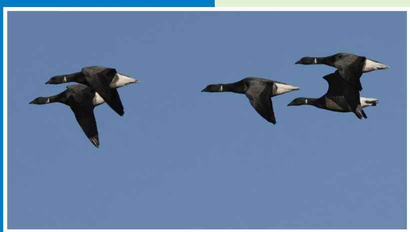
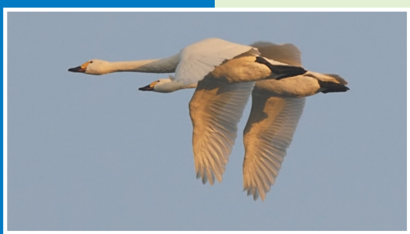
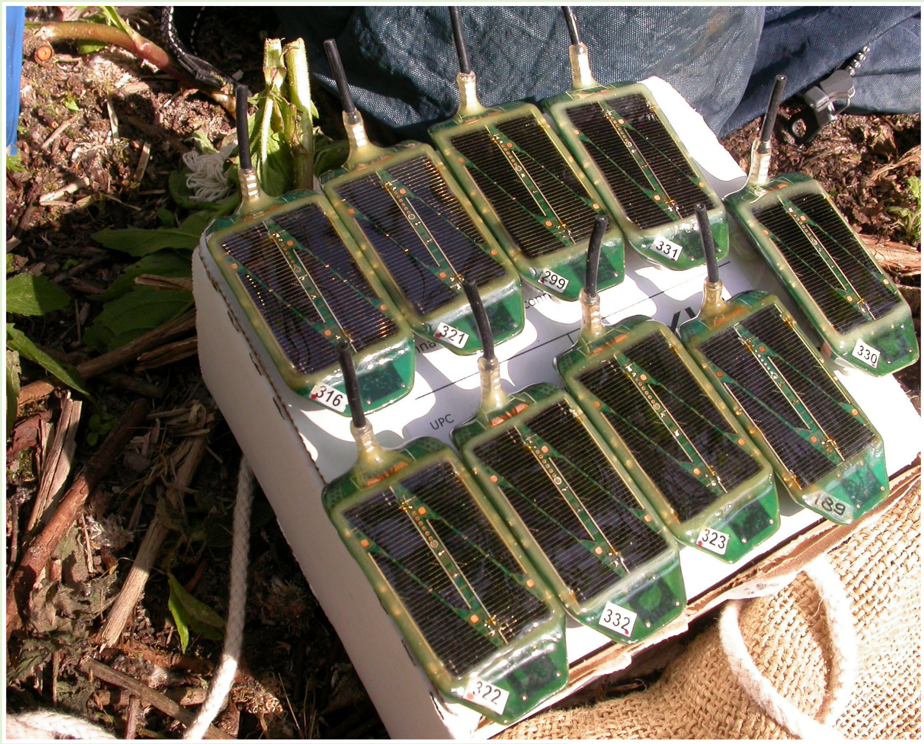
Review and analysis of tracking data to delineate flight characteristics and migration routes of birds over the Southern North Sea







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Preface

Rijkswaterstaat has, under the Wozep project (Wind Power at Sea Ecological Program), commissioned Bureau Waardenburg to review the available published data on bird tracking studies as well as information on existing datasets of tracked birds that contain migration routes, offshore flight speed, altitude or nocturnal activity of species that migrate over the Southern North Sea.

The aim of this study is to produce improved figures for use in collision rate models in relation to wind farm developments in the Southern North Sea. The project was designed with three main lines of investigation:

1. To review the data, published and unpublished, currently available on migration routes and flight behaviour, for designated priority and similar species.
2. To carry out additional analyses of existing data to obtain figures on flight speed, flight height and nocturnal activity.
3. To carry out new calculations with the SOSS Band model, in order to obtain improved figures on the number of collision victims.

Internal quality control of this report was conducted by H. Prinsen (Bureau Waardenburg).

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1 Introduction

1.1 Wind Power at Sea Ecological Programme (Wozep)

In 2015, the Dutch Ministry of Economic Affairs and the Ministry of Infrastructure and Environment initiated an integrated monitoring programme to address gaps in the knowledge relating to the effects of offshore wind farms on the North Sea ecosystem. This monitoring and evaluation programme (Wozep) focuses on important environmental issues related to the construction and operation of offshore wind farms, not specific to particular wind farm locations. The Wozep replaces the monitoring obligations of individual wind farm initiatives.

1.2 Background

Large numbers of wind farms are currently being planned or have already been constructed. Notwithstanding the benefits of this development including low carbon emission and energy security, collision victims among birds are considered one of the major ecological drawbacks of wind energy. Unlike other effects of wind turbines on birds, such as disturbance, barrier effects and habitat loss, the consequences of collisions are potentially directly evident in a population within a short temporal scale.

The KEC study (Rijkswaterstaat 2015) and the Environmental Impact Assessments (EIAs) of several offshore wind farms described that among several species of migratory birds substantial numbers of collision victims can be expected in the Southern North Sea. Some of these species are susceptible to such additional mortality, either because they have altogether a small flyway population or because a major part of the population is flying over the Southern North Sea. Some species might also have concentrated migration corridors between the Netherlands and the UK that could fall within the areas of future wind farm sites.

Based on the above, swans, geese, ducks, waders, gulls and skuas are expected to be especially vulnerable to offshore wind power developments. In table 1, the 18 migrant species that are expected to reach collision mortalities above 1% of the potential biological removal (PBR) according to the KEC study (Rijkswaterstaat 2015) are highlighted. Most of these species belong to the groups of wildfowl and waders. In addition, based on the KEC study (Rijkswaterstaat 2015), later impact assessments of offshore wind farms (Fijn et al. 2015, Gyimesi et al. 2016c) and expert judgement it is expected that Herring Gull (*Larus argentatus*), Lesser Black-backed Gull (*Larus fuscus*), Great Black-backed Gull (*Larus marinus*), Little Gull (*Larus minutus*) and Great Skua (*Stercorarius skua*) may be subject to relatively large numbers of collisions with offshore wind turbines.

Table 1 Species highlighted in the KEC study (Rijkswaterstaat 2015) as having an expected collision probability higher than 1% of the potential biological removal (PBR). Size of the species is indicated as mean weight (g; source: BTO Birdfacts), where ranges are given for species with distinctive differences between males and females. Species in bold are discussed in present study.

Species group	Species	% Collision of PBR	Mean weight (g)
Wildfowl	**Bewick's Swan**	42%	5300-6400
	Pink-footed Goose	2%	2500
	Brent Goose	2%	1500
	Common Shelduck	4%	1000-1200
	Greater Scaup	3%	1000
	Tufted Duck	1%	760
Waders	**Curlew**	57%	770-1000
	Bar-tailed Godwit	6%	300-370
	Woodcock	1%	280
	Lapwing	3%	230
	Knot	10%	140
	Redshank	4%	110-130
	Turnstone	2%	120
	Snipe	2%	110
	Sanderling	20%	59
Terns	Black Tern	50%	73
Passerines	Starling	12%	78
	Skylark	3%	35-42

Assessments as to the potential numbers of collisions at proposed offshore wind farms are commonly determined using the SOSS Band model (Band 2012). This model incorporates a number of species- and location-specific parameters, including: size, flight speed, flight altitude and level of nocturnal activity, as well as local bird densities. Due to the influence on numbers of birds exposed, encounter probability and collision risk, the parameters flight speed, altitude and nocturnal activity have particular influence on the estimated number of collisions. In the absence of site-specific data, these parameters are often obtained from the literature. Figures for flight speed are commonly based on flights tracked by radar (Alerstam et al. 1993, Alerstam et al. 2007). Available flight height profiles are often largely based on visual observations, which are subject to crude classifications and biased towards situations with good visibility (e.g. during daytime rather than at night). Therefore, improved estimates are therefore needed (Furness *et al.* 2013). Furthermore, published estimates of nocturnal activity are based on few or no empirical data (Garthe and Hüppop 2004, Furness et al. 2013).

Detailed measurements of flight speeds, altitudes and nocturnal activity have recently been made possible by tracking studies, namely by deploying GPS loggers and satellite transmitters. Moreover, due to the continued decrease in the size of the equipment, the movements of smaller and smaller species can be studied. Most studies follow guidelines that the weight of the tags should not exceed 3-5% of the body mass of the bird (Barron et al. 2010), with researchers commonly following a conservative 3% as a general rule. As the smallest tracking devices that can *remotely transmit* GPS data are around 5 g, this corresponds to approximately 150 g body weight (López-López 2016). According to this rough estimate, all wildfowl and approximately half of the wader species presented in table 1 are large enough to be equipped with a logger or transmitter. Species of the size of the Redshank (*Tringa totanus*; 110-130 g) or smaller, including the Black Tern (*Chlidonias niger*) and the two passerine species are currently unlikely to be studied by remote download tracking devices registering GPS data, flight speed or flight height. This report summarizes the current knowledge on tracking studies on the largest 11 species of table 1, as well as for Great Black-backed Gull, Little Gull and Great Skua. However, due to the limited information on some of these species, comparative studies on closely related species that were equipped with tracking devices are reviewed. Detailed studies on the movements, flight speeds and altitudes of Herring Gull and Lesser Black-backed Gull have been reported elsewhere (Gyimesi et al. 2016a).

1.3 Aim of this study

The **first part** of this study reviews the currently available data, focussing on tracking studies that were published in peer-reviewed papers, with particular relevance to species that migrate through the Southern North Sea or studies that obtained flight speed and flight altitude measurements. In addition, an overview is provided on datasets per species that have not yet been published but may contain relevant data.

The **second part** of this study comprises an analysis of the available unpublished data identified in part 1, providing information about offshore flight speed, altitude and activity, in order to calculate improved figures for use in collision rate models. In addition, the final report will contain advice on future research based on the findings of the review, with the aim of addressing gaps in the knowledge of relevant species.

PART 1 - REVIEW OF TRACKING STUDIES

Below we describe the available tracking studies or data on flight behaviour and migration strategy of priority species. The review focused on the availability of data on migration routes, flight speed and altitude. The review is based on an extensive literature research and direct contact with researchers. Data on Lesser Black-backed Gull and Herring Gull are reported elsewhere and in greater detail (Gyimesi *et al.* 2016).

2 Species accounts

2.1 Bewick's Swan

In January and February 2014, the Wildfowl & Wetlands Trust (WWT) caught eight Bewick's Swans and a further 14 in winter 2014/15 in southern England. The birds were fitted with collar-mounted radio-GPS-GSM data loggers, which provide up to half-hourly location data via the mobile phone network. This tracking of Bewick's Swan migration in relation to offshore wind farm sites between their wintering grounds in the UK and their breeding areas in the Russian Arctic was undertaken by WWT for the Department of Energy and Climate Change (DECC; now the Department for Business, Energy & Industrial Strategy) to inform the UK Government's Strategic Environmental Assessment of offshore renewable energy projects. The study aimed specifically to describe the swans' movements between the UK and continental Europe (Griffin et al. 2016).

After some technological problems with most of the tags deployed in 2013/14, the upgraded loggers fitted in 2014/15 gave detailed half-hourly to hourly location data on movements across the North Sea (Figure 2.1.1), with five tags also collecting altitude data. Analysis of the Bewick's Swan tracks is still on-going, but for example it is known that one individual tracked in spring 2014 crossed two consented offshore wind farms in Dutch coastal waters (Griffin et al. 2016).

In addition to this research targeted on the effects of offshore wind farms, the Netherlands Institute of Ecology (NIOO) deployed neck collars on Bewick's Swans between 2006 and 2011. In total, 48 birds were equipped with a coded neck collar containing a GPS data logger (2006/2007: 12, 2009/2010: 23, 2010/2011: 13). The loggers recorded the GPS location of the swans two (2006/2007), four (2009/2010) or eight (2010/2011) times per day for a full year. In total, 7 year-round tracks of individual Bewick's Swans were obtained. The loggers recorded the GPS position of the swans eight times per day for the first year (and then once per day as long as the battery worked). The precision of the measurements was high, on average 3.5 m (Nuijten *et al.* 2014). At least one of the tracked swans also crossed the North Sea to England (Nolet et al. 2014). There is a limited amount of unpublished data on other crossings (pers. comm. B. Nolet). The loggers also recorded speed but no information is published on these measurements.

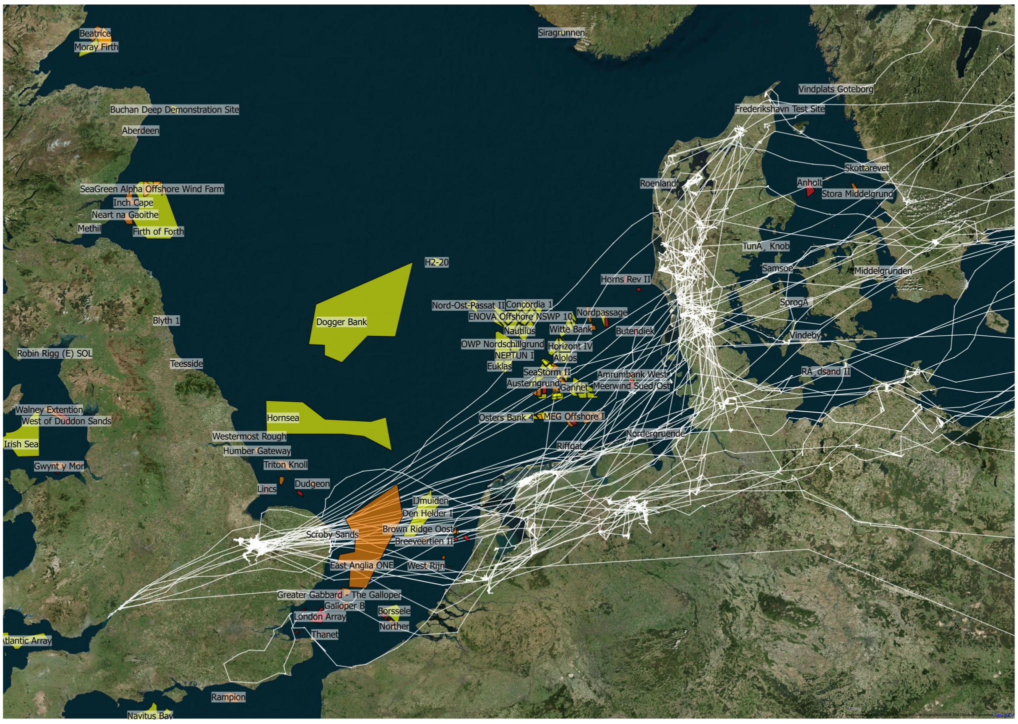

Figure 2.1.1 Crossings of Bewick's Swans equipped with GPS-loggers from England to the Netherlands (figure from Griffin et al. *2016).*

Based on satellite tracking NIOO published calculated ground speeds for Bewick's Swan on migration. Based on seven return migratory tracks from 1993 and 1996, the flight speed during migration (spring and autumn?) was estimated at 72 km/h (Beekman et al. 2002). Another eight Bewick's Swans equipped with satellite transmitters in combination with altimeters and activity sensors measured flight altitude during spring migration from Denmark to northern Russia in 1996. During the 82 occasions where a swan's location was recorded in flight, average flight altitude was 165 m above sea level (a.s.l.), with a maximum of 759 m a.s.l., despite winds often being more favourable at higher altitudes.

Lately, within the programme "The odyssey of the Bewick's Swan – another route to Greece" an initiative was taken in 2015 by the Severtsov Institute for Ecology and Evolution (Moscow) and the Royal Belgian Institute of Natural Sciences (Brussels), in partnership with Greek research institutes to track Bewick's Swans migrating from the Yamal Peninsula in Arctic Russia to their wintering grounds. More tagging and marking with neck collars of Bewick's Swans on the Yamal Peninsula is being planned for future years but according to the data for the first year, these swans are migrating east of the Ural mountains (Vangeluwe et al. 2016). Nevertheless, flight speed and flight height data are available (pers. comm. D. Vangeluwe) and might be a valuable addition to the database of Bewick's Swans. The researchers are open for co-operation.

In addition to data on Bewick's Swans, the Alaska Science Center of the US Geological Survey monitored the fates of 50 satellite-implanted Tundra Swans (*Cygnus columbianus* of which the Bewick's Swan is a closely related species) over four years from five disparate breeding areas in Alaska, among its aims to determine migration distances and migratory flyways (Ely and Meixell 2016). During this research, the Argos (Microwave) PTTs did not record altitude but did record speed. An examination of just a few trajectories where birds were certainly in flight shows flight speed values as high as 120km/h and as low as 40km/h (pers. comm. C. Ely). The authors are working on a new publication summarizing migration timing of Tundra Swans, where they will make some reference to maximum flight speeds (ground speed). On request, the authors are currently looking into the possibility to make estimates on flight speed from a reduced set of birds known to be in flight (pers. comm. C. Ely).

