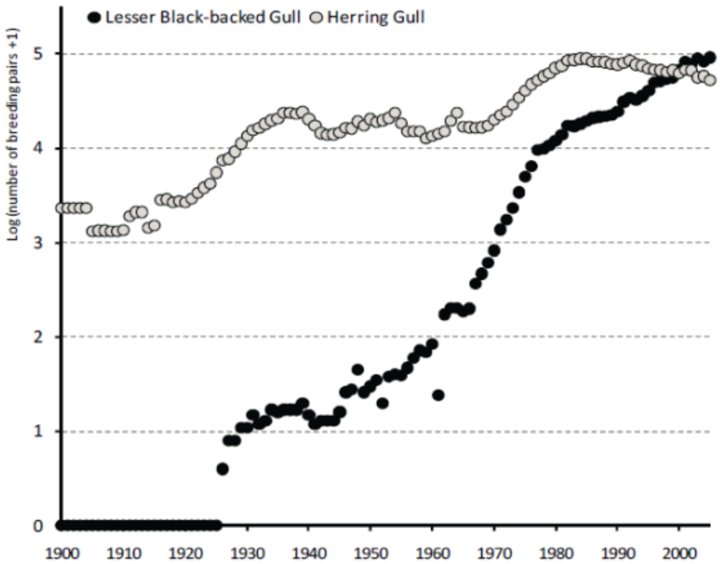

Figure 7 *Contrasting trends in numbers of breeding pairs of Herring Gulls (grey) and Lesser Black-backed Gulls (black) in The Netherlands (log n+1). Figure taken from Camphuysen (2013).*

Herring Gulls breeding in the Netherlands are hardly migratory. Some 20.5% of 3124 birds colour-ringed as chicks (n= 3124) in 12 Dutch colonies in 1986-88 were never seen more than 5 km away from their natal colony (n= 86,247 ring-readings) and only 0.8% were reported >300 km from the place where they were ringed. However, birds from NE Netherlands were slightly more dispersive than birds from the SW (Camphuysen *et al*. 2011).

Herring Gull breeding success was slightly higher than that of Lesser Black-backed Gulls, but overwinter survival was lower (Camphuysen 2013), indicating that, even when the competition from Lesser Black-backed Gulls is relaxed after these migrate to more southerly latitudes, Herring Gulls do not get an "easy" life here. In the non-breeding season, the SE North Sea fills up with Great Black-backed Gulls and with Herring Gulls from elsewhere, presumably from the Nordic and Baltic countries and Scotland, where Herring Gulls are more migratory than their Dutch conspecifics (Wernham *et al*. 2002; Bakken *et al*. 2003). As most Dutch birds remain in the region (Figure 8), they now have to face competition with these Great Black-backed Gulls and Herring Gulls.

Figure 8 *Typical wintering Dutch Herring Gull: colour ringed as a chick in 2010 in southern Texel and observed wintering each year since in the port of Oudeschild, Texel, just 9.4 km from its former nest (photo: Mardik Leopold).*

The winter dispersal at sea of Herring Gulls is currently being studied, using birds with GPS loggers (http://www.uva-bits.nl/project/foraging-opportunities-for-herring-gulls-from-texel-throughout-the-annual-cycle/). The first indications of this work are that the ("Dutch") birds stay closely inshore. If this would be true generally, Dutch Herring Gulls are only expected to come near offshore wind farms in the breeding season, while most encounters of this species with wind farms in the North Sea will involve birds from more northerly origin. There is little reason to believe such birds would claim a particular part of the open sea for themselves in winter, but this may change once solid structures are put in place here. Colour ringed birds sighted on land are often seen in many successive years at the same location, and such habituation may also evolve at sea, around offshore wind farms. Catching and marking birds roosting in such wind farms would be a way to study such behaviour and learn more about the origin of birds in wind farms.

Implications for WOZEP*: Herring Gulls are probably most likely to be impacted from offshore wind farms through collisions and increased competition with other large gulls, if these are better at occupying wind farms, of if gulls in general would be displaced from offshore wind farms (which currently seems unlikely). Birds breeding in The Netherlands are unlikely to be impacted much directly, as offshore wind farms generally are situated too far offshore. Wintering birds, mostly from other countries are probably most vulnerable, but these are difficult to study. How gulls compete, both between species and within the same species, in and around offshore wind farms, and how this competition might relate to collision risks, is uncharted territory. Studies of gulls in and around wind farms might elucidate this and a "local population" of marked and tagged birds would be a first necessity.*

5.5 Northern Gannet *Morus bassanus*

Only two Northern Gannet breeding colonies are found within the southern North Sea, Bempton Cliffs in England (ca 2500 pairs; Mitchell *et al*. 2004) and Helgoland (656 nest sites in 2014; Garthe *et al*. 2016). These two colonies are dwarfed by the largest colony in the North Sea (and since 2014: the world); Bass Rock in NE Scotland, with some 75,000 pairs (Murray *et al*. 2014). Northern Gannets (further: Gannets) are strong flyers that range far from their breeding colonies. Therefore, also birds breeding north of the study area, particularly from Bass Rock, may visit the southern North Sea (Wakefield *et al*. 2013), while migrants from colonies further north may also migrate through the North Sea in autumn and spring, or winter here.

Birds from Bempton Cliffs easily fly to forage >100 km offshore (Langston & Boggio 2011), as do birds from Bass Rock (Hamer *et al*. 2000, 2007; Furness 2016) and birds from either colony may even reach the Dutch sector of the North Sea on feeding trips, as may also do birds from Normandy, France (McClellan *et al*. 2014). The most recent study on Gannet movement in the breeding season was done on a small number of birds from Helgoland (Garthe *et al*. 2016). Foraging parents ranged up to 320.8 km from the colony and the birds largely avoided a recently developed wind farm area north of Helgoland (Figure 9). This avoidance behaviour implies that, although Gannets may avoid being killed directly by rotor blades, they may experience substantial habitat loss. However, Furness (2016) surmises that large numbers of Gannets fly at rotor height and that there is still much uncertainty in collision risk modelling of this species, while future changes in behaviour (habituation) cannot be predicted, but are likely to make things worse. Furness (2016) thus argues for better monitoring of flight altitudes and avoidance rates of Gannets. Population development on Helgoland is followed closely and the future trajectory of the numbers of breeders will be interesting in the light of intensive offshore wind farm development around the island.

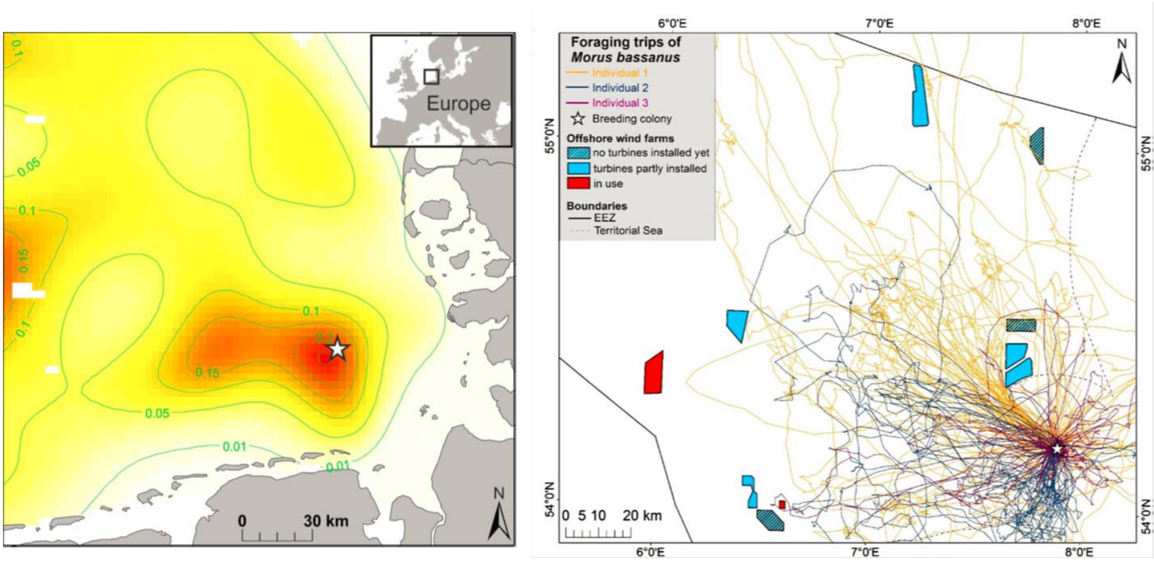

Figure 9 *Left: Densities of Northern Gannets around Helgoland in the breeding season the pre-offshore wind farm years 2005-2012 (ship-based survey data). Increasing bird densities are visualised by colours from yellow through orange to red. The white star indicated the breeding colony.*
Right: Flight tracks of three Northern Gannets breeding on Helgoland, and fitted with GPS loggers, over 4, 5, and 9 weeks, respectively, from early July 2014 onwards. The birds clearly avoided wind farms, even those under construction. From: Garthe et al*. (2016).*

Most adult Gannets that use the southern North Sea in the breeding season are probably tied to the two regional colonies (Wakefield *et al.* 2013), but at other times of the year tens of thousands of Gannets from colonies outside the southern North Sea use this area (Camphuysen *et al*. 1995). Like in most seabirds, mortality is relatively high in non-adults. Wanless *et al*. (2016; in Furness 2016 (reference not given)) estimated, for the Bass Rock colony where Gannets have been extensively ringed, adult survival rate at 0.919, against juvenile survival rate of 0.42. Annual survival increases from 0.829 for 1-2 year olds, to 0.891 for 2-3 year olds, to 0.895 for 3-4 year olds.

The European breeding population is estimated at 418,250 birds (BirdLife International 2004), most of which may pass through the southern North Sea at some time in their lives. With the population increasing, it is unlikely to have reached carrying capacity. As Gannets are known to avoid offshore wind farms strongly (Krijgsveld 2014; Garthe *et al*. 2016), this may soon change with accelerating offshore wind farm development. Should Gannets be forced to make more use of wind farm areas, collision mortality may further impact population development (Murray *et al*. 2014). Furness (2016) concludes that here is [as yet] "no scientific assessment of habituation by gannets, [but that] it is clear from anecdote that this does occur. Gannets might, therefore, show habituation to offshore wind farms over time. Whether any habituation would result in an increased [usage of offshore wind farms, and thus in an increased] collision risk is uncertain, but that might be a possibility".
Gannets occur widely spread throughout the southern North Sea (Figure 9). Concentrations are found near the breeding colonies, and intermittedly, at various places further offshore, when birds respond to temporarily available rich feeding opportunities. A rather large area in the German Bight is avoided, to some extent, i.e., has relatively low densities throughout the year (obviously excepting the waters around Helgoland).