2.2 Pink-footed Goose

In 2011 and 2012, Aarhus University deployed 12 satellite transmitters (PTT solar Argos/GPS) on adult male Pink-footed Geese (*Anser brachyrhynchus*) within western Denmark in order to study foraging behaviour and fuel accumulation at spring stopover sites (Chudzińska et al. 2016). The birds were migrating from Denmark along Norway to their breeding sites in Svalbard, yet some information is available on migration routes from the following autumn migration towards the Netherlands and Belgium (Figure 2.2.1; unpublished data M. Chudzinska). Birds crossed offshore areas during migration without problems (unpublished data M. Chudzinska). The project finished in 2015. Data collection did not include height or instantaneous speed data, only locations (pers. comm. J. Madsen).

Previously, Aarhus University has also deployed satellite transmitters (PTTs) on Pink-footed Geese in 2003 and 2004 (Glahder et al. 2006). The study did not include speed or height measurements and the birds travelled between breeding sites on Svalbard and wintering sites in Denmark. Therefore, no information is available from the Southern North Sea. The researchers provided access to both of their datasets.

The Wildfowl & Wetlands Trust (WWT) in the UK caught two Pink-footed Geese near Halslon Lake, east Iceland and fitted them with GPS tags in 2013 (pers. comm. C. Mitchell). The project aimed to monitor the migration routes of Pink-footed Geese from their moulting grounds in Iceland to their winter areas in Britain. The birds did not cross the North Sea (apart from near shore movements along the east coast of the UK) and speed measurements during migration were not carried out.

Figure 2.2.1 An example of the GPS positions of a Pink-footed Goose during its spring migration in 2012 (unpublished data M. Chudzinska & J. Madsen).

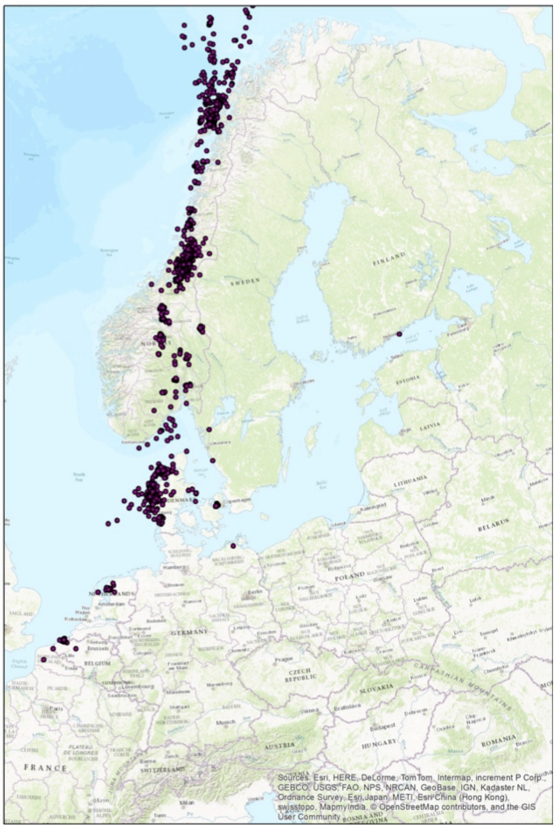

Figure 2.2.2 Spring migration of Pink-footed geese in 2011 and 2012 between wintering sites and the breeding sites on Svalbard (unpublished data M. Chudzinska & J. Madsen).

2.3 Brent Goose

The project “Habitat use of Brent Geese (*Branta bernicla*) along their flyway” is funded by the Wadden Fund project Metawad‐1. Metawad‐1 is a 5-year research programme carried out by a consortium made up of NIOZ, the University of Groningen, The Netherlands Institute of Ecology (NIOO), The Nature Information Foundation (Stichting Natuurinformatie) and the Dutch Centre for Field Ornithology (SOVON). Within this project a total of 30 birds were tagged with GPS trackers on the islands of Terschelling and Schiermonnikoog in the Dutch Wadden Sea in 2012. The birds were fitted with loggers of the University of Amsterdam (UvA BiTS). The tags record the birds’ geographic position every hour year-round, in addition to flight speed and flight height. Data on migration routes, flight speed and flight height from this research have not yet been published. However, it is known that several of these geese crossed the North Sea between England and the Netherlands during their migration in autumn and early spring (pers. comm. A. Dokter).

Previously, the University of Bristol has used GPS transmitters with the Argos satellite system to track two Brent Geese of the light-bellied subspecies (*hrota*) between Iceland and Arctic Canada (Pennycuick *et al.* 2011). Although the migration route of this population is not relevant for current study, flight height and speed is expected to be representative for the both the Svalbard population of Light-bellied Brent Geese and the Dark-bellied (*bernicla*) subspecies. In addition, Green *et al.* (2002) recorded flight speeds that ranged between 58 and 109 km/h during migration by equipping nine satellite transmitters on Brent Geese in the Dutch Wadden Sea. In another study also relying on satellite platform transmitting terminal (PTT) transmitters, adults of another closely related subspecies the Grey-bellied Brent Geese (*nigricans*), were captured in the Canadian High Arctic in 2002 and 2005. The average ground speed over the mid-portion of the Pacific Ocean for two of these geese was estimated at *c.* 50 km/h (Boyd et al. 2013).

Before that, average airspeeds at migration were measured by radar and range finder resulting in speeds of 69 km/h in spring and 61 km/h in autumn (Green and Alerstam 2000), that fit within the range measured by the satellite transmitters. During the same study flight altitudes were also measured that resulted in mean values of 341 m (±163 m SD) in spring and 215 m (±172 m SD) in autumn (Green and Alerstam 2000). Later, during a more extended radar study similar flight heights (297 m ±125 m SD) and flight speeds (71 km/h) were measured (Green 2004).

2.4 Shelducks

2.4.1 Common Shelduck

In 2009, the Royal Belgian Institute of Natural Sciences tagged five Common Shelducks (*Tadorna tadorna*) in Belgium using solar powered GPS PTT’s. More recently, two young, and eight adult male Common Shelducks were equipped with a

GPS-GSM transmitter in November 2014 and November 2015 respectively (Figure 2.4.1). These Common Shelducks move between France, the United Kingdom, the Netherlands and Germany. Unfortunately, no speed or height measurements were recorded (pers. comm. D. Vangeluwe). The Royal Belgian Institute of Natural Sciences have indicated that they are willing to make their data available for a financial compensation.

The German NABU institute equipped recently in Schleswig-Holstein (Germany) eleven Common Shelducks with GPS tags. Unfortunately the tags did not record proper data on the flight heights of the birds and also the flight speed has not been recorded properly (pers. comm. D. Cimiotti). The research took place about 50 kilometres north of the moulting areas in the Elbe estuary. There was no need for the birds to fly over the sea to reach the moulting areas and so they only flew in the neighbourhood over land or along the coast.

In addition, the British Trust of Ornithology (BTO) has worked on collecting GPS measurements on the local movements of the Common Shelduck in the UK. Tags were attached with a glue-mount. Data were only collected over the winter and the tags had stopped functioning before migration, so there are no migratory data available (pers. comm. E. Scragg). Relevant data on flight height or speeds were not collected.

Figure 2.4.1 Common Shelduck equipped with a GPS-GSM transmitter in November 2015 in Belgium (Vangeluwe 2015).

2.4.1 Ruddy Shelduck

In addition to the Common Shelduck (*Tadorna ferruginea*), flight height and speed data have been extensively measured for the closely related Ruddy Shelduck in Asia. The results of the research on the flight behaviour of Ruddy Shelducks will be submitted as a manuscript to a journal later this autumn. The authors are looking into the possibility of sharing information on flight speeds and height as long as it would not interfere with their publication (pers. comm. J.Y. Takekawa).

2.5 Ducks

In table 1 the Greater Scaup (*Aythya marila*) and the Tufted Duck (*Aythya fuligula*) are indicated as species of which the population might be particularly vulnerable to collision mortality in the Southern North Sea. However, there is no information available that any tracking studies are conducted on the Greater Scaup and there is only very limited work conducted on Tufted Ducks. Generally, diving birds are more difficult to equip with tracking devices. Therefore, below we also describe the results available on two other duck species that were successfully tagged in the past.

2.5.1 Greater Scaup

In the spring of 2016, the U.S. Geological Survey tagged a total of 226 birds of seven different duck species. Both the Greater Scaup and closely related Lesser Scaup were among the targeted species with birds from Atlantic populations being marked. At present, it is unclear whether there are any relevant measurements on flight height and flight speed available for this species.

2.5.2 Tufted Duck

In 2007, the Max Planck Institute for Ornithology deployed Argos transmitters, in order to track the movements of waterbirds related to Lake Constance (initially part of an avian influenza study). Tufted Ducks were among the tagged species and three of these birds returned successful measurements. However, the results concern local movements and it is unlikely that these Argos transmitters measured speed or height.

In addition, DHI (Denmark) and BioConsult (Germany) implanted Argos PTT transmitters in Tufted Ducks in the Fehmarn Belt in Denmark in order to investigate local and long-distant movements of wintering birds. No reliable altitude and speed information was acquired. Only a few individuals of Tufted Ducks were tracked successfully and these did not visit the North Sea (pers. comm. R. Zydelis).

2.5.3 Mallard

No direct data on migration routes, flight speeds or flight heights are directly available for the Mallard (*Anas platyrhynchos*) from the Southern North Sea. However, Safi *et al.* (2013) reviewed flight speed data that were collected from GPS tags applied elsewhere on 108 individuals between 2008 and 2010. Based on 1293 tracks, they calculated a mean airspeed of 15.86 m/s for Mallard.

Furthermore, in 2008 and 2009, the Max Planck Institute for Ornithology equipped 76 juvenile females with either 22 or 30 g solar-powered Argos/GPS platform transmitter terminals in Sweden and Germany (Ottenby and Lake Constance) in order to measure migration behaviour (van Toor et al. 2013). Flight speed was measured for 22 of the birds, but height measurements were not part of the study. Most of the birds made migration movements above land but some individuals flew long distances offshore (Figure 2.5.1). Data are freely available from the Movebank Data Repository and the authors have agreed to the use of the data (pers. comm. W. Fiedler, M. van Toor and J. Waldenström).

The Linnaeus University of Sweden caught 40 wild Mallards (24 males and 16 females, all first calendar year birds) in October 2010, and equipped them with a GPS device. Each device was set to record one data point every 15 minutes, including information about time, location (usually accurate to within 10 meters) and ground speed (Bengtsson et al. 2014). These birds were marked in Sweden and the recorded flight speeds of these birds could be representative for Mallards crossing between the Netherlands and the United Kingdom. At this moment it is unclear whether the leaders of this study would be willing to cooperate in current project.

Figure 2.5.1 Map of tracked Mallards in the study of van Toor et al. (2013). The release locations are highlighted by red circles, black lines indicate migratory movements.

In 2013, the Max-Planck Institute for Ornithology together with the Management Authority of Evros Delta in Greece tagged a single Mallard in order to study the daily movements and seasonal migration of the species. There were only three successful

speed measurements. Moreover, according to the GPS positions the bird flew to the Danube Delta, and hence the study has no relevance for the current project.
In order to examine movements of migratory birds in relation to potential transmission of avian influenza, the USGS Western Ecological Research Center tagged 20 birds of six different duck species (including Mallard) in Turkey in 2010. The data were collected by Argos transmitters with an accuracy of approximately 100m (pers. comm. J.Y. Takekawa). No height and speed measurements are available and it is unlikely that birds from this study migrated through the North Sea.

As mentioned above (see §2.5.1), the USGS tagged a large number of ducks in the spring of 2016. The study included measurements on flight speed but to date have not included altitude with data transmission from the tags. Due to the limited number of tagged Mallards migration speed could only roughly be estimated and resulted in a median speed of 83 km/h (pers. comm. C. Overton).

2.5.3 Pintail

No direct data on migration routes, flight speeds or flight heights from the Southern North Sea were published for Pintail (*Anas acuta*). Parejo *et al.* (2015) fitted six Pintails with GPS-GSM tags to study the birds on migration between Spain towards their breeding grounds in northern Russia. However, as two individuals died from hunting in France and the remaining four died between the Netherlands and France, no data are available for the North Sea. More tagging of Pintail is planned for the near future (pers. comm. M. Parejo).

Previously, the Western Ecological Research of the U.S. Geological Survey published ground speeds of Pintails on migration based on satellite tracking data. Based on data from 17 PTT-tagged females along 21 migratory flight paths, Pintails migrated at an average groundspeed of 77.6 km/h (Miller et al. 2005).

The study of the USGS Western Ecological Research Center examining the movements of migratory birds in relation to transmission of avian influenza (see §2.5.2) also included Pintails. However, as Argos transmitters were used, no height or speed measurements are available and it is unlikely that birds from this study migrated through the North Sea.

As mentioned above, the U.S. Geological Survey (see §2.5.1) tagged a large number of ducks in the spring of 2016. The Pintail was again tagged, and gave the majority of the measurements on flight height and speed during migration of all species. From the available information the median migration flight speed is estimated at 75 km/h (pers. comm. C. Overton), being really close to estimated earlier for migrating Pintails (Miller et al. 2005).

2.6 Curlew

The German Federal Agency of Nature Conservation (BfN) is currently running the project called BIRDMOVE that is intended to investigate movements of birds in connection with the establishment of offshore wind farm sites in the North and Baltic Seas. Within this project, four Curlews (*Numenius arquata*) were equipped with GPS data loggers and their migration patterns between the German Wadden Sea and north-eastern Russia were recorded during 2014–2015 (Schwemmer et al. 2016). The mean flight speed of these four birds was 63.7 km/h over the autumn and spring migration. No flights heights have been collected within the project so far.

In addition, the British Trust of Ornithology (BTO) has worked on collecting GPS measurements on the Curlew, Redshank, Teal (*Anas crecca*), Wigeon (*Anas penelope)* and Shelduck in the UK. Tags were attached with a glue-mount. Data were only collected over a single winter and the tags had stopped functioning prior to migration, so no migratory data are available. Relevant data on flight heights or speeds were not collected (pers. comm. E. Scragg).

In France, the University of La Rochelle is working on tracking studies of Curlews. They have tracked 12 Curlews, of which some also crossed the North Sea (pers. comm. P. Bocher). However, only speed measurements were carried out and no height measurements. The coordinator of the programme is willing to cooperate but it is yet unclear upon what conditions.

2.7 Bar-tailed Godwits

2.7.1 European subspecies

The Dutch Wadden Sea is an important stop-over site for Bar-tailed Godwits (*Limosa lapponica*) during their seasonal migration (Duijns et al. 2015, Buiter et al. 2016). In comparison with other wader species there have been many GPS logger studies carried out on this species, mostly on the subspecies that migrates between Asia, Australia and New Zealand.

The University of Groningen is currently conducting research on the European subspecies of Bar-tailed Godwits (*Limosa lapponica lapponica*) within the Wadden Fund project Metawad. The study is based on a long-lasting colour-ringing programme that has also shown that birds from the Wadden Sea regularly cross the North Sea to England if conditions in the Netherlands are not favourable (Figure 2.7.1). The first unpublished tracks of godwits crossing the North Sea carrying tags have been recorded (pers. comm. T. Piersma). Speed and height during the flights are recorded but have yet to be analysed. The researchers are open to cooperation if resources are available to analyse the data.

The Norwegian Ornithological Society has tagged since 2009 nine individuals with <5gr Argos satellite transmitters to follow the migration movements of Bar-tailed Godwits. However, due to technical problems only three transmitters have recorded proper migration data, the remainder only registering local movements. The first preliminary results of the records are depicted in Figure 2.7.2 (unpubl. data T. Aarvak), and clearly indicate that some individuals from the Wadden Sea directly fly to Ireland during the winter. The researchers are in the process of writing up some of the results, but due to the limitations of the Argos transmitters, no direct height or speed measurements are available. Based on subsequent positions, flight speeds could be calculated for a few flights, but the usefulness of these is doubtful as no information is available on whether birds stopped on their way or not. Flight speeds determined this way range from approximately 50 km/h to more than 170km/h. The latter happened on northward migration of a bird flying with tailwind in a strong south gale. The researchers plan to continue the project by deploying approximately 10 more transmitters.

In France, the University of La Rochelle is working on tracking studies of Bar-tailed Godwits. They have tracked 2 Bar-tailed Godwits, of which one flew from East-England to Siberia and thereby crossed the North Sea (pers. comm. P. Bocher). However, only speed measurements were carried out and no height measurements. The coordinator of the program is willing to cooperate but it is yet unclear upon what conditions.

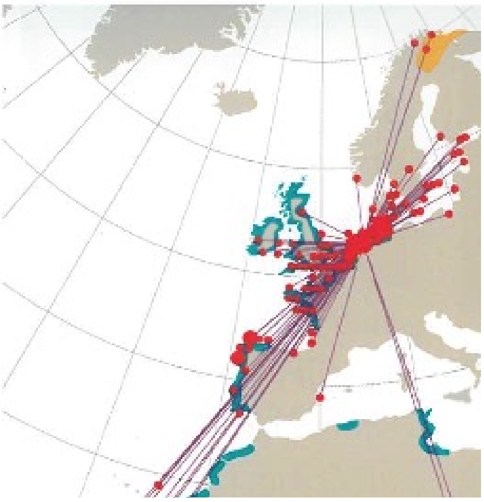

Figure 2.7.1 Movements of colour-ringed Bar-tailed Godwits in Europe. The red dots are positions where colour-ringed individuals were sighted. Lines connect positions where one certain individual was seen (Buiter et al. 2016).