Implications for WOZEP*: Northern Gannets are probably most likely to be impacted from offshore wind farms through habitat loss as the species strongly avoids offshore wind farms. As long as there is "enough sea" to accommodate the still growing population, there is probably little reason for concern. Furness (2016) also reaches this conclusion: "The ecological features of the gannet suggest that displacement and barrier effects are unlikely to affect survival rates of adults or immatures. Modelling of displacement/barrier effects on gannets suggests that even offshore wind farms placed relatively close to a colony are unlikely to have a detectable impact on productivity or survival". However, should the growing number of offshore wind farms reach a point where habitat loss becomes limiting, it will probably be too late to take action. Reaching this point might become clear in advance, if population growth slows down (but this may also happen because of other reasons than offshore wind farm development) and increasing usage of the wind farms by Gannets. Particularly the latter should be seen as a warning sign that carrying capacity might be reached. Therefore, studies of sea-usage of this species, either through on-site observations or through logger studies, should be encouraged. However, given the diffuse nature of the problem, the WOZEP-specific success rate of such studies will probably be low, particularly at first as carrying capacity may not yet be reached (given the still on-going population growth) and it might be advisable to just follow developments at Helgoland closely as well as population development around the North Sea at large. Furness (2016) argues that collision mortality may be quite different for adult and immature Gannets, as their at-sea distribution may differ considerably. He also argues that our current knowledge of age-related Gannet distribution is outdated and in urgent need for an update. This is easily done for Dutch waters, with many aerial and ship-based surveys having collected data on the age of recorded Gannets.*

5.6 Common Guillemot *Uria aalge*

Common Guillemots (further: Guillemots) are among the most numerous seabirds in the southern North Sea, and prone to displacement from offshore windfarms. Most birds probably originate from British and Irish colonies, particularly from NE Scotland, but ringed birds from all around the British Isles (Speek & Speek 1984; Wernham *et al*. 2002), as well as from Helgoland, Iceland, Faroe and Norway have been recovered on Dutch beaches. Ringed birds from eastern North America, Iceland, Faeroe, Norway and Russia winter north (Iceland-Russia) and west (Newfoundland-Greenland) of the North Sea. Most birds that breed in the Baltic never leave this semi-enclosed sea (Nettleship & Birkhead 1985; Anker-Nilssen *et al*. 2000; Olsson *et al*. 2000; Bakken *et al*. 2003; Hammer *et al*. 2014).

Males and juveniles predominated in samples of dissected beached birds in The Netherlands (Camphuysen 1989). Causes of death of birds ringed in the British Isles were drowning in fishing nets (43%), pollution, mainly by oil but also by other lipophilic substances (35%), hunting (13%) and "other" (9%), which included many cases of starvation (Wernham *et al*. 2002). These percentages have varied over time and space, however, with hunting and oiling becoming gradually less important, and drowning in fishing gear becoming a more frequent cause of death. Birds found on Dutch beaches used to be mostly oil victims but this has changed to birds being mostly clean, and starved (Wernham *et al*. 2002; Camphuysen 2010), or drowned (Camphuysen & Leopold, unpublished). Guillemots are typical seabirds, with a long life span, high year to year adult survival and low breeding output. The current record of old age stands at 42yrs 10mths for a Baltic Guillemot (record of a bird still alive, with its ring read in the field; http://www.euring.org/data-and-codes/longevity-list, accessed 26-10-2016). Yearly adult survival has been estimated at circa 91.5% for Skomer Island, Wales, where the population size was declining and at 88-92% at Isle of May, eastern Scotland, where bird numbers were increasing, depending on year and the age of the birds (all ringed as adults; Crespin *et al*. 2006). Harris *et al*. (2000) presented even higher figures for annual survival in Guillemots on the Isle of May, which they found to vary between 92% and 99% between 1986 and 1996. Breeding success on Skomer averaged 0.7 fledged chicks per pair per year and 0.62-0.81 at Isle of May. Survival of fledged chicks (on Skomer) was much lower, 16-27% (Birkhead & Hudson 1977).

Tracking devices on a limited number of breeding birds on the Isle of May showed that most foraging (self-feeding and foraging for the chick at the nest) took place within 30 km of the colony, with males venturing slightly further out to sea than females (Thaxter *et al*. 2009). Studies with GPS loggers have not yet been conducted in the non-breeding season on Guillemots in the North Sea. One such study in the NW Atlantic (McFarlane Tranquilla *et al*. 2015) has shown that the species merely disperses out to sea without clearly separated wintering ranges between colonies. At present, it is not possible to link specific offshore wind farms sites in the southern North Sea to Guillemot breeding colonies.

Ship-based surveys of Guillemots in the southern North Sea are picking up regional differences in "bird quality" (Geelhoed *et al., in prep*.). Some areas, such as the greater Brown Ridge area, seem to have relatively many birds in advanced stages of head moult in late winter (e.g. many summer plumage birds, which are likely experienced adults). Displacement in such areas likely impacts the most "valuable" part of the population. Furness (2016) suggested that a relatively high proportion of birds with poor chances of survival may find their way into wind farms, with yet unknown population consequences. Conversely, if feeding conditions within wind farms will increase through high local fish densities, also birds of high quality may choose to exploit this new resource. An issue for study, therefore, will be assessing Guillemot quality and Guillemot diet within and away from wind farms. Vanermen *et al*. (2013) found first evidence of habituation in Belgium, possibly in response to a within-wind farm increase in food availability.

Implications for WOZEP*: It would be useful to develop a map of Guillemot quality (percentage of birds in summer plumage in any one season) for the southern North Sea, i.e. analyse existing data of ship-based surveys that hold this information, to identify regions that are particularly most valuable for this species. Next, it would be important to work out, where such birds are going to breed, to learn which specific colonies might be most impacted from loss of feeding / wintering area. Teaming up with researchers that know how to catch birds at sea (e.g. the Zydelis team) could be a fast way to learn* *the methods needed for such studies. A global, growing number of tagging studies is likely to produce more valuable data on colony dispersal in the near future, but given the large range from where birds wintering in the southern North Sea may originate from, a complete overview is unlikely to become available any time soon. Therefore, it is probably advisable to consider the opposite: catching and tagging birds at sea and following these back to the colonies of origin. This species spends hardly any time flying at rotor height and collision studies are not a topic needing further study. Studies on displacement or, conversely, habituation and diet will be key to understanding the impact of offshore wind development on this species (Furness 2016).*