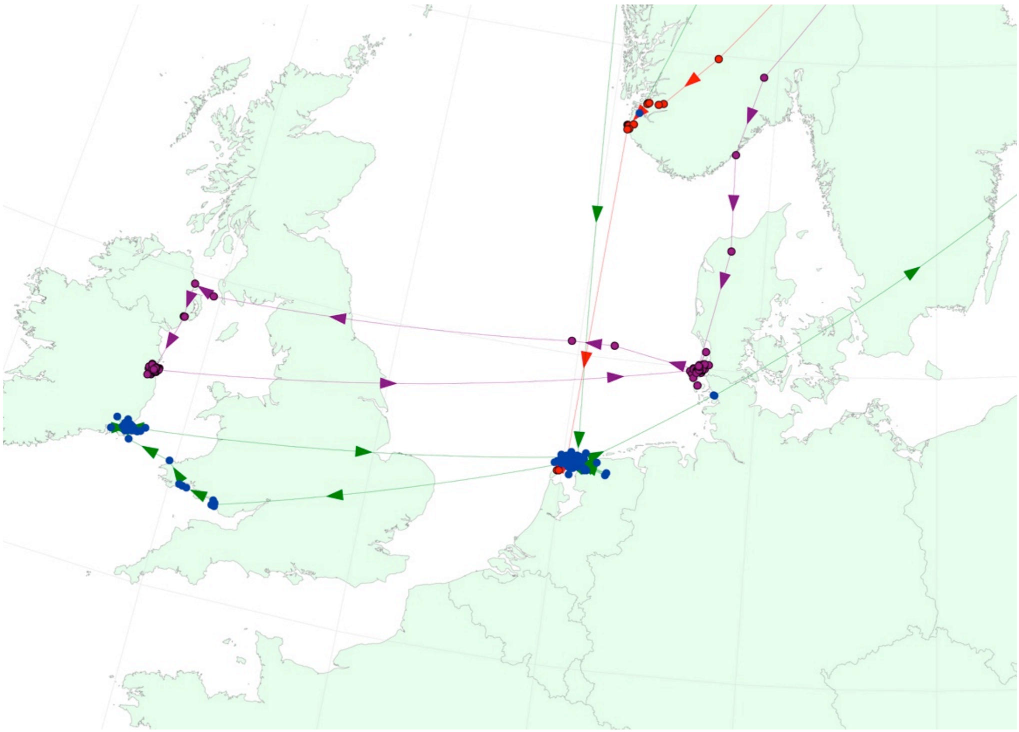

Figure 2.7.2 Migratory movements of Bar-tailed Godwits tagged in Norway. Colours indicate different individuals (unpubl. data T. Aarvak).

The Institute of Avian Research “Vogelwarte Helgoland“recently marked Bar-tailed Godwits with PTTs. However, the study was deemed successful as most PTTs failed after a few weeks or months (pers. comm. M. Exo).

2.7.2 Other subspecies

Published records (Battley et al. 2012) for flight speed are directly available for the subspecies *baueri* (ranging from 53.3 km/h to 63.3 km/h) and *menzbieri* (ranging from 58.2 km/h to 76.3 km/h), which occur from the Central Asian to Central Pacific flyways.

In November 2015, NIOZ researchers, together with biologists from the Sultan Qaboos University, attached PTT transmitters on ten female Bar-tailed Godwits of the subspecies *taymyrensis* at an intertidal area of Oman. Migration routes of this subspecies are not relevant and speed is not measured as part of this study. Although the first results are available on height measurements it is currently unclear how accurate these are (pers. comm. R. Bom) and hence whether they are of value for the current project.

2.7.2 Black-tailed Godwit

Besides the Bar-tailed Godwit, there are also studies conducted on the related Black-tailed Godwit (*Limosa limosa*). For example, the University of Groningen is using UvA-

BiTS transmitters to identify habitats used by Black-tailed Godwits throughout their annual cycle (both during migration and the breeding season) since 2012. Both speed and height measurements are carried out. Moreover, the high frequency measurements also allow identification of nocturnal activity for this species. Data of this research are not yet publicly available, as a forthcoming publication on the topic is in preparation (pers. comm. N. Senner).

Since 2015, two Black-tailed Godwits have been fitted with a PTT transmitter within a pilot project of the University of East Anglia. From the data available, providing details on migration routes is possible, but direct flight speeds are not measured. The transmitters have pressure sensors but data have not yet been analysed (pers. comm. J. Alves).

2.8 Woodcock

The Game & Wildlife Conservation Trust in the UK conducts the only known research on Woodcocks (*Scolopax rusticola*). Beginning with an initial sample of 12 Argos satellite transmitters in 2012, 59 migrant Woodcocks have been caught and satellite-tagged to date within the “Woodcock Watch” project. These have been tagged at a range of wintering sites across the UK and Ireland in order to answer questions as to the origins of these birds and on differences between wintering populations and between years. The data suggest that Woodcocks from Russia and the Baltic States travel to Britain across a broad front, whereas Scandinavian birds appear more restricted to Scotland, Wales and Ireland, with a lower proportion reaching southern England (Figure 2.8.1). Flight speed and height during migration are not measured.

Earlier, only satellite platform transmitter terminals (PTTs) could be attached to Woodcocks. From 2006 to 2012, 20 wintering Woodcocks were tagged in Spain but no speed or flight height was measured and the birds migrated between Russia and Spain, not crossing any offshore areas (Arizaga et al. 2015).

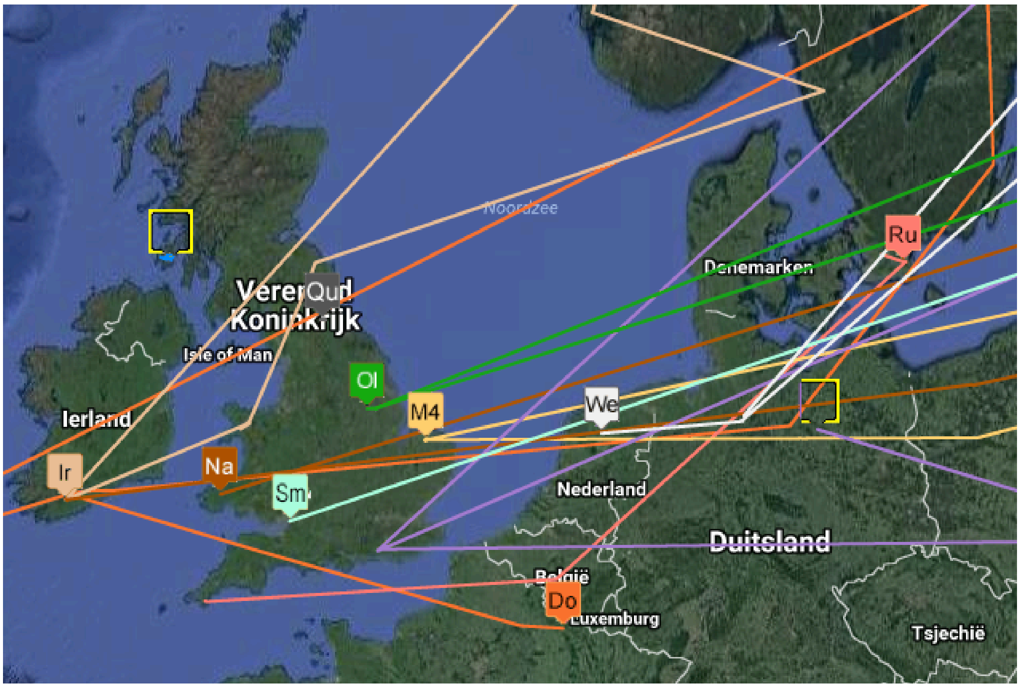

Figure 2.8.1 Migratory movements of Woodcocks wintering in Britain and Ireland (source: http://www.woodcockwatch.com).

2.9 Lapwing

Currently, there are no GPS or satellite tracking studies known that are conducted on the Northern Lapwing (*Vanellus vanellus*). However, since 2008, Birdlife International, together with the RSPB and Swarovski Optik is working on a conservation project of the Sociable Lapwing in Kazakhstan and southern Russia, using also satellite tracking. At this moment it is unclear whether there are also successful measurements on speed and height.

2.10 Red Knot

Red Knots (*Calidris canutus*) weigh on average 120 g, and hence are too light to be equipped with commonly used GPS loggers or satellite transmitters. In the spring of 2016, researchers of the Netherlands Institute for Sea Research (NIOZ) equipped a prototype of a micro-satellite transmitter of only 2 g on a Red Knot. The transmitter has an extremely powerful solar panel, and transmits data through satellites. The bird successfully completed a whole migratory journey (Figure 2.10.1). In the near future, more birds are planned to be tagged with this type of loggers (pers. comm. E. Kok).

Red Knots were equipped in the past with a precursor of this transmitter, which weighed 5 grams. However, the birds equipped with these transmitters did seem to have difficulties and hence their data are not reliable.

Figure 2.10.1 Migration route of a Red Knot between North-Canada and the Dutch Wadden Sea. The red dots are the positions that were reported back via satellite to the NIOZ.

2.11 Great Skua

The BTO, on behalf of the UK Government, is using UvA-BiTS technology to study the movements of Great Skuas. In the summers of 2010 and 2011, UvA-BiTS tags were fitted to 14 adult Great Skuas breeding on the island of Foula, Shetland. The measurements include flight speed, flight height and geographical location. Published information on these data suggest that most flight heights are clustered near the sea surface (within 1 – 2 m of the sea surface) with decreasing time spent at increasing height up to and beyond 50 m (Thaxter et al. 2011, Ross-Smith et al. 2016). No direct information on flight speeds is currently available from publications.

In 2014, the Norwegian Polar Institute deployed Ecotone GPS loggers with GSM and radio download on Great Skuas at Bjornoya Island during the breeding period. These devices recorded GPS position, speed and activity, flight altitude was not measured. All data from this research have been processed and a manuscript has been submitted (pers. comm. L. Iliszko). The authors have indicated to be open for collaboration with the current project.

2.12 Great Black-backed Gull

Lund University and fellow collaborators have been tagging a number of species in the Baltic Sea on Swedish islands (Stora Karlsö near Gotland and Fågelsundet/ Björn Archipelago near Uppsala). Species include Lesser Black-backed Gull, Herring Gull and Great Black-backed Gull. The study uses UvA-BiTs tags and the tracking study is on-going, although the main GPS deployments were in 2013 and 2014. Suitable data are available for three Great Black-backed Gulls, but these include a large number of foraging trips including many flights with a single known record of a Great Black-backed Gull migrating across the North Sea (north of the Netherlands) to the UK (pers. comm. T. Evans). Most of the data collected, including flight heights and speeds, are yet to be published but the researchers are open to collaboration.

Within the Birdmove project (see §2.6 Curlew), seven breeding Great Black-backed Gulls were caught on a North Sea island in Germany in 2016 (pers. comm. R. Borrman). Individuals were equipped with 30 g GPS-GSM transmitters (type Ornitela) with a harness in order to study foraging patterns during the breeding season. Flight speed and flight height are also measured. The tags are expected to function for approximately a year, and hence results of the migration period should be collected within the study.

Also in 2016, Aarhus University in Denmark deployed five UvA-BiTs GPS devices on Great Black-backed Gulls in the Kattegat (pers. comm. M. Frederiksen, J.F. Linnebjerg). Data from the migration or wintering areas will only be available next year There are currently data available from three of the birds for approximately five weeks in the summer. These devices collect information on flight speed and flight height. The other two devices had download problems, although data were collected. The researchers have currently no resources to analyse the data but are willing to collaborate.

The British Trust for Ornithology thus far tagged one Great Black-backed Gull but no results were retrieved as it most likely ate its tag, plans exist for tagging Great Black-backed Gulls in the future (pers. comm. N. Burton).

2.13 Little Gull

No GPS data from Little Gulls is known. Aarhus University in Denmark was planning to deploy GPS tags on Little Gulls in the summer of 2016 but could not find enough funding for the project. Currently they are looking for funding for next year, together with colleagues in Finland, Estonia and Lithuania (pers. comm. I.K. Petersen).

3 Summary of inventory of tracking studies

Currently, a large number of studies are running or have started that use GPS or satellite transmitters to track birds during migration. The devices are getting increasingly smaller and more reliable, making it possible that more and more species can be studied.

Our review revealed that nearly all of the focal species presented in table 1 have been studied or are being studied using GPS or satellite transmitters. Many of these species are even studied in the focal area of the Southern North Sea. Therefore, in the chapter below, we group the species based on availability of results.

3.1 Categorization of species based on available amount of data

3.1.1 Species for which extensive research has been carried out in the Southern North Sea

- Bewick's Swan: The WWT in the UK is currently undertaking a thorough GPS tracking study, explicitly investigating the collision risk of the species in the Southern North Sea. It is not yet clear when the study results will become available.
- Brent Goose: The NIOO has tracked Brent Geese during their migration with UvABits transmitters that also measure speed and height. Some data are also available on tracks between England and the Netherlands.
- Bar-tailed Godwit: The University of Groningen is currently tracking Bar-tailed Godwits using UvABits transmitters. These devices measure flight speed and height. The tagged birds also regularly cross the Southern North Sea.

3.1.2 Species with limited data of the Southern North Sea

- Pink-footed Goose: Aarhus University tracked Pink-footed Geese for several years. The birds also crossed the North Sea between Denmark and the Netherlands. However, no speed or height measurements were carried out.
- Common Shelduck: The Royal Belgian Institute of Natural Sciences is tracking several Common Shelduck in and around the Netherlands that can provide insights in their migration routes. However, there are no speed and height measurements available.
- Curlew: The German Federal Agency of Nature Conservation measured flight speed of Curlew on migration, but have no tracks in the Southern North Sea. Likely, data collected by the University of La Rochelle contains also migration routes of curlews through the Southern North Sea.
- Woodcock: Game & Wildlife Conservation Trust in the UK has extensive data on migration tracks, but no data on flight speed or height.
- Knot: The NIOZ has the first successful measurements of migration tracks of the Knot with a prototype of an extremely small satellite transmitter.

- Great Black-backed Gull: Recently, several different research groups in Sweden, Norway and Germany have been working on tagging studies of Great Black-backed Gulls. Up until now, data are mainly available from the breeding season and to a limited extent from the Southern North Sea. Next year, more data will likely be available from during migration.
- Great Skua: The BTO and the Norwegian Polar Institute collected detailed information on flight height and flight speed of Great Skuas during the breeding season. However, tracks from the migration period through the Southern North Sea are not yet directly available.

3.1.3 Species with very limited or no data

- Greater Scaup: Except for one American study, no further data have been collected from this species.
- Tufted Duck: Tagging this species has up till now not led to success. Therefore, no migration routes, flight speed or height are known.
- Lapwing: Currently no research has been conducted on the Northern Lapwing, only on a related species, the Sociable Lapwing.
- Little Gull: At present, no research with tracking devices has been conducted on Little Gulls. Aarhus University is seeking funding to tag Little Gulls.

3.2 Available data for SOSS Band model

In the previous section, species are classified based on the amount of tracking data currently available. However, updating the current collision victim estimates of birds at offshore wind farms by the SOSS Band model mainly requires improved figures on flight speed and flight height. In addition to the species **Bewick's Swan, Brent Goose and Bar-tailed Godwit** (see §3.1.1), this information is (at least partly) available for other species as well. Detailed measurements on flight speed and flight height exist for **Great Skua** and **Great Black-backed Gull**. In addition, accurate measurements on the flight speed of **Curlews** have also been collected. Therefore, the calculation of new collision victim estimates would be possible for all of these species. However, except for Great Skua and Bewick's Swan and the flight speed of Curlews, no published GPS data on flight speed and flight height of the other species mentioned in Table 1 are currently available. Researchers working on projects concerning the other species have all indicated that they are open to collaboration (either sharing data or perform additional analyses) but may request a financial contribution to make their data available.

PART II – DATA ANALYSIS AND COLLISION RISK MODELLING

Below we give account of the analysis on GPS logger data made available for the Bewick's Swan, Brent Goose, Great Skua and Great Black-backed Gull by researchers conducting tracking studies on these species. The aim of this part of the study was to analyse flight variables that are required in collision risk modelling by the extended Band model. Due to different methods used in the Band model, the variables differ for seabirds and migratory species. Estimates on flight speed, flight height, fraction of time spent in flight and nocturnal flight activity are required for seabird species and flight speed, flight height and, if available, migration routes for species migrating through the southern North Sea. Finally, based on the newly obtained values, calculations with the extended Band-model were carried out to update estimates on the number of collision victims in the southern North Sea.