5.7 Great Skua *Stercorarius skua*

Great Skuas are considered vulnerable to collisions with offshore wind turbines, because of their very small (world) population, numbering no more than circa 16,000 pairs. There is yet insufficient data available on skua behaviour in offshore wind farms, and the way the species react when it flies towards or through an offshore wind farms is poorly known. Vanermen *et al*. (2013) offers the best data on wind farm vulnerability of this species, but must conclude that, to date, even the best data are still extremely unreliable, due to a very limited number of observations in offshore wind farms, so this issue needs to be resolved. Most of the world population breeds on Orkney and Shetland, while on Iceland numbers have increased over the last century, resulting in range expansion towards the north (Barents Sea) and to the south, into Scotland (Wernham *et al*. 2002; Mitchell *et al*. 2004). The southern North Sea is an important migration route for Great Skuas (Wernham *et al*. 2002), as may be inferred from ring recoveries in The Netherlands (Leopold 2006; Figure 10).

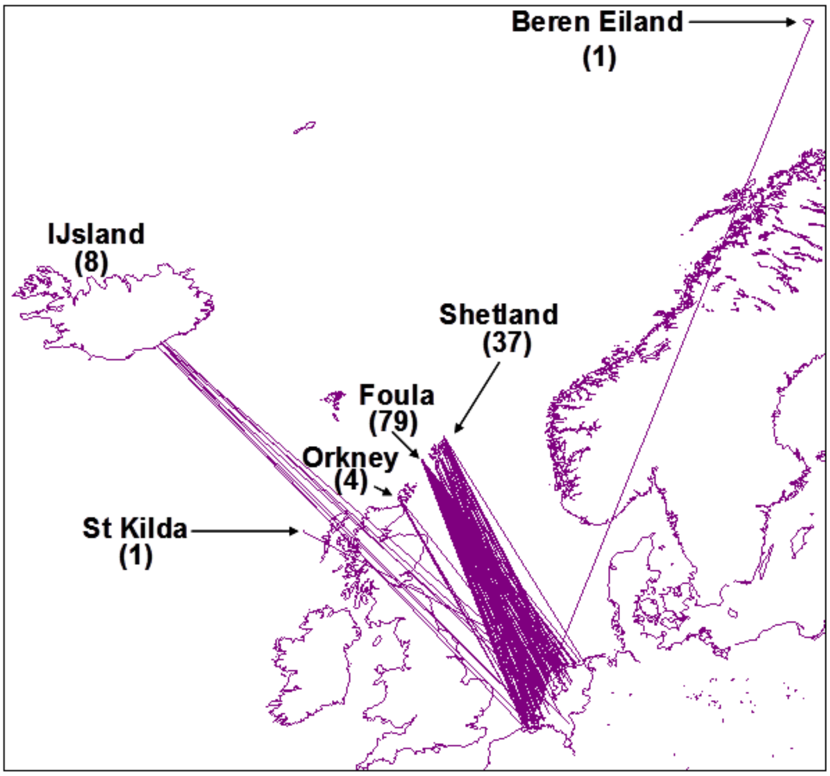

Figure 10 *Ringing recoveries of Great Skuas in The Netherlands, connected (by straight lines) to the locations where these birds were ringed (from: Leopold 2006).*

Migration, particularly in autumn, is leisurely. Great Skuas do not migrate over very large distances as most winter in the Biscay area (Wernham *et al*. 2002; Magnusdottir *et al*. 2012), and birds on migration may linger for some time in areas that provide good feeding. Remarkably, these birds combine migration with primary moult and do so for instance in the southern North Sea, where this has been documented in the Brown Ridge area (NL) by Van Bemmelen *et al*. (2012). Moult is slow, and starts right after the birds leave their breeding areas, late July or early August, and is completed in the wintering quarters, in January/February (Van Bemmelen *et al*. 2012).

Implications for WOZEP*: Given their small total population size and intensive usage of the southern North Sea during migration (Figure 10), the species would seem vulnerable to extra mortality, possibly particularly during wing moult. Direct mortality, from turbine strikes, could potentially be highly detrimental to this species. However, these birds are extremely manoeuvrable in the air (possibly less so during wing moult). It would therefore be a priority to study Great Skua behaviour in relation to offshore wind farms, during autumn migration, should this be possible anywhere in the North Sea. At present, a suitable site cannot be identified, as concentration areas of Great Skuas in the southern North Sea are not known. Therefore, the best way forward probably is to accumulate pieces of incidental information on the behaviour of skuas in offshore wind farms, anywhere. Approaching* *researchers involved in on-site offshore wind farm studies around the North Sea may help this forward.*

5.8 Red- and Black-throated Divers *Gavia stellata & G. arctica*

The parts of the North Sea that are relatively nearshore and shallow (<20 m deep south of Helgoland and <30 m deep north of Helgoland, in the eastern North Sea) comprise a major wintering area for Red-throated Divers and, in spring, also an important moulting area (particularly the parts north of Helgoland, in German and Danish waters: Skov *et al*. 1995). Black-throated Divers are probably mostly passage migrants, but small numbers also winter in the North Sea. In winter, the species are very similar in appearance and cannot always be separated when seen at distance, therefore the two species are taken together. We note, however, that the vast majority of divers wintering in the southern North Sea are Red-throated Divers (Camphuysen & Leopold 1994; Dierschke *et al*. 2012). To the north and northeast of Helgoland, relative numbers of Black-throated Divers have been reported to be higher than elsewhere in the North Sea, at 22% of all small divers (Christensen *et al*. 2006), although more recent surveys here set this percentage back to 9% (Petersen *et al*. 2014), which is more in line with percentages found elsewhere. Further south, Black-throated Divers are seen mostly in spring, when there is a short but marked migration peak along the Dutch coastline (Camphuysen & Van Dijk 1983; Platteeuw *et al*. 1994).

An estimated 38,000 small divers winter along the eastern seaboard of the southern North Sea, concentrating in the German Bight (Skov *et al*. 1995), and roughly 10,000 birds winter off the English east coast, concentrating in the outer Thames (O'Brien *et al.* 2008, 2012). These birds are highly sensitive to disturbance, either from shipping traffic (Schwemmer *et al*. 2011) or from offshore wind farms (Rexstad & Buckland 2012; Leopold *et al*. 2013; Furness *et al*. 2013; Percival 2014).

Divers arrive in the study area in August/September and their numbers build up further in October/November, to remain high over winter, with the highest densities in waters off NE Helgoland. In this same area, numbers peak in spring, when birds gather here in large numbers to moult. On the UK side, a large concentration starts building up off the Norfolk coast in autumn (October/November) and densities remain high here, and over a wide area stretching quite far offshore, until April/May. At present, most offshore wind farms in the North Sea are either present in diver habitat, or projected to be built here.

Red-throated Divers were found to avoid offshore wind farms to a large extent in most post-construction studies (Dierschke *et al*. 2016). With circa half the European population of Red-throated Divers wintering in the North Sea (the other half winters in the Baltic, also an area where offshore wind is becoming increasingly harvested), habitat loss might amount to a significant part of the total amount of habitat available to this species. Only low numbers of divers wash up dead in winter on Dutch shores, despite the nearshore abundance of divers in winter, suggesting low mortality rates, even in juveniles. An increase in this vital parameter might do significant damage to the population, that has little scope of moving elsewhere to winter. GPS-tracking of Red-throated Divers has been done in Iceland (Ib Krag Petersen, *pers. comm*.). It was hoped that these birds would migrate into the North Sea to winter, which might have yielded data on their reactions to the presence of offshore wind farms. However, these Icelandic birds all wintered in Icelandic coastal waters, and tracking information from birds in the North Sea is still lacking. Increasing habitat loss due to ongoing offshore wind farm development will need to be critically followed.

Implications for WOZEP*: In the Netherlands, offshore wind farms are generally projected too far offshore to impact many divers. This is quite different in e.g. Germany and in the UK, where many offshore wind farms are projected in prime diver habitat. These two countries are currently exploring possibilities to study these problems (including catching divers at sea for logger deployment: Ramunas Zydelis, pers. comm.). It is therefore advised to wait and see what results of these studies will be, rather than to try to study diver-offshore wind farm interactions in Dutch waters, where such* *interactions are much less severe. However, a close watch should be kept regarding possible developments in inshore waters: should wind farms be developed in e.g. the Voordelta, this situation changes dramatically and the Dutch would also be developing offshore wind farms in prime diver habitat. In that case, seeking a good working relationship through joint projects with the leading researchers abroad would be most advisable. It would also be possible to use the known concentration area in the Voordelta to launch our own (Dutch) diver studies, by setting up catching and tagging studies here.*

5.9 Razorbill *Alca torda*

Razorbills are very similar to Common Guillemots, but differ significantly in several ecological parameters. While generally breeding in the same sites, often in mixed colonies, their prey base and the way they catch their prey is different, at least in the non-breeding season. While Common Guillemot take a rather wide variety of prey in winter, including both very small and rather large fishes, mostly roundfish but also flatfish occasionally, many of which are probably caught near the sea floor, Razorbills are specialists taking mostly small clupeids, sandeels and three-spined sticklebacks *Gasterosteus aculeatus* in the southern North Sea in winter (Ouwehand *et al*. 2004; Leopold & Camphuysen unpublished). Behavioural observations of feeding auks in Dutch waters have indicated that wintering Razorbills are mostly shallow divers, a behaviour that often attracts parasitic Little Gulls *Hydrocoloeus minutus* and Black-legged Kittiwakes. These associations are seen much less with diving Common Guillemots. Further, in areas where auks concentrate in the non-breeding season, such as the Frisian Front in late summer and autumn and the Brown Ridge area in winter, Razorbills arrive here several months later than the Common Guillemots and are mostly found in the core area of these offshore habitats, while Common Guillemots occur more widely spread out. These findings seem to indicate that Razorbills might be much more specialists, that might be highly critical of habitat parameters. If this is the case, the amount of suitable habitat for Razorbills could be much more restricted that it is for Common Guillemots, and the impact of habitat loss, if this involves parts of the most critical habitat, would be much more severe.

Ringed Razorbills found in The Netherlands mostly stem from the UK, perhaps surprisingly from the west coast (Speek & Speek 1984; Wernham *et al*. 2002). Relatively few birds from Norway (Bakken *et al*. 2003) have been found here, as well as occasional birds from Iceland (Kees Camphuysen, *pers. comm*.).

On the Isle of May between 1986 and 1996, the average adult survival of Razorbills has been reported at 90.5% (Harris *et al*. 2000), which was lower than the value for Common Guillemots (95.2%). Razorbill survival was relatively low in 1995 (73% compared with a long-term average of 91%); such an "off-year" was not found in the Guillemot in that study.

GPS loggers have not yet been used on wintering Razorbills. With only information from classic ringing, very little can be said about the origin of Razorbills wintering in the North Sea, or on specific survival bottlenecks in their yearly cycle. Tentatively, one could say that Razorbills are the more critical auk species (compared to the Common Guillemot) which may have more to lose from habitat degradation and could already be facing lower adult survival.