4 Flight behaviour variables per species

4.1 Bewick's Swan

In January and February 2014, the Wildfowl & Wetland Trust (WWT) caught eight Bewick's Swans and a further 14 in winter 2014/15 in southern England. The birds were fitted with collar-mounted radio-GPS-GSM data loggers. Of these, 18 birds collected relevant data that could be used in this study, either for analysing flight height/speed or for migration routes over the southern North Sea. As Bewick's Swans only migrate through the southern North Sea, for the collision risk modelling (see Chapter 5) the Band model subset for migratory species was used, in which the variables nocturnal flight activity and percentage of time flying are not used. Therefore, these variables are not analysed in the current study. However, Griffin *et al.* (2016) have analysed that approximately 35-40% of Bewick's Swan migration movements between England and the Netherlands takes place during the night.

4.1.1 Speed

For the GPS records (n = 6,255), 8 individuals with 2,069 GPS points had no speed measurements, leaving 10 individuals with speed measurements. Another 510 measurements had a speed of 0.0 km/h. 89% of the remaining data (n = 3,334 points) had a speed below 1.5 knots (= 2.8 km/h). Excluding all these irrelevant data, the final dataset contained 342 points of five individuals with a speed above 1.5 knots.

Generally, speed measurements show a bimodal distribution with a peak at or just above 0 km/h, concerning non-flight behaviour, and a second peak that can be considered as the common speed in flight (Gyimesi et al. 2016a). In order to exclude records of stationary, walking and floating behaviour with low speed, measurements below 5 knots were excluded from the analysis based on the speed distribution of Bewick's Swans (Figure 4.1.1). The final dataset with a minimum flight speed of 9.26 km/h contained 293 measurements (Figure 4.1.2).

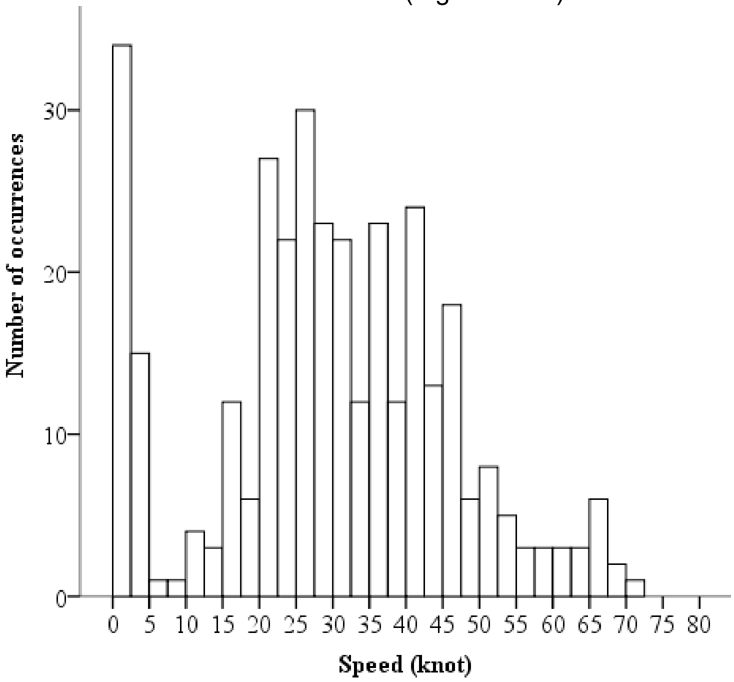

Figure 4.1.1 Frequency distribution (number of records) of speed measurements (knots) of Bewick's Swans.

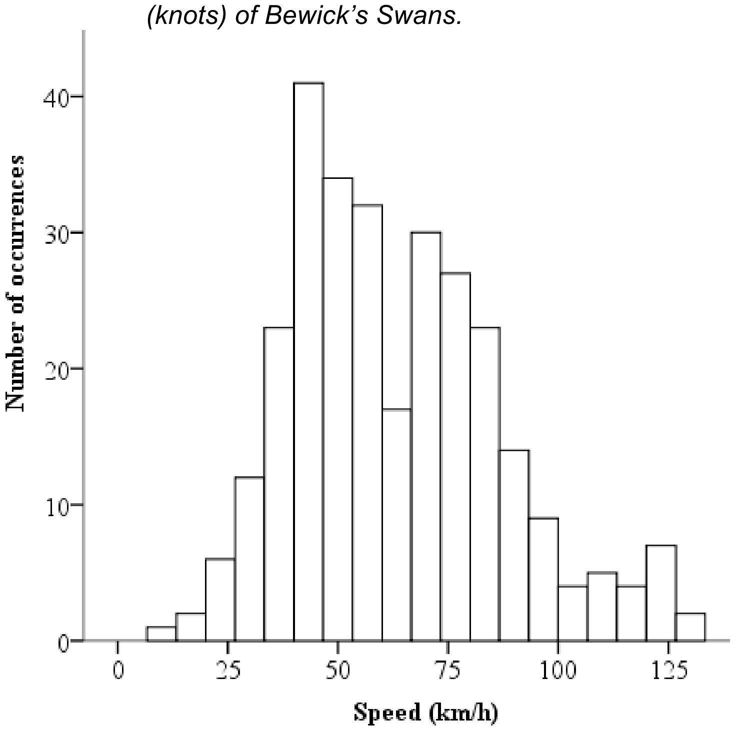

Figure 4.1.2 Frequency distribution (number of records) of flight speeds (km/h) of five Bewick's Swans equipped with GPS-loggers at South England.

Interestingly, the final dataset still showed a bimodal distribution with a general mean of 63 km/h and median of 57.4 km/h. Based on an analysis differentiating data for two seasons (October – January autumn/winter when swans cross the North Sea from the Netherlands to England; February-March spring when swans start their migration towards the breeding grounds in northern Russia) it becomes obvious that the two modi are dependent on the time of migration (Figure 4.1.3). The flight speeds in the two periods (mean 50.6 km/h in autumn and 80,9 km/h in spring) were significantly different (based on square-root transformed values $F_{1,292} = 186.5$; $p < 0.001$; Figure 4.1.4).

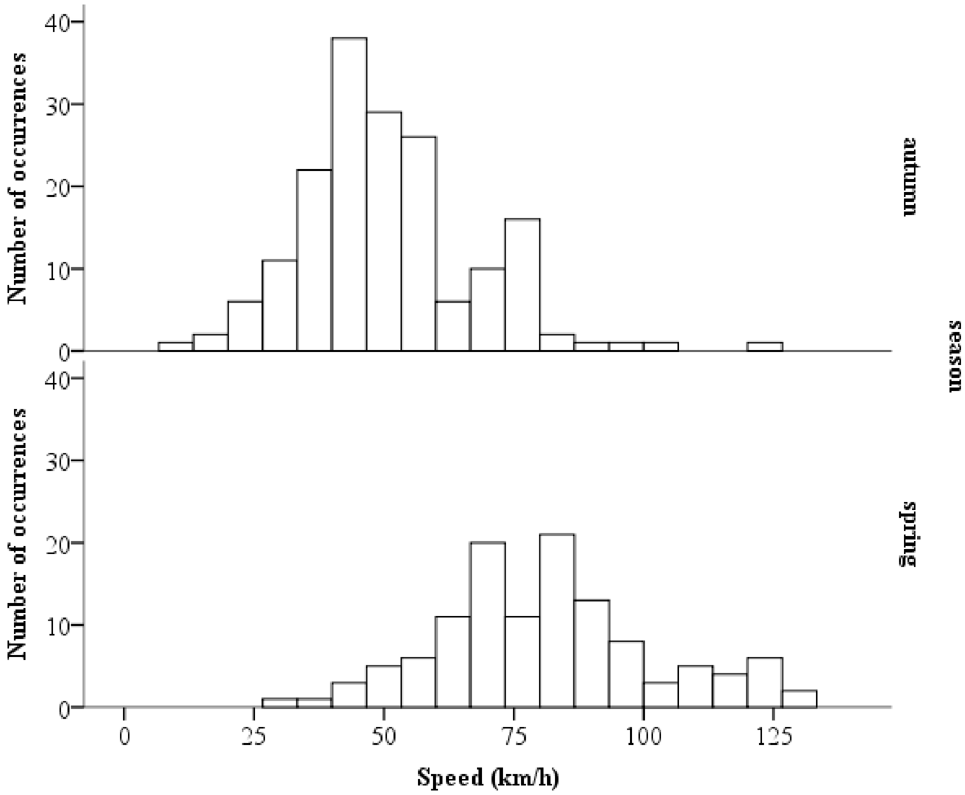

Figure 4.1.3 Frequency distribution (number of records) of flight speeds (km/h) of Bewick's Swans during the autumn (October-January) and spring migration period (February-March).

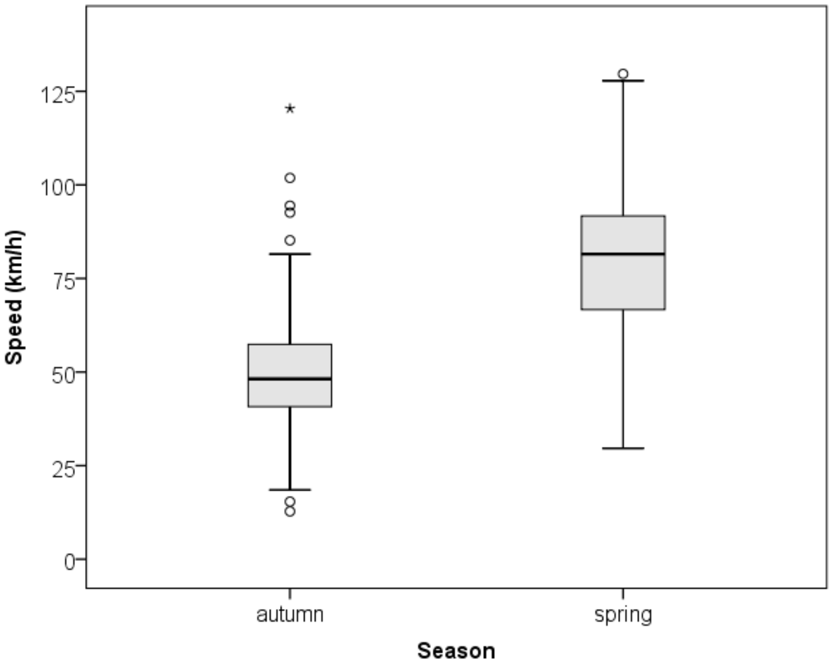

Figure 4.1.4 Speed measurements of five Bewick's Swans during autumn (October-January; left boxplot) and during spring (February-March; right boxplot). Dark line in the middle of the boxes is the median, boxes indicate 25 and 75% percentiles, T-bars 1.5 times the height of the box and points are outliers.

Data recording intervals could vary among individuals, during the study period or even within a day. In order to correct for the confounding influence of these different data recording intervals, locational fixes collected within 5 minutes of each other were omitted (leaving 281 measurements). For the same reason, frequently recorded data were given a lower weight and less frequently recorded data were given a higher weight. The resulting weighted mean was 58.2 km/h. A further analysis showed that also the effects of the individual swan, country being traversed and whether or not the bird was onshore or offshore were significant (Figure 4.1.5). Therefore, the final analysis was carried out separately for onshore and offshore, as being relevant for offshore wind farm developments. The weighted mean for flights onshore was 50.6 km/h and 64.2 km/h for offshore flights.

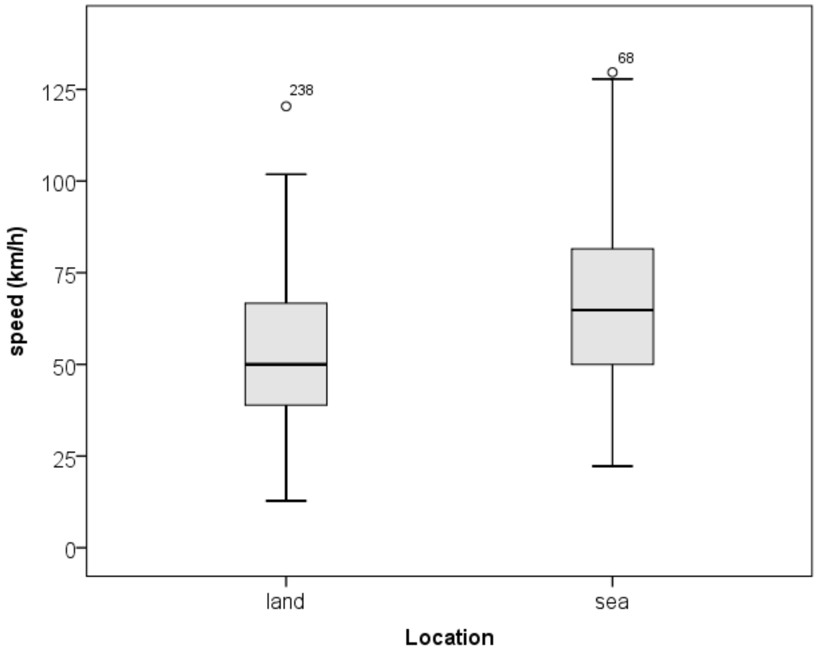

Figure 4.1.5 Speed measurements of five Bewick's Swans above land (left boxplot) and above sea (right boxplot). Dark line in the middle of the boxes is the median, boxes indicate 25 and 75% percentiles, T-bars 1.5 times the height of the box and points are outliers.

4.1.2 Flight height

There were altogether 765 height measurements available in the dataset. Due to the inaccuracy of the altitude measurements of GPS-loggers (generally considered to be around 20 m), a number of data points occurred below sea level (Figure 4.1.6). The occurrence of negative flight heights was dependent on the location of the measurement. Birds flew much lower offshore than onshore (Figure 4.1.7). There were negative height values onshore as well, but the majority of values were above zero. The situation offshore was the other way round. A further step in the data selection procedure was to exclude the outliers (upper and lower 5% of values), thus values below -142 m and above 343 m (this latter mainly concerning values > 1,000 m). In addition, eight measurements below -50 m formed an obvious outlier group as well (Figure 4.1.8). After excluding these latter low values as well, 174 offshore measurements and 511 onshore measurements remained in the dataset.

Only 24 of these measurements occurred above the North Sea, the rest elsewhere along the migration route. There was a significant difference in flight heights between the different sea areas ($X^2_6 = 90.2$; $p < 0.001$). Flight heights accross the North Sea seemed to be the lowest among all, with also one of the lowest standard deviations (Figure 4.1.9). Nevertheless, due to the low sample size, all offshore measurements were pooled to obtain a flight height distribution (n = 174). Due to the inaccuracy of the altitude measurements of the GPS devices, some of the measurements were negative values. Based on a general inaccuracy of 20 m, these negative values could indicate swans flying low over the sea level. All in all, approximately 70% of the Bewick's Swans could be flying low just above the sea surface during migration, with 85% of the measurements occurring below 25 m, in general out of the range of the rotor-swept zone.

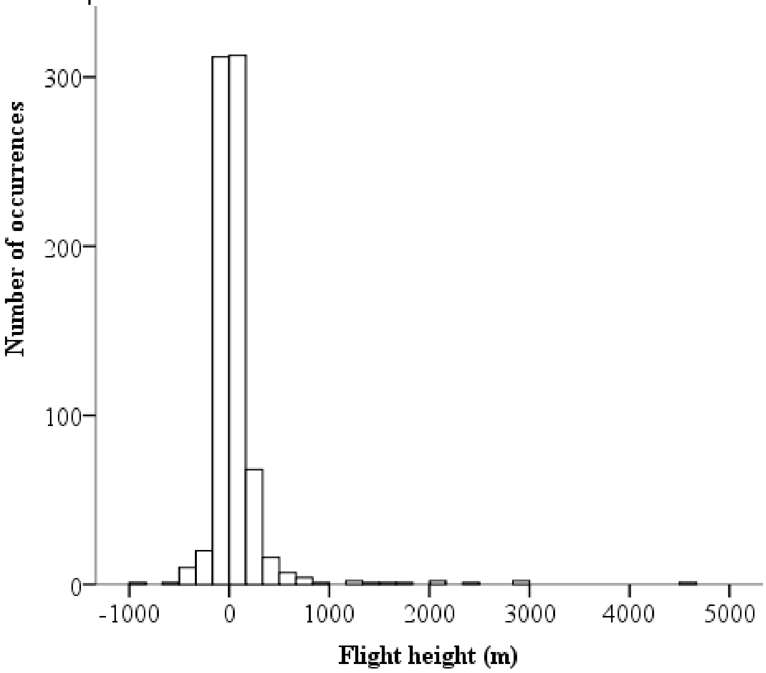

Figure 4.1.6 Frequency distribution (number of records) of flight heights of Bewick's Swans equipped with GPS-loggers in South England.

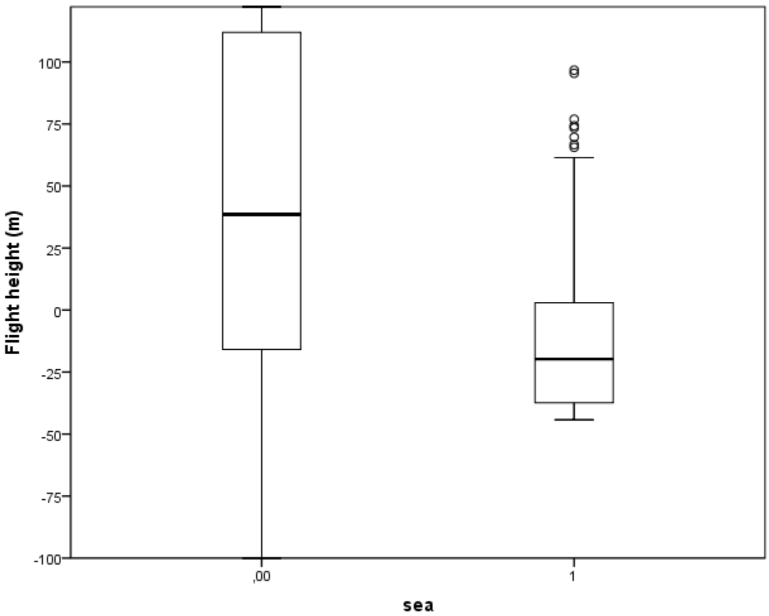

Figure 4.1.7 Altitude measurements of Bewick's Swans during flight onshore (left boxplot) and in flight offshore (right boxplot). Dark line in the middle of the boxes is the median, boxes indicate 25 and 75% percentiles, T-bars 1.5 times the height of the box and points are outliers.

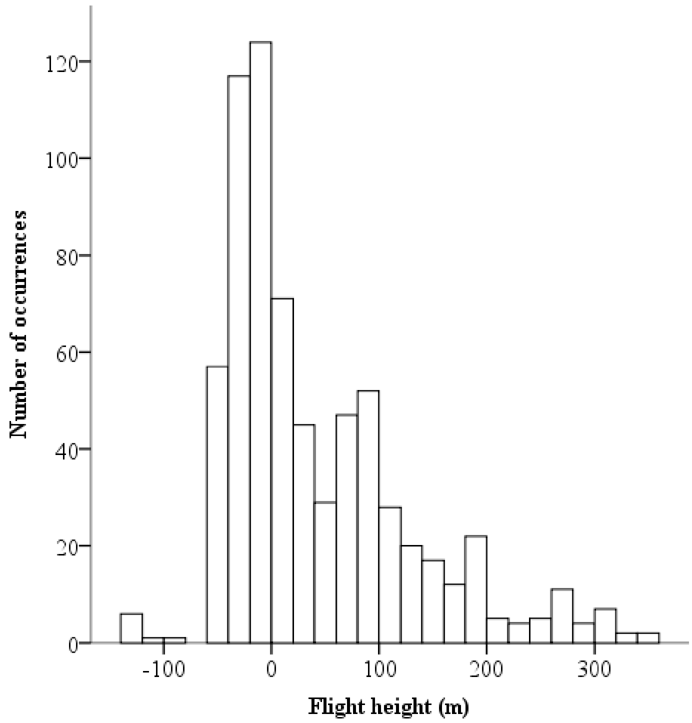

Figure 4.1.8 Frequency distribution (number of records) of flight heights of Bewick's Swans after excluding outliers. Due to inaccuracy of the altitude measurements of the GPS devices, some measurements are below 0 m. Values below -50 m are excluded from the final dataset.

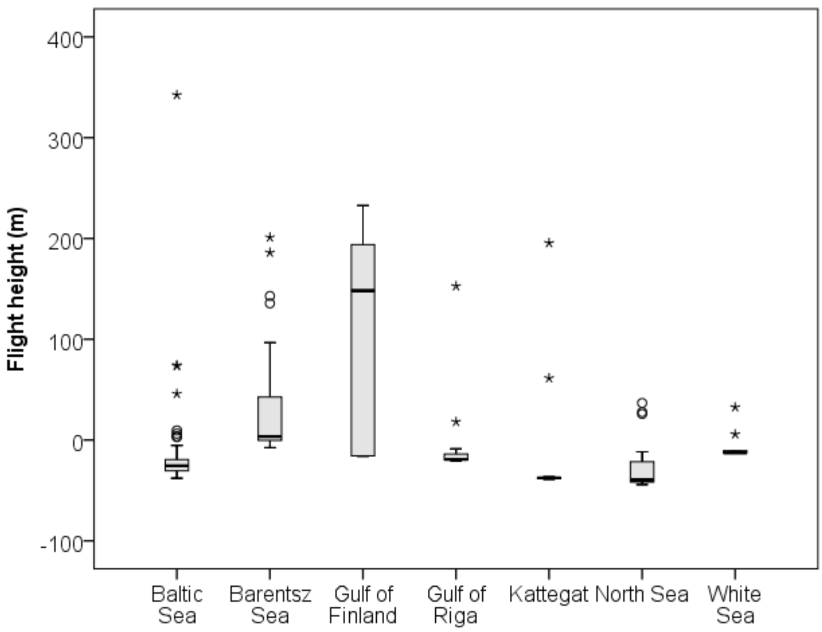

Figure 4.1.9 Height measurements of the Bewick's Swans along the migration route between north Russia and England. The horizontal axis provides the different sea regions. The pooled data of these locations were used to calculate a flight height distribution.

4.2 Brent Goose

In 2012, within the framework of the project "Habitat use of Brent Geese along their flyway" 9 Brent Geese were caught at the island of Schiermonnikoog and 32 at the island of Terschelling in the Netherlands and were equipped with UvA-BiTS GPS logger devices. The whole study delivered approximately 400,000 measurements along the migratory flyway and throughout the year. Below we report on the speed and flight height measurements in the southern North Sea region, providing the most relevant values for collision risk modelling with wind turbines situated or planned in offshore waters of the southern North Sea. In order to exclude data points from local foraging movements and to focus on data points collected in open sea areas presumably during migratory flights, we selected only measurements at least 5 km from the coastline. This resulted in a dataset of 1,989 data points, recorded in the offshore areas of six different countries (Table 4.2.1).

Table 4.2.1 Number of data points collected by GPS-loggers on Brent Geese in territorial waters of six countries in the southern North Sea.

	Number of data points	Percent
Belgium	9	0,5
Denmark	1	0,1
France	197	9,9
Germany	558	28,1
Netherlands	761	38,3
United Kingdom	463	23,3
Total	1,989	100,0

As in the collision risk modelling of migrating species, such as the Brent Goose over the North Sea, nocturnal flight activity and percentage of time flying does not play a role, these variables were not analysed in the current study.

4.2.1 Speed

Generally, speed measurements show a bimodal distribution with a peak just above 0 km/h, concerning non-flight behaviour, and a second peak that can be considered as the common speed in flight (Gyimesi et al. 2016a). In order to exclude records of stationary, walking and floating behaviour with low speed, measurements below 6 m/s (21.6 km/h) were excluded from the analysis based on the speed distribution of Brent Geese (Figure 4.2.1). After excluding low-speed (non-flight behaviour) measurements, 578 data points of 21 individuals were left over (Figure 4.2.2).

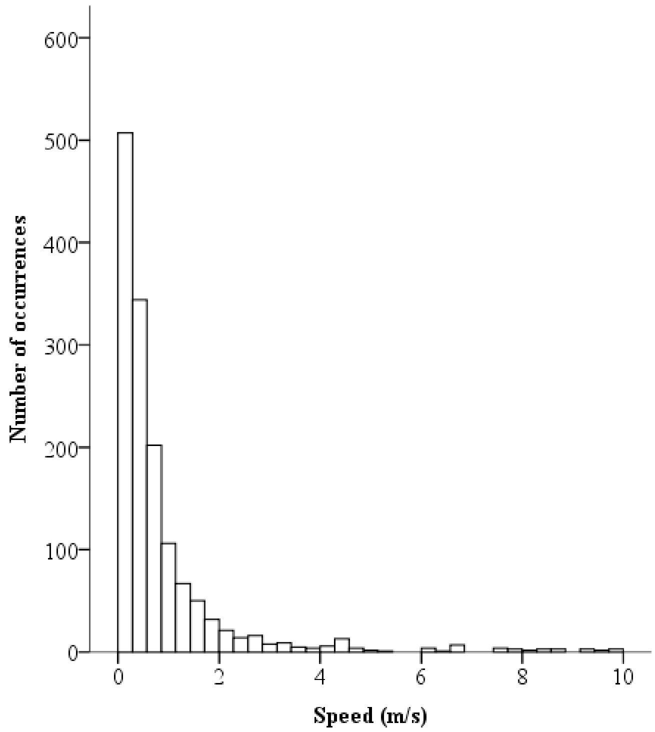

Figure 4.2.1 Frequency distribution (number of records) of low speed (m/s) measurements of Brent Geese.

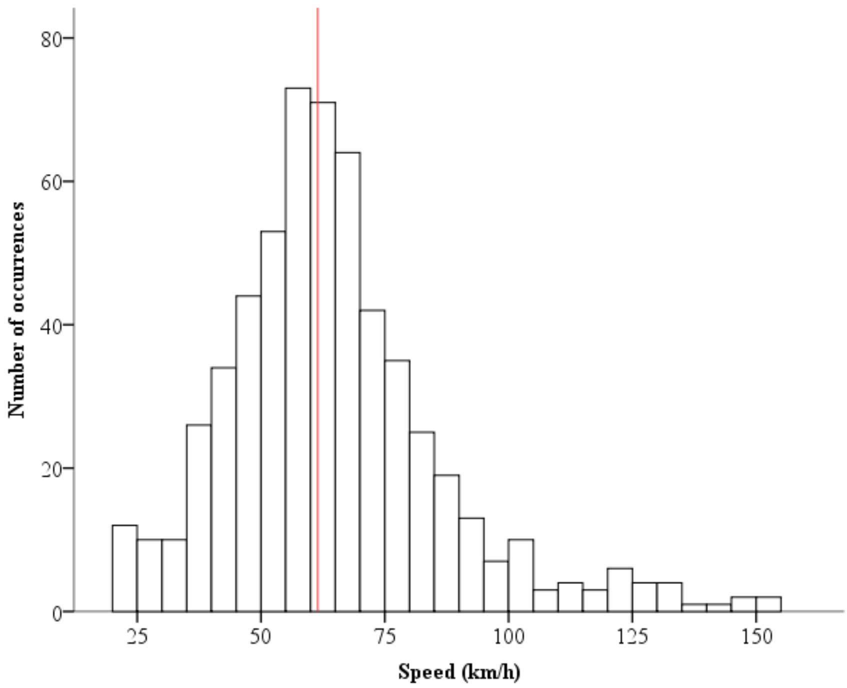

Figure 4.2.2 Frequency distribution (number of records) of flight speeds (km/h) of Brent Geese in offshore areas of the southern North Sea. Red vertical line provides the calculated median of the measurements.

The final dataset showed one obvious peak, indicating the common flight speed of Brent Geese in offshore areas. Based on this dataset Brent Geese cross the southern North Sea with a mean speed of 64.5 km/h (± SD 22.0 km/h; median speed 61.4 km/h) but can even reach speeds of approximately 150 km/h.

4.2.2 Flight height

Based on the dataset containing exclusively flight data points (see §4.1.1), the flight height of Brent Geese in offshore areas of the southern North Sea was also analysed. The majority of the measurements (98%) occurred below 600 m. In fact, only 15 measurements occurred above 600 m, but these could be at altitudes up to 50,000 m. Of these, four measurements were below 2,000 m, another four between 2,000 and 10,000 m. As these measurements form a minor fraction of the dataset, are likely erroneous and are irrelevant for wind farm assessments, we arbitrarily excluded the measurements above 2,000 m.

Most of the measurements occurred around sea level (Figure 4.2.3). Furthermore, due to the inaccuracy of the altitude measurements of GPS-loggers (generally considered to be around 20 m), a number of data points occurred below sea level (Figure 4.2.3). One measurement occurred 100 m below sea level. As this value was an obvious outlier, it was excluded from the final dataset.

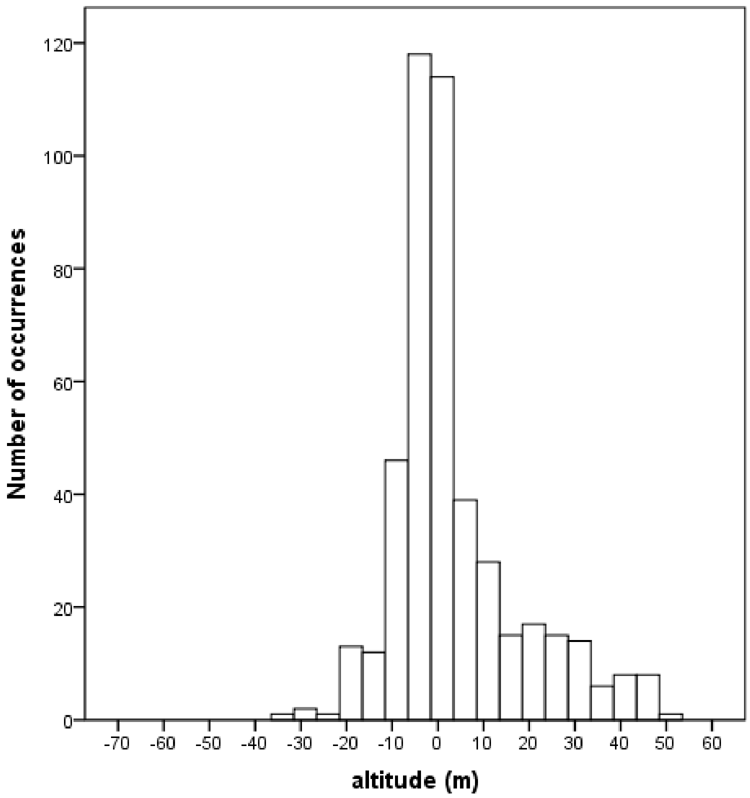

Figure 4.2.3 Frequency distribution (number of records) of flight heights of Brent Geese in offshore areas of the southern North Sea.

The selection procedure left 566 measurements (partly negative values) for determining the offshore flight height distribution of Brent Geese. The median flight height of these Brent Geese was 2 m, with 73% of the measurements occurring below 25 m, commonly out of the rotor swept zone.

4.3 Great Skua

In 2014 the Norwegian Polar Institute deployed Ecotone GPS loggers with GSM and VHF download on 20 Great Skuas at the southern part of Bjørnøya during the breeding period. Altogether 24,540 measurements were recorded. The loggers collected information on GPS positions, flight speed and flight height during June, July and August. At this latitude, the sun is practically all day above the horizon in this whole time of the year, and hence calculation of nocturnal flight activity was not possible.

4.3.1 Speed

Out of all the GPS records, 19,622 contained a valid speed measurement. In order to exclude records with low speed due to stationary, walking and floating behaviour, the minimum flight speed was set at 6 km/h, based on the speed distribution of Great Skuas (Figure 4.3.1). Non-flight behaviour causes a peak in the number of records just around 0 km/h. The number of records steadily decreased after this peak and above 6 km/h only a few infrequent records occurred (Figure 4.3.1).

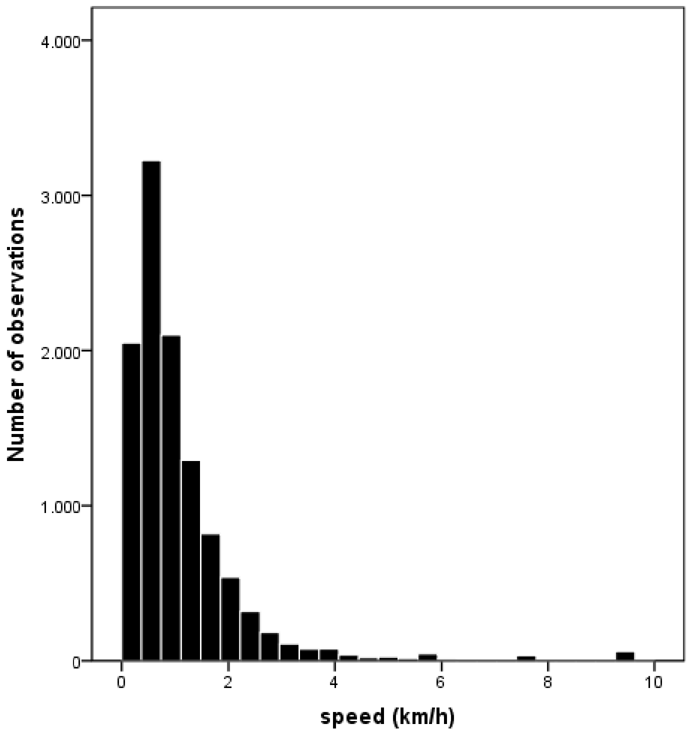

Figure 4.3.1 Frequency distribution (number of records) of low speed measurements of Great Skuas at Bjørnøya Island.

Considering only measurements above 6 km/h, a number of records were obvious outliers, as the maximum measured speed reached 1,716 km/h. A further analysis revealed that three individuals were recording structurally higher speeds than the other 17 individuals (Figure 4.3.2). With mean speeds of 75, 102 and 145 km/h and maximum flight speeds of 933, 937 and 1,716 km/h, the speeds of these three individuals were obvious outliers (see also Figure 4.3.2) and were excluded from the analysis. Therefore, the final dataset contained measurements > 6 km/h of 17 individuals, considering altogether 3,049 data points. Based on these measurements a frequency distribution of flight speeds was determined (Figure 4.3.3). The maximum flight speed in this dataset was 125.9 km/h, with most of the speed measurements occurring between 30 – 60 km/h. The mean flight speed was calculated to be 41.8 km/h (± 13.6 SD) km/h and the median 40.7 km/h.

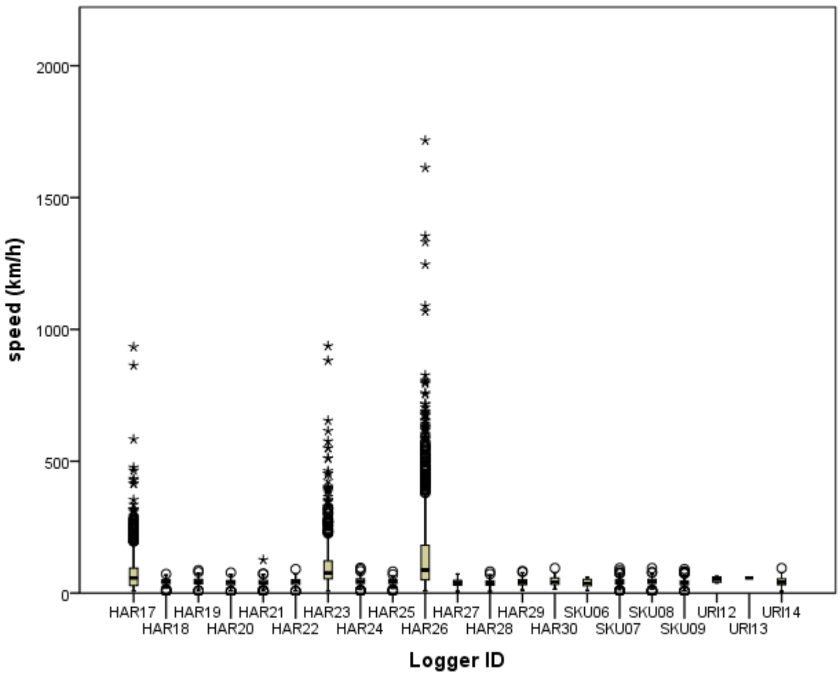

Figure 4.3.2 Speed measurements of 20 Great Skuas equipped with GPS-loggers at Bjørnøya Island. The horizontal axis provides the GPS-logger IDs, with HAR17, HAR23 and HAR26 showing extremely high velocities.

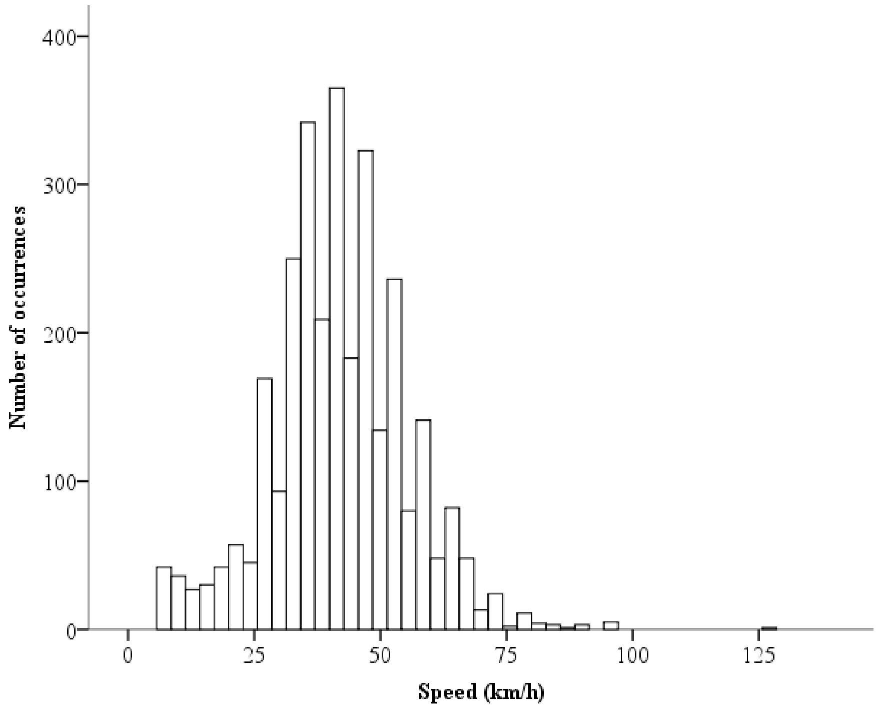

Figure 4.3.3 Frequency distribution (number of records) of flight speeds of 17 Great Skuas equipped with GPS-loggers at Bjørnøya Island.

4.3.2 Flight height

Based on the same dataset as for determining flight speed (17 individuals with measurements > 6 km/h), also the distribution of flight heights was analysed. Furthermore, due to the inaccuracy of the altitude measurements of GPS-loggers (generally considered to be around 20 m), 167 data points occurred below sea level, some even below –600 m (Figure 4.3.4). In fact all of these measurements occurred below -50 m. As measurements between 0 and -50 m could be valid but inaccurate measurements (see other species in this document), but even lower values are likely erroneous measurements, all values below -50 m were excluded of further analysis. The occurrence of negative flight heights was not dependent on individuals, the searching time of the logger for satellites, or the charging levels of the logger.

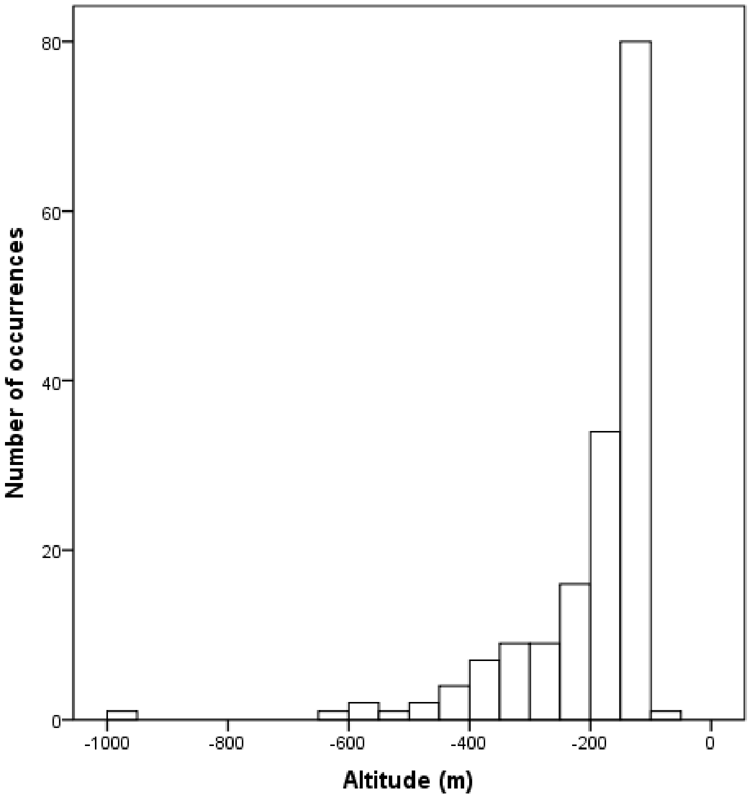

Figure 4.3.4 Frequency distribution (number of records) of negative flight height measurements of 17 Great Skuas equipped with GPS-loggers at Bjørnøya Island.

At the upper end of the flight height measurements, there was one indicating a flight height of 2,563 m, all others were below 2,000 m. In fact, only 19 measurements occurred above 500 m. As the southern part of Bjørnøya where the skuas breed is mountainous, the highest top being above 500 metres, we selected only data points 5 km from the coast of the island (n = 1,743), in order to exclusively gain insight in the flight behaviour of Great Skuas at open sea (relevant for Great Skuas in and around wind farms in the southern North Sea), not influenced by flight heights of skuas returning to the cliffs of the island. The resulting frequency distribution of these data points revealed relatively high flight heights (Figure 4.3.5). Based on this data, only 39% of measurements were below 25 m.

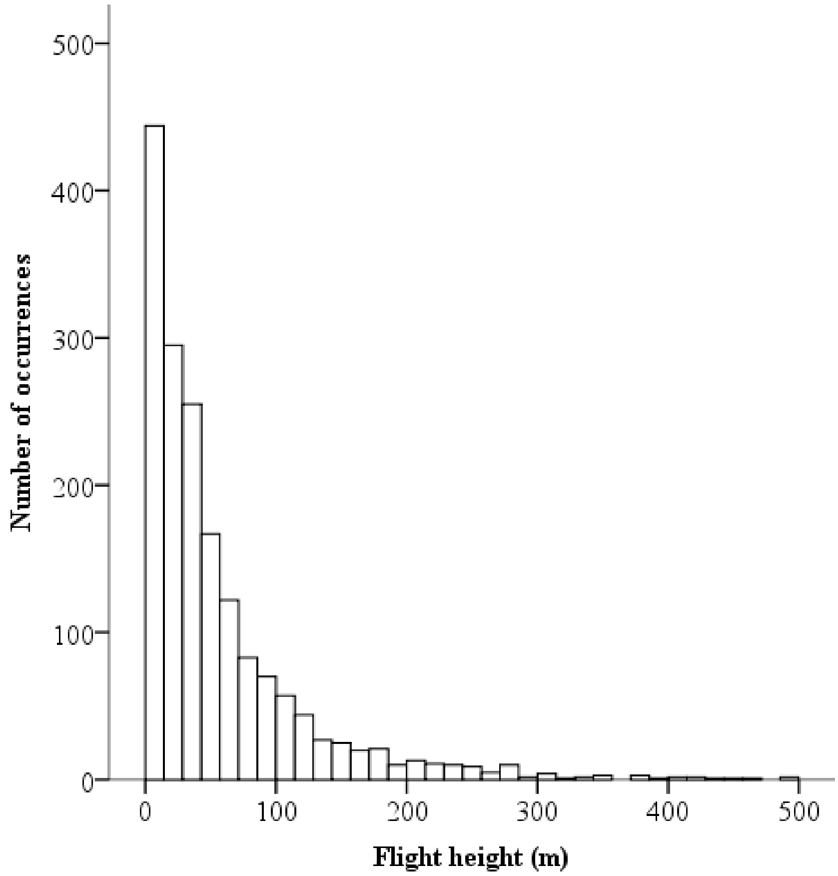

Figure 4.3.5 Frequency distribution (number of records) of flight heights of 17 Great Skuas equipped with GPS-loggers at Bjørnøya Island minimally 5 km from the coast.

As an extra control step, the height distribution of data points collected minimally 5 km from the coast that based on the speed measurements were classified as flight behaviour were compared with those classified as non-flight behaviour. As depicted on Figure 4.3.6, the height distribution of flight measurements and non-flight measurements were highly similar, with relatively high altitudes, with both medians being between 35 m and 40 m. In fact the median of offshore non-flight measurements was even higher than of flight measurements. Based on this, we expect that the altitude measurements of the GPS-loggers were erroneous.

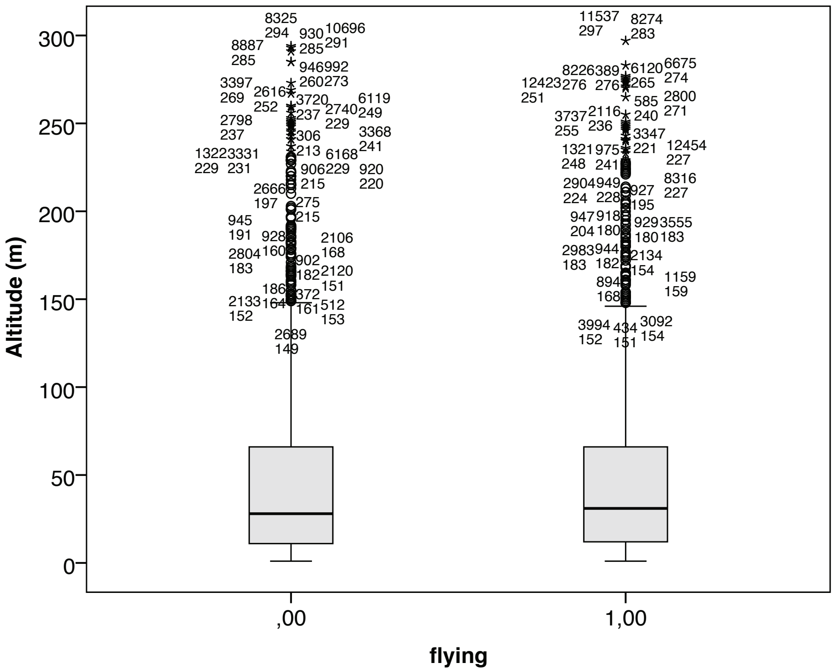

Figure 4.3.6 Altitude measurements of 17 Great Skuas equipped with GPS-loggers at Bjørnøya Island minimally 5 km from the coast during non-flight (left boxplot; speed < 6 km/h) and in flight (right boxplot; speed > 6 km/h). Dark line in the middle of the boxes is the median, boxes indicate 25 and 75% percentiles, T-bars 1.5 times the height of the box and points are outliers.

4.3.3 Percentage of flying

Based on all measurements (land and sea together), 21% of the measurements were considering flying birds (speed > 6 km/h). The ratios turn the opposite if only measurements above open sea are considered: 64% of the data points are recorded in flight and only 36% during non-flight behaviour.

4.4 Great Black-backed Gull

The analysis of Great Black-backed Gulls relied on two separate datasets, one from Sweden and the other from Denmark. During the breeding season in 2013 three Great Black-backed gulls were caught on the east coast of Sweden (approx. 17.93 E, 60.63 N) and were equipped with UvA-BiTS GPS logger devices. Two individuals collected data only during the breeding period of 2013, and one includes data from two breeding seasons, and some data from the winter period (with long gaps in the data collection during this latter period). In Denmark, Aarhus University deployed GPS devices on three Great Black-backed Gulls in the Kattegat during the summer (June and July) of 2016. The night-time sampling interval was the same as the daytime. However, GPS recording intervals varied throughout the season, so points were weighted by time interval (i.e. longer time interval points got greater weight than high sample interval points) and resampled to 5 minutes bins. Only flight data were included in the analysis, with flight identified as GPS locations where the instantaneous velocity (that recorded by the GPS) was >4 m/s. This threshold was identified from a bi-modal distribution in speed measurements. Also points 500 m around the colony were excluded from the analyses. The final Swedish dataset of offshore points comprised of 44,590 data points, and the Danish dataset of 3,338.

4.4.1 Speed

Based on the Swedish GPS records, the flight speed distributions of Great Black-backed Gulls were largely similar above land and above sea, during the day and during the night (Figure 4.4.1). Based on this dataset, the offshore mean flight speed of Great Black-backed Gulls is 45.1 km/h (± SD 15.7 km/h) and the median 43.8 km/h.