Figure 11 *Razorbills are superficially similar to Common Guillemots, but are much more specialist feeders on small pelagic round fish and probably much more restricted in where they can go to feed, and thus more likely to be affected by displacement. Photograph: Hans Verdaat, 2 November 2016 in the Brown Ridge future SPA for these two auk species.*

Implications for WOZEP*: The at-sea ecology of Razorbills is less well known than that of Common Guillemots. Razorbills might a more "critical" seabird species, with fewer possibilities to use alternatives if preferred feeding areas are cut off. Identifying key habitats at sea for Razorbills is therefore at least as important for this species, as it is for Common Guillemots. Catching and tagging birds at sea, preferably in key areas for the species, would greatly help to understand its winter ecology at sea better, and the links "Dutch" birds must have to distant colonies. Like in Common Guillemots, Razorbills spend hardly any time flying at rotor height and collision studies are not a topic needing further study. Studies on displacement or, conversely, habituation and diet will be key to understanding the impact of offshore wind development on this species (Furness 2016).*

Other species

Dierschke *et al*. (2016) reviewed a wider range of seabird species and identified several (that were not treated above) as potentially vulnerable. These include three or four seaducks: Common Eider *Somateria mollissima*, Long-tailed Duck *Clangula hyemalis* and Common Scoter *Melanitta nigra* and possibly also Velvet Scoter *Melanitta fusca*; Great Crested Grebe *Podiceps cristatus*, Northern Fulmar *Fulmarus glacialis*, Little Gull and Sandwich Tern *Thalasseus sandvicensis*, while two smaller auks, Puffin *Fratercula arctica* and Little Auk *Alle alle* were data-deficient. One might add the White-billed Diver *Gavia adamsii* to this list: a rare species of diver that has recently been discovered to winter in low numbers in the Dogger Bank region (Burton *et al.* 2013; Andy Webb, *pers. comm.*). Not all of these species are relevant for wind farms in the Dutch part of the North Sea. The seaducks and the Great Crested Grebe typically occur here in nearshore waters (Leopold *et al*. 2014), where wind farms are not planned to be constructed (these species were identified to be vulnerable in the Baltic where this situation is different). Sandwich Tern and Little Gull venture further offshore and might come into contact with offshore wind farms. Sandwich Terns are being intensively studied in the Dutch Delta area (Prins *et al*. 2013; Fijn & Poot 2014, Fijn *et al*. 2016) with aerial surveys, studies of breeding biology and colour ringing and telemetry (GPS loggers), while colour ringing schemes have also been initiated on Texel, Ameland and Griend. The other species listed here (Northern Fulmar, Puffin, Little Auk and White-billed Diver) occur most commonly in the central and northern North Sea and are, currently, of little relevance to Dutch offshore wind farms (operational or planned). This may change in the future, if the Dutch will join in British initiatives developing the Dogger Bank area for offshore wind harvesting. The British have done much (T-zero) survey work in this area, but access to these data is still limited, for instance in the case of the White-billed Divers. Great Cormorants, finally, are birds that are probably positively impacted by offshore wind farms and a great deal can be learned about (positive) bird-wind farms relations by studying coastal Great Cormorants better.

Implications for WOZEP*: There would seem to be no need for specific, Dutch studies of those birds that reside generally too closely inshore to be impacted much by Dutch offshore wind farm development (seaducks, mergansers, grebes). Likewise, there is no need for Dutch studies on birds that generally live further offshore than our most offshore wind farms (Northern Fulmar, Puffin, Little Auk, White-billed Diver). This would only change if the Dogger Bank area will ever be developed by the Dutch. This leaves the Little Gull and the Sandwich Tern as birds that probably do overlap with our offshore wind farms. In the case of Little Gulls, this overlap is restricted in time, to the (rather short) period of heavy spring passage. During this time, Little Gulls use a wide band of coastal and slightly more offshore waters for foraging, between bouts of true migration. Distribution and habitat use should be much better known, and this could be done by a combination of dedicated aerial surveys (mapping) and ship-based sampling of potential prey and studies of at-sea behaviour of this species, in the few weeks that "migration" peaks off our coasts. In the case of Sandwich Terns, telemetry studies are clearly the next step forward and this could be stimulated by WOZEP.*

Coastal cormorants are severely under-studied and a WOZEP program to study range, diet, feeding behaviour and the use of offshore wind farms versus "natural" feeding sites would be a great help to get to know this species better, particularly in an offshore wind farm setting.

6 Conclusions and recommendations

The available data on the seabird species considered most vulnerable to offshore wind harvesting development are mostly insufficient to pinpoint specific colonies of origin, or identify survival bottlenecks within their yearly cycle that might interfere with offshore wind farms. Birds have been followed intensively in too few different colonies, and many colonies that would seem most relevant for offshore wind development in the southern North Sea have yet to be studied. Ideally, data would exist for situations in which wind farms are placed within the feeding range of colonies, that have received long-term monitoring. Most long-term monitoring, however, has been initiated independently from offshore wind development. Good example is the intensive monitoring of Lesser Black-backed Gulls and Herring Gulls on Texel (Camphuysen 2013), in a colony situated rather far from existing offshore wind farms, or the intensive monitoring of seabirds in the Isle of May. Direct, wind farm related monitoring of birds in breeding colonies is rare, but this is now being done on Helgoland, where a variety of seabird species is currently studied by tracking devices.

There are three main issues that need to be addressed if the impact of further offshore wind farm development is to be understood:

1. What is the origin (breeding colony) of birds present in specific offshore wind farms or in broader areas designated for offshore wind development?
2. How do birds behave in response to offshore wind farms?
3. What are survival bottlenecks of seabirds commonly occurring in areas designated for offshore wind development? Are these bottlenecks geographically and temporarily linked to their usage of these areas and if so, what population segment is most affected?

Regarding research question #1: birds breeding in colonies within the Netherlands may be involved (gulls, terns, Great Cormorant), for which research programmes are either already running, or could be organised with relative ease. There are, however, also bird species involved (divers, auks, some gulls, skuas, Northern Gannet, seaducks, mergansers, grebes, Northern Fulmar), that do not breed in The Netherlands which makes colony work more difficult to organise.

Regarding research question #2: several aspects of bird behaviour in, or in the vicinity of offshore wind farms are important: avoidance (leading to fewer collisions), displacement (leading to habitat loss), habituation (counteracting displacement) or even exploiting offshore wind farms for resting or enhanced feeding. Collision modelling can still benefit largely from better data on flying heights and avoidance, while effects of displacement are still largely unclear. Altered feeding behaviour within offshore wind farms is still to be explored from scratch.

Regarding research question #3: it has been shown that wind farms within feeding range of breeding colonies can affect the breeders. Due to lack of (tracking) studies on non-breeders, effects on immatures or on adults outside the breeding season are largely unknown. Similarly, it is often impossible to know where birds that migrate past or through wind farms, or stage here in the non-breeding season, originate from. In other words: it is often impossible to know where birds from a certain breeding colony spend most of their life at sea.

Within the context of WOZEP, several priorities for research can be identified, and consequently, other issues and species may be considered less important:
it seems wise not to invest (much) into species that are currently not thought to be at risk, such as seaducks, mergansers, grebes, Northern Fulmar, Atlantic Puffin and Little Auk. It may also be prudent to leave species that are more at risk in other countries than The Netherlands, to research programmes conducted elsewhere (where these species are more at risk, or where such species are more accessible in breeding colonies): e.g. divers, Northern Gannet, Great Skua, and concentrate efforts on species breeding in The Netherlands: Lesser Black-backed and Herring Gulls, Sandwich

Tern, Great Cormorant. Kittiwake and Red-throated Divers are borderline cases, as is explained further below.

The first fruitful approach within WOZEP will be to make use of existing data, which mostly will be ringing data. Large data sets exist for several species that are relevant to offshore wind farm development in Dutch waters. Lesser Black-backed Gulls and Herring Gulls have been colour ringed extensively, all along the Dutch coastline (Camphuysen *et al*. 2011; Camphuysen 2013; Huig *et al*. 2016) and the same applies to Sandwich Tern (Stienen 2006). These ringing data have been analysed to some extent, but detailed analyses of survival (site, year, season, sex and age-class related) have not yet been done. Such analyses are complicated but very well possible (Tamar Lok and Kees Camphuysen, *pers. comm*.) and would help our understanding of seasonal mortality (survival bottlenecks), and age and sex-related survival, as well as migration. Similar analyses may be contemplated for the Sandwich Tern, for which a large, long-term dataset exists for the once largest colony in The Netherlands (and in Europe): Griend. This species too, has been colour-ringed in several colonies in The Netherlands, with the longest monitoring in the Dutch Delta area. This dataset, with future extensions using the growing colour ring datasets for Texel, Ameland and Griend, would be an interesting starting point for this species. Preliminary analyses have shown initial northward, rather than southward post-breeding dispersal, which takes birds across the North Sea to e.g. Denmark and Scotland, possibly via offshore wind farm areas. The relative extent and wind farm associated risks have yet to be established.

First analyses of GPS-tracks of gulls (at sea: mostly Lesser Black-backed Gulls) have already been presented (Camphuysen 2011), but this dataset has been rapidly growing and in all likelihood, more insight can be gained from extended analysis (Kees Camphuysen, *pers. comm*.). Analyses of tracking data will elucidate usage of various parts of the North Sea (including wind farms) and may also provide data on flying heights, even in response to wind farms (Kees Camphuysen, *pers. comm*.). One problem with these data might be, that the study colony is situated on Texel, relatively far away from the nearest offshore wind farm.

A second option for WOZEP studies would thus be useful to extend the work with GPS loggers to colonies closest to existing and (near) future offshore wind farms: Schiermonnikoog (wind farm Gemini); IJmuiden (wind farms OWEZ, PAWP and Luchterduinen, and future wind farms off the Dutch mainland coastline) and Europoort/Maasvlakte (wind farms Borssele). Birds from these colonies are much more likely to venture near or into wind farms at sea, which makes collecting data here more relevant if responses to offshore wind farms are to be measured and modelled.

For seabird species that breed outside the Netherlands, such as Northern Fulmars, Northern Gannets, Common Guillemots, Razorbills, Puffins, we must rely on studies from abroad, or seek active co-operation with researchers there. Results are, however, not guaranteed as it is a priori impossible to tag exactly those individuals that will later winter in Dutch waters with offshore wind farms. The further the study colony is from (Dutch) offshore wind farms, the less likely it is that individual birds from these colonies, that visit these wind farms, can be equipped with data loggers. A first geolocator studies on Puffins, done in colonies along the west coast of the British Isles (Guildford *et al*. 2011) showed that these birds do not go to fixed wintering quarters but rather make a "wintering journey across vast areas of sea and ocean; that individual birds from the same colony make quite different wintering journeys but also that individuals tend to repeat journeys from year to year". Similar wide wintering ranges and inter-individual differences and intra-individual consistencies were found for Isle of May Puffins (Harris *et al*. 2013). These Puffins were found to winter both in the North Sea and in the Atlantic, with the ocean probably being a second-best option in years of food shortage in the North Sea. Likewise, Common Guillemots from Isle of May were found to disperse widely (Figure 12, taken from Harris *et al*. 2015).