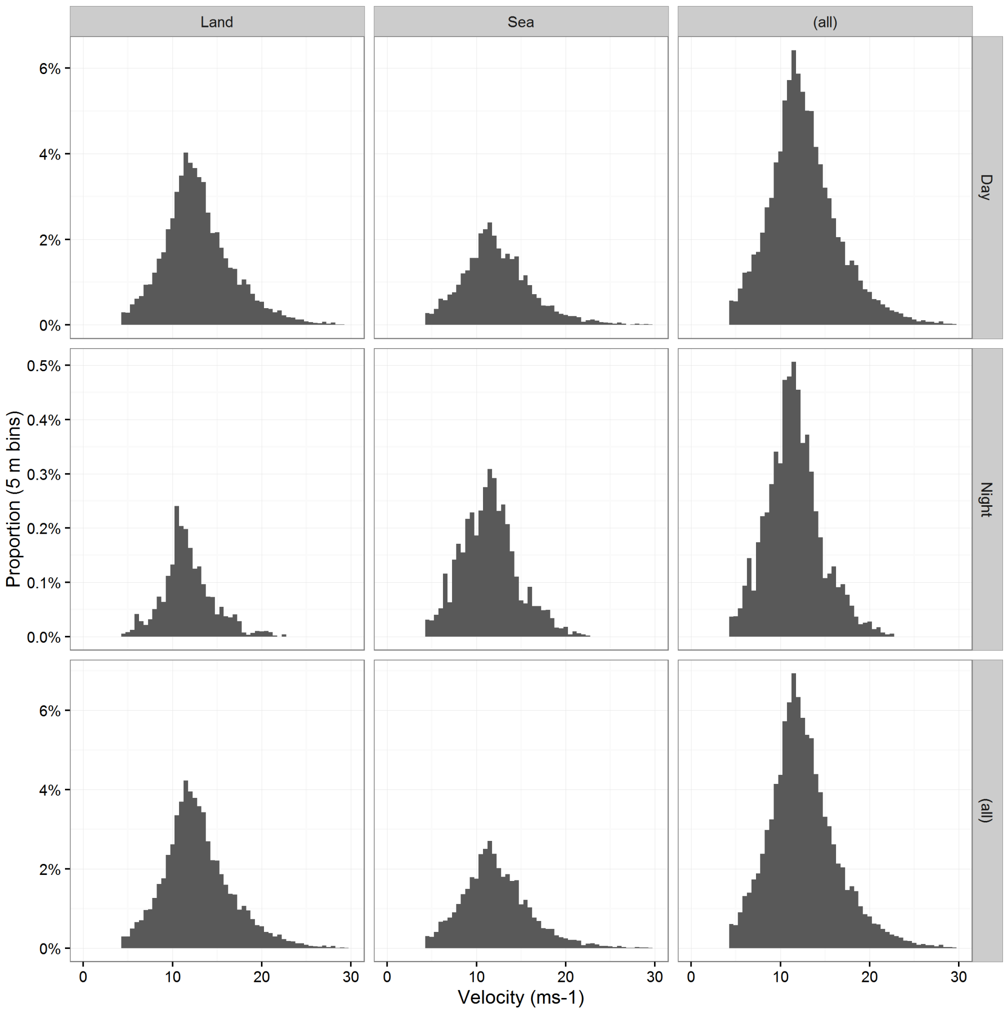

Figure 4.4.1 Frequency distribution of speed measurements of Great Black-backed Gulls above sea and land (also classified for night and day) in Sweden. Percentages in the plots represent the proportion of all flight records. Only data with instantaneous velocity >4 m/s are included.

The Danish offshore data had a similar distribution curve (Figure 4.4.2), but the mean and median values were lower, respectively 38.8 km/h and 37.1 km/h.

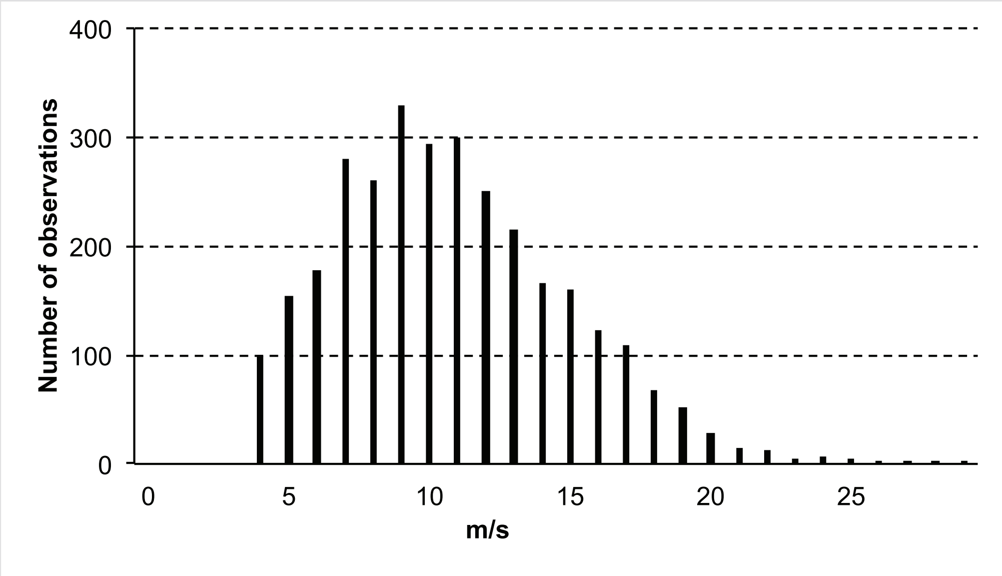

Figure 4.4.2 Frequency distribution (number of records) of flight speeds of Great Black-backed Gulls equipped with GPS-loggers in Denmark.

4.4.2 Flight height

The flight height distributions per altitude meter class in Sweden and Denmark are summarized respectively in figures 4.4.3 and 4.4.4. The range -5 m to 1000 m were included, comprising 98.7% and 99.2% of all flight records in Sweden and Denmark, respectively. Values beyond this range were considered outliers, comprising only a small fraction of all values. The results highlight that the gulls fly relatively high. Daytime flight is noticeably higher than during the night, with a larger contrast over land than over sea. In addition, flight over sea is generally lower than flight over land, over sea most flights are <50 m, over land most >50 m. The median offshore flight height in Denmark was 16 m. In the Swedish data the median flight height was 36 m.

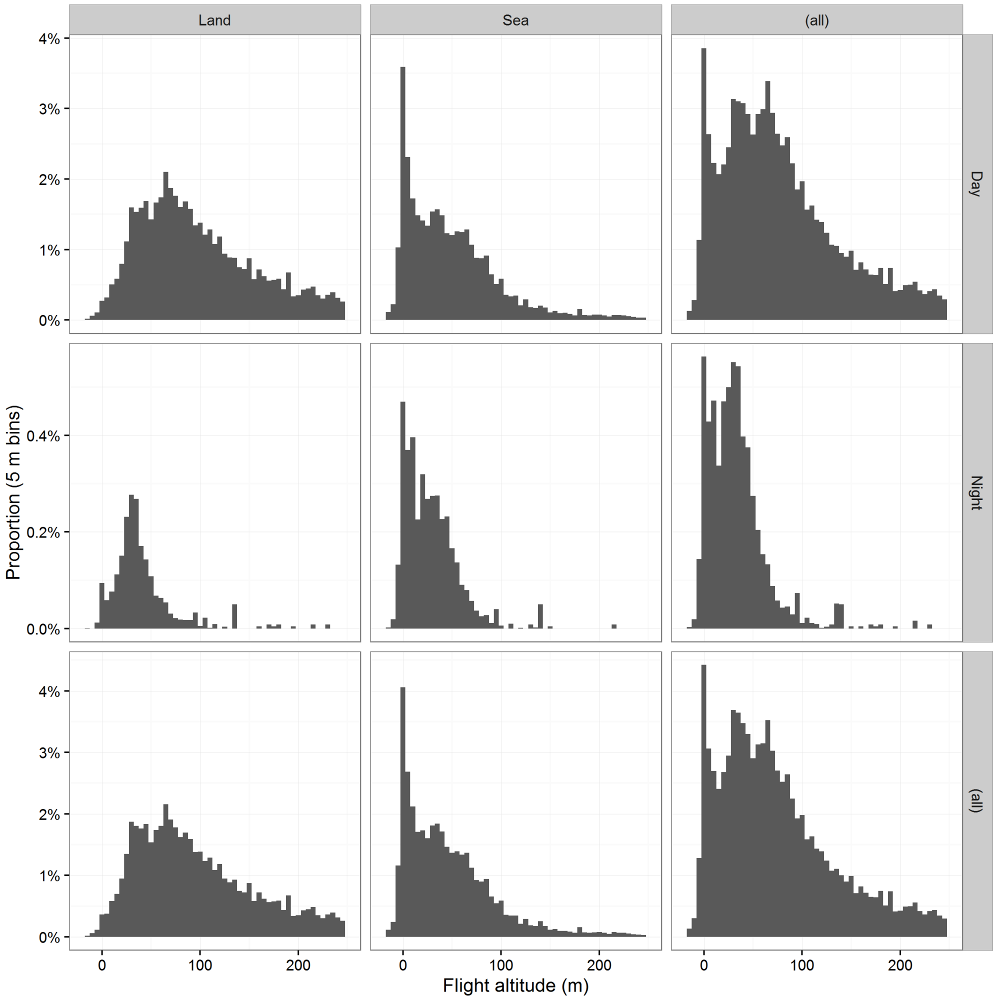

Figure 4.4.3 Flight height distributions (depicted in 5 meter classes) of Great Black-backed gulls tagged in Sweden. Percentages in the plots represent the proportion of all flight records. Only data with instantaneous velocity >4 m/s were included. Points are also classified as over land or sea and night or day.

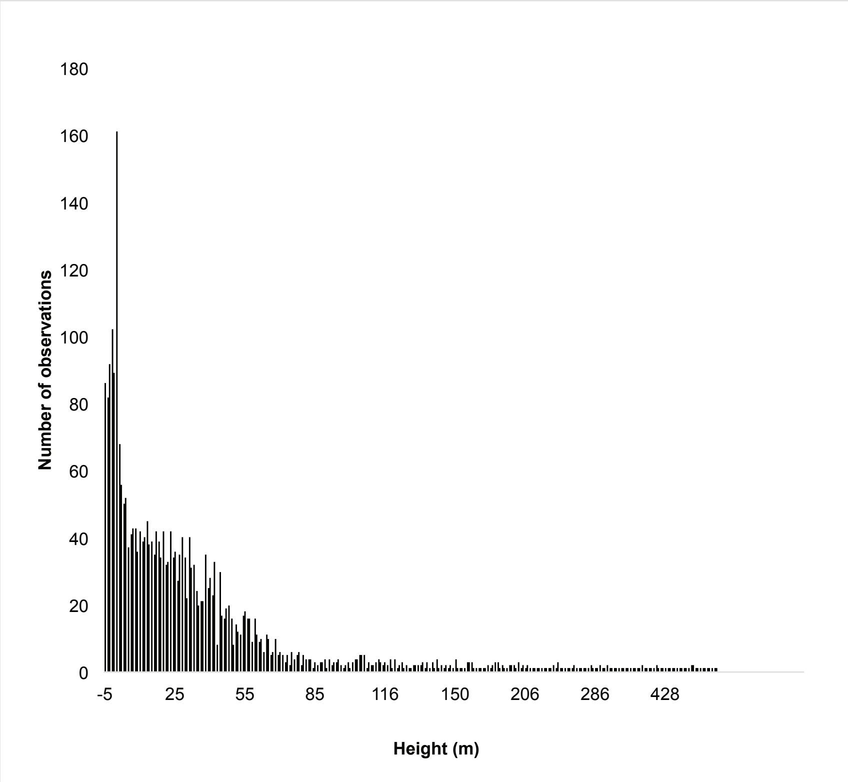

Figure 4.4.4 Frequency distribution (number of records) of flight heights of Great Black-backed Gulls equipped with GPS-loggers in Denmark. Bars represent the number of observations per altitude meter category. Only data with instantaneous velocity >4 m/s were included.

4.4.3 Percentage of flying

In Denmark, 29% of the offshore records were flight measurements. In Sweden 19% of the offshore data points were measurements in flight. To keep values comparable, the Swedish data was here filtered to keep only the breeding locations (<150 km from colony; >500 m from the colony, and over sea).

4.4.4 Nocturnal flight activity

Great Black-backed Gulls were flying both during the day and during the night, but much more flight activity occurred during daytime. As the sampling intervals were the same during the day and the night or otherwise corrected for, the number of observations were used as a measure for nocturnal flight activity.

At the latitude of the Swedish research (>60 N) the night period is short. The data was collected throughout the year, but was dominated by the breeding period (May-July), when the night is less than 8 hours long. In general, 6.2% of the flight activity occurred at night, despite the night period being 20-30% of the day. Therefore, a reduction of approximately 75% compared to daily activity is assumed for nocturnal flight activity.

In Denmark the night is approximately 23% of the day, but only 3.9% of the flights occurred during that period. This corresponds to a reduction in activity of 83%.

One thing to be aware of is that a concentration of foraging trip departures occurs around dawn, on the turning point of day and night. As for determining nocturnal flight activity these flight measurements had to be classified either day or night, we chose as a worst-case scenario to classify these as night flights. The reason for this is that in the collision risk modelling nocturnal flight activity is used to correct daytime counts to night time bird densities, as these latter are not available. By a worst-case scenario the night activity is higher, resulting in higher bird densities during the night.

5 Collision risk modelling

5.1 Estimation of collisions using the extended SOSS Band model

Based on the newly derived values for flight speed, flight altitude, percentage of flying birds and nocturnal activity, the cumulative number of collisions of Bewick's Swans, Brent Geese and Great Black-backed Gulls were estimated in all planned and existing offshore wind farms in the southern North Sea, using the extended SOSS Band model (Band 2012). However, in the case of the Great Skuas, the comparable (and high) height distribution of flight and non-flight data suggests that these measurements are erroneous and hence was this species not included in the collision risk modelling.

The extended SOSS Band model (2012) is specifically developed for use with offshore wind farms. It is species- and wind farm-specific, meaning that the number of collisions is calculated for a specific species at a specific wind turbine and applied to a specific number of turbines (wind farm). The calculations were based on densities of Great Black-backed Gulls recorded during the ESAS (European Seabirds At Sea) and MWTL (Monitoring Waterstaatkundige Toestand des Lands) surveys in the southern North Sea. Densities corresponded with those published in the 2^{nd} iteration of the KEC study for Great Black-backed Gulls (van der Wal et al. 2015), except for densities that were newly defined for wind farm Hollandse Kust South after taking an spatial extension into account (Gyimesi et al. 2016b). These earlier densities were based on species-specific estimates on the percentage of time flying. Based on the newly derived percentage of time flying in the current study, these bird densities were recalculated. Based on the derived densities, the extended Band model provides a standard method for calculating the numbers of birds passing through the rotor-swept area and consequently for the number of collisions for a specific wind farm.

The extended Band model provides a separate method for calculating the number of collisions for migrating species, such as the Bewick's Swan and the Brent Goose. For these species the average flux through the southern North Sea published in the KEC study (Rijkswaterstaat 2015) was the starting point. In the calculations for the KEC study, the average flux of 26.67 birds/km/year for Bewick's Swans and 266.67 birds/km/year for Brent Geese was applied to all planned and existing offshore wind farms in the southern North Sea (Rijkswaterstaat 2015). As GPS-logger studies provide valuable data on migration routes, in the current study we determined location-specific fluxes (see Chapter 5.2) for the same wind farms as used in the KEC study (Rijkswaterstaat 2015).

The physical parameters of the turbines and wind farms corresponded to the characteristics used in the latest environmental impact assessment of the Dutch offshore wind farm Hollandse Kust South (Gyimesi et al. 2016b), largely equivalent to the parameters provided by Rijkswaterstaat for a previous study (Gyimesi and Fijn 2015).

As flight speed and altitude influence collision probability, new turbine/species-specific values were determined. These probabilities were then applied to the number of birds crossing the rotor-swept area of an entire wind farm. Finally, an avoidance factor of 99.5% (Cook et al. 2014) was applied for Great Skuas and Great Black-backed Gulls and 98% for Bewick's Swans and Brent Geese (cf. SNH 2010, Rijkswaterstaat 2015).

5.2 Migration routes of Bewick's Swans and Brent Geese

Based on the data presented in Chapter 4 and locations of planned or operating offshore wind farms in the southern North Sea, we defined migration routes of Bewick's Swans and Brent Geese crossing these wind farms. In figure 5.2.1 and 5.2.2 the available GPS-tracks are depicted together with the offshore wind farm areas used in the calculations.

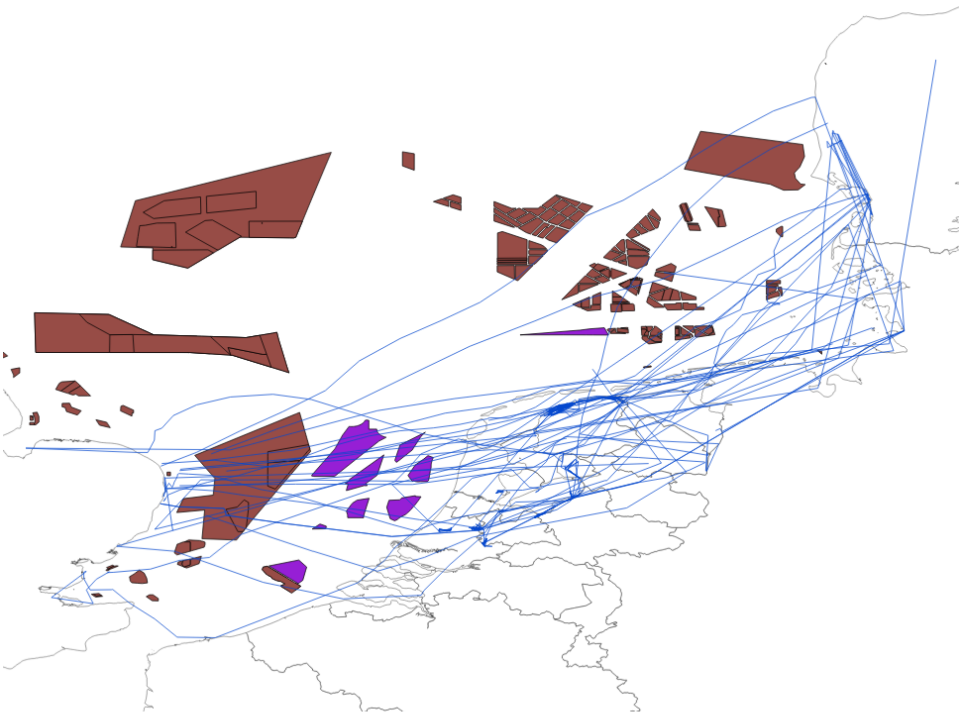

Figure 5.2.1 GPS tracks (blue lines) of Bewick's Swans in the southern North Sea and locations of planned and operating Dutch (purple) and foreign (brown) wind farms.

Figure 5.2.2 GPS tracks (green lines) of Brent Geese in the southern North Sea and locations of planned and operating Dutch (green) and foreign (purple) wind farms.

Wind farms were classified to lie along the following migratory corridors:
Flights crossing the German Bight:

1. Direct flights from Denmark to England;
2. Direct flights from Denmark to the Netherlands;
3. Flights from Denmark through Germany and the Netherlands to England.

Flights crossing the North Sea between the Netherlands and England:

4. Flights crossing from the Wadden Islands to England
5. Flights from North Holland to England
6. Flights from South Holland to England
7. Flights from Zeeland to England
8. Flight from Belgium to England
9. Flights along the Dutch coast towards France

The majority of Brent Geese flew directly from North-Germany to the West German and Dutch Wadden Islands (Figure 5.2.1), whereas a larger proportion of Bewick's Swans seems to follow the coastline (Figure 5.2.2). Brent Geese have also above the North Sea between England and the Netherlands a wide migratory pathway, while most of the Bewick's Swans cross between the coast of North-Holland and East-Anglia. Despite the newly gained detailed insights in migration routes, no reliable information on spatially explicit migration intensities could be determined due to the low sample size of migratory routes from the GPS tracking studies. However, based on the relative frequency of tracks through the migratory corridors, we could adjust the average fluxes of the KEC study (Rijkswaterstaat 2015), in order to define location-specific fluxes across the southern North Sea. Consequently, in the current study we could use a location-specific flux for each wind farm, instead of the overall mean used in the KEC study (Rijkswaterstaat 2015). The overall mean of our applied fluxes crossing the German Bight and the North Sea between the Netherlands and England remained the same as the average fluxes reported in the KEC study (Rijkswaterstaat 2015). The fluxes per route used in the collision risk models are presented in Table 5.2.1.

*Table 5.2.1 Migration fluxes of Bewick's Swans and Brent Geese in the southern North Sea along different migratory corridors based on GPS-logger data. * indicate corridors that were not relevant for the species.*

Migration routes	Migration corridors	Flux (birds/km/y) Bewick's Swan	Brent Goose
German Bight	1	8	106
	2	29	45
	3	49	649
North Sea England-NL	4	11	98
	5	80	585
	6	21	65
	7	11	98
	8	11	0*
	9	0*	488

5.3 Estimated number of collision victims

Based on the extended SOSS Band model calculations, the numbers of collision victims were estimated for Bewick's Swans, Brent Geese and Great Black-backed Gulls at existing or planned wind farms in the southern North Sea, using the newly determined values of flight speed, flight altitude, nocturnal activity and percentage of time flying. The old and new values (presented in §4) of these variables are presented in Table 5.3.1. The results of Great Skuas are also presented in the table, highlighting how much the newly derived height distribution deviates from earlier measurements. The current flight and non-flight data were comparable, both showing high altitude measurements suggesting that these measurements are erroneous (see §4.3).

Generally, the newly derived flight speeds were lower than previously measured. These latter were mainly based on radar measurements of flights above land, which may deviate from flights at sea. In addition, flight heights seem to be commonly underestimated in previous studies (cf. Gyimesi et al. 2016a). Available flight height profiles are often largely based on visual observations, which are subject to crude classifications and biased towards situations with good visibility (e.g. during daytime rather than at night). Finally, nocturnal flight activity and percentage of time flying were previously estimated to considerably higher than based on the current results.

Table 5.3.1 Overview of earlier published (old) and new estimates based on the current study for various behavioural parameters of Bewick's Swans, Brent Geese, Great Skuas and Great Black-backed Gulls.

	Bewick's Swan estimates		Brent Goose estimates		Great Skua estimates		Great Black-backed Gull estimates	
	Old	New	Old	New	Old	New	Old	New (DK/S)
Speed (m/s)	18.5	16.6	17.7	17.1	14.9	11.3	13.7	10.3/12.2
Percentage < 25 m	-	85%	-	73%	97%	39%	75%	57%/40%
Nocturnal activity	-	±33%	-	n.a.	0%	-	50%	17%/25%
Percentage flying	-	n.a.	-	n.a.	80%	64%	40%	29%/19%

The results of the collision risk modelling are summarized in Table 5.3.2. The new values led to a considerable reduction in the estimated number of collision victims for the Bewick's Swan and a relatively lower reduction for the Brent Goose and the Great Black-backed Gull based on the Danish data. However, the collision estimates based on the Swedish data were much higher than that of the Danish data and were 30% higher than the previous estimates by Gyimesi *et al.* (2016b). As the new estimates of speed, nocturnal activity and percentage flying were all lower than the pervious estimates, the higher number of collision victims in this case are directly caused by the considerably higher flight height (nearly twice as many birds flying >25 m).

Table 5.3.2 Number of collisions of Bewick's Swans, Brent Geese and Great Black-backed Gulls (based on Danish and Swedish data) estimated with the extended SOSS Band model (Band 2012) at wind farms in the southern North Sea (presented separately for wind farms outside the Netherlands (foreign wind farms) and for existing or planned Dutch wind farms). Previously published estimates (Gyimesi et al. 2016) are provided for comparison. For reference, the changes are also presented as a fraction of the published Potential Biological Removal (PBR) values (Rijkswaterstaat 2015).

	Bewick's Swan	Brent Goose	Great Black-backed Gull	
			Denmark	Sweden
foreign OWP	17	102	2568	4197
NL operating	1	11	102	134
NL planned	5	32	167	291
total	23	145	2837	4622
old value	58	155	3146	3146
difference in %	-60	-6	-10	47
PBR	131	6056	4144	4144
%of PBR	18	2	68	112

6 Discussion

Our study collated valuable information on various studies that have been or are being conducted using GPS-loggers or satellite transmitters to track birds. Based on data from Bewick's Swans, Brent Geese, Great Skuas and Great Black-backed Gulls we highlighted that deviations from previous estimates can have large consequences for the estimated number of collision victims.

Tagging studies usually have the limitation that the number of individuals involved is relatively small. In our case, this is especially the case for the number of individuals with relevant measurements of the Bewick's Swan and the Great Black-backed Gull. Nevertheless, previous estimates on the analysed variables also commonly relied on a limited number of individuals. Moreover, published measurements in offshore environments of the studied species were scarce (Great Skua) or non-yet existing (Bewick's Swan, Brent Goose, Great Black-backed Gull).

Previously, the most reliable data existed on **flight speed**, mainly estimated by radar measurements above land. Based on our current study and previous analysis on Herring Gulls and Lesser Black-backed Gulls (Gyimesi et al. 2016a), it seems that these previous speed measurements are structurally higher than those resulting from GPS measurements, probably due to different flight behaviour of birds in onshore and offshore environments. Nevertheless, the differences between the old and new estimates are not striking and partly due to this, changes in this variable have a relatively small influence on the outcome of the collision risk modelling.

In contrast, **flight altitude** measurements collected earlier (based on boat-surveys and radar measurements) seem to underestimate flight heights of seabirds at sea when compared with GPS-logger measurements. Although altitude measurements of the GPS-loggers are considered to be less accurate than measurements in the horizontal plane, we argue that they are in general still more objective than the previous estimates. Namely, as the earlier flight height estimates are based largely on visual observations (Johnston et al. 2014), it could be argued that observers are logically focussing on the lower air layers and the water surface (as especially boat-based surveyors are mainly looking for floating birds like divers and guillemots at the sea surface), and hence miss a relatively larger part of the higher flying birds. A good example of the strength of the GPS-loggers is the confirmation of structurally higher flight heights onshore compared with offshore areas in completely different bird species. On the other hand, there is no control over the output of the GPS loggers. The example of the Great Skuas in our current study highlights that higher flight altitude profiles can lead to much more birds flying at the rotor-swept zone. Although it seems unlikely that Great Skuas have such a different flight height distribution than known up till now (e.g. Ross-Smith et al. 2016), foraging birds or birds around colonies may have largely deviating flight heights compared with birds on migration.

Without validation (e.g. with laser range finder) of the height measurements it remains speculative how these unusually high altitudes were recorded.

The most promising improvements in obtaining estimates for collision risk model variables can be achieved for the **percentage of flying birds** and **nocturnal flight activity**. These variables have a direct and large influence on the number of birds used to calculate the number of collisions at offshore wind farms. However, there were virtually no measurements on these variables up till now, especially not for offshore environments (Garthe and Hüppop 2004).

Similarly, **migration routes** of land birds in offshore environments were also largely unknown. The highly accurate GPS-logger positions can shed light on these migration corridors. However, knowledge on these routes should ideally be accompanied by more information on the migration intensity per route. Due to the large number of field observers in the Netherlands, it might be worthwhile to see whether freely available datasets such as those published on www.trektellen.nl, with a dense network of posts of migratory counts, could not provide more insight in the migration intensity of land birds leaving the Dutch coast.

The comparisons between the Danish and Swedish Great Black-backed Gull datasets provides also insights in possible **differences between populations** of the same species. Although the Danish data had a much smaller sample size, it is not implausible that different populations have a different flight characteristics based on e.g. the food sources they are exploiting or the offshore environmental circumstances they have to cope with. Especially, that such differences have been detected between populations of Lesser Black-backed Gulls as well (Corman and Garthe 2014, Ross-Smith et al. 2016). Collecting more data in the future should reveal whether this is a matter of sample sizes or real differences between populations.

Comparably, there are likely also differences in behaviour in **different periods of the year**. Our current analysis relied for the Great Black-backed Gull and the Great Skua on data from the breeding season. These birds are mainly conducting flights to and from the colony. Likely the behaviour of these birds will change during the migration and winter period when they are not constricted by chick rearing. It would be worthwhile to compare the current results with future measurements collected outside the breeding period, especially that collisions in Dutch offshore wind farms are mainly expected outside the breeding season (Table 6.1.1).

Moreover, measurements along **different parts of the migratory route** might also deviate. This seems to be indicated by the varying flight heights of Bewick's Swans by crossing various seas. The current measurements indicate that flight height of Bewick's Swans is relatively lower at the North Sea, but the sample size is small and hence should be verified by future measurements whether the differences are really present.

Table 6.1.1 Overview of the data collection periodes of the current study and main periods when collision victims in Dutch offshore wind farms are expected for Bewick's Swans, Brent Geese, Great Skuas and Great Black-backed Gulls.

	data collection period	main periods with collision victims
Bewick's Swan	migration	migration
Brent Goose	migration	migration
Great Skua	breeding	migration and winter
Great Black-backed Gull	breeding	migration and winter

Finally, one of the key parameters that has a major influence on the outcome of the collision rate model is **avoidance behaviour**. Despite obtaining more and more accurate estimates on flight behaviour and flight paths, accurate avoidance rates remain scarce. For example, Whitfield & Urquhart (2015) have recently argued for using avoidance rates of 99.7% or 99.8% for Bewick's swans, instead of earlier estimates of 98% (SNH 2010). In the case of the current study that would mean a reduction from 23 to respectively 3 or 2 collision victims, a reduction of 85% or 90%. However, Whitfield & Urquhart (2015) have relied in their calculations on one study, conducted on land in the Netherlands (Fijn et al. 2007). These enormous differences in the number of collision victims due to a small change in avoidance rates highlight the need of more thorough research on this topic.

7 Conclusions and recommendations

7.1 Conclusions

This current study including a review on GPS-studies, revealed that many of the focal species vulnerable to collisions with offshore wind farms in the southern North Sea have been studied or are being studied using GPS-loggers or satellite transmitters. Many studies are in the starting-up phase or had no published results yet, especially not on figures relevant for collision risk modelling in offshore environments.

Therefore in the second part of the project, we obtained GPS-logger data from the Bewick's Swan, Brent Goose, Great Skua and Great Black-backed Gull. The analysis revealed a few general phenomena.

- Flight speeds in offshore environments seem to be lower than previously estimated by mainly radar measurements on land;
- Offshore flight altitudes of seabirds seem to be higher than previously estimated by visual observations;
- Offshore flight altitudes of migrating birds are lower compared with altitudes above land;
- Percentage of time flying and nocturnal activity seem to be lower than previously estimated, often based on expert judgements;

Based on the new figures, we calculated updated estimates on the number of collision victims in offshore wind farms of the southern North Sea. The new values led to a considerable reduction (60%) in the estimated number of collision victims for the Bewick's Swan and a relatively lower reduction for the Brent Goose (6%) and the Great Black-backed Gull based on Danish data (10%). Once again, the data showed the sensitivity of the Band model to the used flight altitude distribution. Namely, despite lower estimates of speed, nocturnal activity and percentage flying, the higher flight altitude profile of Great Black Backed-Gulls in Sweden resulted in higher collision victim estimates than the previous ones. Even more, the unusually high flight profile of Great Skuas at Bjørnøya Island was considered unreliable and omitted from collision victim modelling.

7.2 Recommendations

Tagging studies on species

Our study resulted in the collection of detailed GPS-measurements on two species migrating through the southern North Sea and on two seabird species. The datasets of Bewick's Swans and Great Black-backed Gulls comprised data of only a few individuals, and hence ideally **more measurements on more individuals** should be conducted to have a more robust dataset. Obviously, the **number of species** studied with GPS-loggers in the southern North Sea could also be increased. A logical way forward would be to include bird species that migrate in large numbers over the North Sea and that have successful tracking experiences with GPS-loggers elsewhere. Examples of such species are **Curlews** and **Bar-tailed Godwits**, that are also estimated to suffer relatively large losses due to collisions with offshore wind farms in the southern North Sea (Rijkswaterstaat 2015). Especially important is that these species both belong to the species group of waders, of which currently no detailed knowledge exists on offshore flight behaviour and migration corridors in the southern North Sea. Another species that is currently studied by GPS-loggers that could relatively easily be extended to collect relevant information for offshore wind farm assessments is the **Shelduck**, again representing a species group (ducks) that currently lacks detailed information from offshore environments. Ideally, individuals of these species should be caught and tagged in East-England (in co-operation with the British Trust of Ornithology) and not in the Netherlands, to have a higher chance of studying birds actually migrating through the North Sea.

Besides the bird species mainly using terrestrial or coastal environments, the **Little Gull** is a species that often uses marine environments and for which the southern North Sea is of special importance during the migration period. Practically nothing is known of the offshore habitat use of this species, a gap of knowledge that should ideally be filled with future studies.

In addition to the above-mentioned species, there are a number of species that are relevant for offshore wind farm assessments but are too small to be studied by currently available GPS tags (see Table 1). However, the example of Red Knots (Chapter 2.10) highlights the possibilities to learn more about their migration routes in the near future. It is recommended to regularly update the current document to follow the quickly developing field of study of GPS-logging technologies.

Migration intensity

Also **migration intensity of mainly terrestrial birds** through the North Sea should be validated. It might be worthwhile to see whether freely available datasets such as those published at www.trektellen.nl, with a dense network of posts of migratory counts, could not provide more insight in the migration intensity of land birds leaving the Dutch coast. Currently, Statistics Netherlands (CBS) is investigating for other purposes whether this dataset could be used for trend analysis. Once the dataset is arranged in a standardized way, a possible cooperation with CBS could provide base for analysing data to define migration intensities that are relevant for offshore wind farm assessments.

Studies on flight characteristics

Furthermore, the current analyses also highlighted that even the quality of the existing data can be further improved. **Flight altitude measurements** of GPS-loggers are prone to inaccuracy and could be more often validated by for example observations carried out by laser range finders. In addition, the data of **Great Black-backed Gulls** and **Great Skuas** was collected during the breeding period. Ideally, the collection of such data should be extended to **the migratory- and winter period**, when these species occur in large numbers in the southern North Sea. In addition, it might be worthwhile to study whether recently developed **Bayesian analysis** techniques (Ross-Smith et al. 2016) provide better ways to correct for negative flight height values of species frequently flying at very low altitudes.

Studies within wind farms

Finally, the current knowledge largely focuses on natural behaviour of birds outside offshore wind farms that is used to feed collision risk models, employing a general avoidance rate to correct for deviations in the natural behaviour once entering the wind farm area. Due to the large amount of **available offshore data in the Netherlands** of Herring Gulls and Lesser Black-backed Gulls, also from areas where wind farms are already operating, we propose to carry out an the analysis on flight behaviour in wind farm areas to learn more about attraction or avoidance of these species to wind farms. In addition, it is recommended to carry out more studies directly focusing on the behaviour of individuals within wind farms, by **deploying GPS tags on individuals in offshore wind farms** on birds occurring.

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