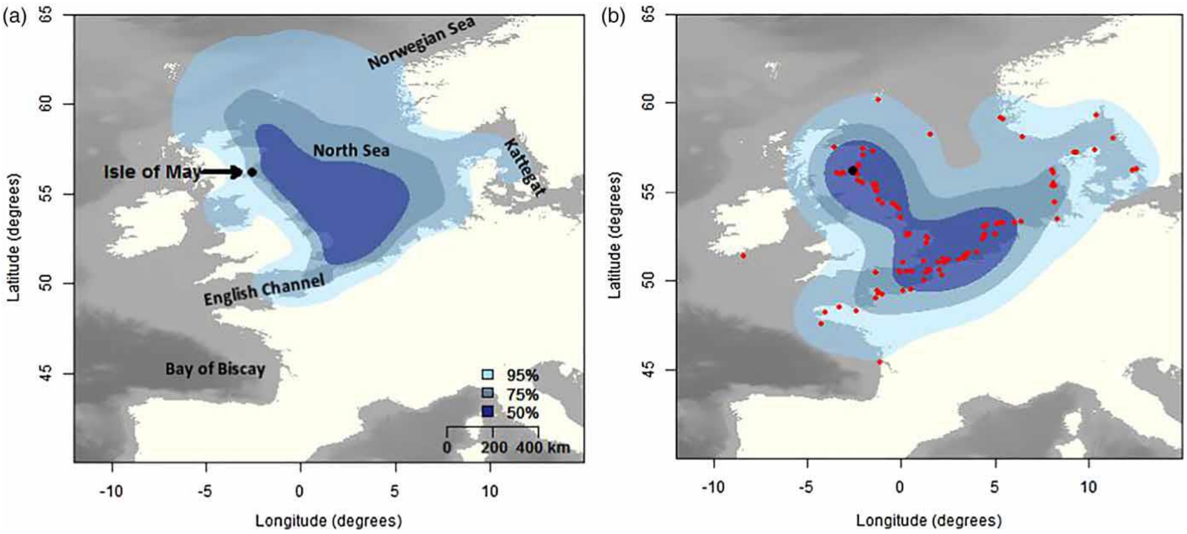

Figure 12 *The difference between geolocator data (left) and ringing recovery data (right), illustrated for Common Guillemots (Harris et al. 2015:* "Usage kernels 20 October to 23 February resulting from the deployment of geolocators on Common Guillemots breeding on the Isle of May over the 2011–2012, 2012–2013 and 2013–2014 winters based on 61 bird-winters (left), and locations of 149 recoveries (red dots) of Common Guillemots ringed on the Isle of May and reported during October to March when they were at least four years old. In both plots the 95%, 75% and 50% kernels are shown in increasing dark shades of blue*). Ringing recoveries from mainland Europe apparently mainly stem from vagrant birds.*

The closest (large) Common Guillemot colony in the UK, which is likely to be the source of relatively many birds that used Dutch offshore wind farm areas in the Netherlands, is on Bempton Cliffs (Mitchell *et al*. 2004). Equipping birds with satellite tags in this colony would yield the highest probability of success to get meaningful data of tracked birds over the Dutch Continental Shelf. This could be achieved by seeking co-operation with seabird researchers in the UK.

For the other seabird colony at relatively close range, Helgoland, the best strategy is probably to follow developments there. Stefan Garthe's group of seabird researchers is currently tracking a range of seabirds here, many relevant to offshore wind farms. Results of several studies will be published shortly (Stefan Garthe, *pers. comm*.).

An interesting possibility for research arises if gas production platforms are decommissioned and re-designed as offshore seabird colonies. It should be possible to facilitate breeding here for Kittiwakes and such a new, artificial colony could be claimed for research purposes. This would make it possible to put tagging devices on Kittiwakes breeding in the Dutch sector of the North Sea, relatively close to Dutch offshore wind farms, and to study there flight paths, as well as their diet.

The third possibility for WOZEP studies would be to launch a program aimed at catching and logging seabirds at sea, in wind farm areas or in areas close by, where seabird densities are higher and environmental conditions for catching more benign. Catching seabirds at sea has been proven to be possible (Ramunas Zydelis, *pers. comm*.). Red-throated Divers have been successfully caught offshore, in the German Bight, using relatively small boats, a strong light and a catching net. The advantage of catching birds directly in the relevant study area are obvious. In the Dutch situation, Red-throated Divers can probably be caught, with "relative ease" near the Brouwersdam, where diver densities are high and seastates generally low.

Clearly, other highly relevant seabirds, most notably Great Cormorants. Lesser Black-backed Gulls, Great Black-backed Gulls and wintering Herring Gulls of a northern origin, can be caught at sea. Several options are open to catch gulls at sea, as these birds can be lured by providing food, either behind a fishing vessel or on a "catching platform" in an offshore wind farm. Cormorants can probably be snared in wind farms, or, alternatively they can be caught in nearby colonies. Great Cormorants from two colonies in Noord-Holland have made offshore wind farms their secondary home and individuals exploiting the offshore wind farms can probably identified within these colonies by food remains at their nests: such birds can then be caught, tagged and followed. Given the extensive usage that Dutch Cormorants make of our offshore wind farms, it would be advisable to consider a research programme directed specifically at these birds.

The fourth possibility for WOZEP studies would be to commence studies on the geographical variation of seabird quality at sea and to conduct observations on feeding behaviour and diet within offshore wind farms. Seabird quality could relatively easily be assessed from existing data on plumage variation (auks, Northern Gannet), while a first pilot study is foreseen on Common Guillemot behaviour in an offshore wind farm; depending on the outcome of pilot, possibilities for further research will be evaluated.

7 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

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Justification

Report C046/17
Project Number: 4315100046

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Dr. Tobias van Kooten
Senior Scientist & WOZEP coordinator for Wageningen Marine Research

Signature: 

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'To explore the potential of marine nature to improve the quality of life'

The Wageningen Marine Research mission

- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
- Wageningen Marine Research is an independent, leading scientific research institute

Wageningen Marine Research is part of the international knowledge organisation Wageningen UR (University & Research centre). Within Wageningen UR, nine specialised research institutes of the Stichting Wageningen Research Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment.