Flight height of seabirds.
A literature study

Auteurs: Ruud H. Jongbloed

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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

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Summary

The flight height of marine birds is one of the most important factors determining the risk of collision of marine birds with offshore wind turbines. Therefore, a literature study is carried out to collect and integrate the available information in order to discuss the current knowledge status and gaps concerning the following issues:

- The flight height distribution of seabirds
- The major factors influencing flight height
- The possible implications of flight height distributions and influencing factors for the seabird collision risk for offshore wind farms

Flight height of birds can be detected by several methods comprising visual observations, tagging, high-definition imagery and radar. There are limitations to all methods applied to determine flight heights.

Flight heights of seabirds are often reported, but (semi) quantitative data for many seabird species over the entire relevant altitude range (up to approx. 300 m above sea level) are scarce. Average flight heights differ considerably among groups of residential and migration seabirds such as gulls, divers, gannets, scoters, guillemots and auks. Flight altitude distributions are modelled for 25 seabird species derived from all available flight height data assigned to height bands during boat-based surveys of offshore wind farms in the UK, the Netherlands, Denmark, Belgium and Germany. Most seabird species fly within 20 m height above sea level for more than 90% of their time during flight. The species with relative high flight altitudes are gulls and the Northern Gannet. Flight percentages at wind turbine rotor height (ca. 20-150 m above sea level) based on evaluation on an extensive literature review are available allowing to rank seabird species. These percentages range from 0 to 35.

The influence of a number of factors on the flight height of seabirds is reviewed. Many knowledge gaps exist. In general flight height is lower during rain/precipitation, certain time of day (night), foraging, habitat type and spatial arrangement (above sea), and presence of fishing boats. On the other hand flight height is higher during migration and orientation. The influence of wind speed, wind direction, season, distance to coast, and offshore wind farm (e.g. also configuration and type of turbines) on flight height is variable depending on the seabird species.

The majority of the seabird species has a low risk for collision to offshore wind turbine blades because they fly almost exclusively under the rotor swept altitude. However a few species are considered at relatively high potential collision risk due to their flight height percentage in the height range of 20 to 150 m above sea level. These are mainly the gull species and the Northern Gannet. Factors that raise the flight height of seabirds to wind rotor height will probably also increase the collision risk for collision to wind turbines, whereas the opposite will be expected for factors reducing flight height. It should be kept in mind that apart from flight height there are more factors determining the collision risk: flight manoeuvrability, percentage of time flying, nocturnal activity and avoidance behaviour of wind farm (large scale avoidance) or wind turbines (small scale avoidance).

Nederlandse samenvatting

De vlieghoogte van zeevogels is één van de meest belangrijke factoren die het risico voor botsing van zeevogels met offshore windturbines bepaalt. In deze studie is een literatuuronderzoek uitgevoerd om informatie te verzamelen en te analyseren ter bepaling van het huidige kennisniveau en kennisleemten ten aanzien van de volgende onderwerpen:

- De vlieghoogteverdeling van zeevogels
- De belangrijkste factoren die de vlieghoogte beïnvloeden
- De mogelijke implicaties van vlieghoogteverdeling en beïnvloedende factoren voor het risico van botsingen van zeevogels met offshore windparken

De vlieghoogte van vogels kan worden gedetecteerd met verschillende methoden zoals zichtwaarnemingen, zenderen, grote beeldscherpte opname en radar. Aan al deze methoden zijn beperkingen verbonden.

Vlieghoogte van zeevogels wordt vaak gerapporteerd, maar (semi)kwantitatieve gegevens voor veel zeevogels over de gehele relevante hoogterange (tot ca. 300 meter boven de zeespiegel) zijn schaars. Dec gemiddelde vlieghoogte verschilt behoorlijk tussen groepen van residerende en migrerende zeevogels zoals meeuwen, duikers, jan van genten, zee-eenden, zeekoeten en alken. Vlieghoogteverdelingen zijn gemodelleerd voor 25 zeevogelsoorten, afgeleid van alle beschikbare vlieghoogtegegevens toegekend aan hoogtelagen gedurende waarnemingen vanaf boten van offshore windparken in de UK, Nederland, Denemarken, België en Duitsland. De meeste zeevogelsoorten vliegen op minder dan 20 meter boven de zeespiegel voor meer dan 90% van hun vliegtijd. De soorten met een relatief hoge vlieghoogte zijn meeuwen en de Jan van Gent. Vlieghoogtepercentages op windturbinerotor hoogte (ca. 20-150 boven de zeespiegel) gebaseerd op evaluatie van een uitgebreide literatuurreview zijn beschikbaar waarmee zeevogelsoorten zijn gerangschikt. Deze percentages variëren van 0 to 35.

De invloed van een aantal factoren op de vlieghoogte van zeevogels is onderzocht. Er bestaan veel kennisleemten. In het algemeen is de vlieghoogte lager gedurende regen en andere neerslag, tijd van de dag (nacht), foerageren, habitat type en ruimtelijke structuur (ook in de hoogte), en aanwezigheid van vissersschepen. Anderzijds is de vlieghoogte hoger tijdens migratie en oriëntatie. De invloed van windsnelheid, windrichting, seizoen, afstand tot de kust, en offshore windpark (bijv. ook configuratie en type windturbines) op vlieghoogte is variabel en afhankelijk van de zeevogelsoort.

De meerderheid van de zeevogelsoorten heeft een laag risico op botsingen met offshore windturbines omdat deze bijna de gehele tijd onder de rotorhoogte vliegen. Een gering aantal soorten worden verondersteld een relatief hoog potentieel risico op botsingen te lopen vanwege hun hogere vlieghoogtepercentage in de hoogterange van 20 tot 150 m boven de zeespiegel. Dit zijn voornamelijk meeuwen en de Jan van Gent. Factoren die de vlieghoogte van zeevogels verhogen tot de hoogte van windturbinerotoren zullen waarschijnlijk ook het risico voor botsingen met windturbinerotoren vergroten, terwijl het tegenovergestelde wordt verwacht voor factoren die de vlieghoogte verlagen. Men dient zich te realiseren dat er naast de vlieghoogte meerdere factoren zijn die het risico op botsingen mede bepalen: vliegwendbaarheid, vliegtijdpercentage tijdens een etmaal, nachtactiviteit en vermijding van windparken (grootschaligere ontwijking) of windturbines (kleinschalige ontwijking).

1 Introduction

1.1 Background

Avian flight heights are currently a focus of interest in terms of assessing possible impacts of offshore and inland wind farms on birds by collision. Certain bird species may be at higher risk due to the time spent at the altitude that matches the wind turbine rotor blade altitude. Thus the flight height distribution of bird species is of major importance as is also stated by Bradbury et al. (2014) and Johnston et al. (2014). Certain environmental or anthropogenic factors may influence the flight height of birds and thereby raising or reducing collision risks of birds (Hüppop et al., 2006). However an overview of these factors is not available and knowledge gaps may exist. In this study we focus on flight heights of seabirds in relation to collision risk for offshore wind farms. Terrestrial birds only fly over sea in migration periods and are not considered here. This subject is dealt with in a parallel study by Bureau Waardenburg (Krijgsveld et al., 2015).

Flight height is widely considered to be of high importance in determining the risk of collision of marine birds with offshore wind turbines (Band, 2012; Cook et al., 2012). Marine birds that only fly very low over the water will be below the area swept by turbine blades, whereas marine birds that habitually fly at greater heights may experience a greater risk of collision with blades if flight heights coincide with rotor swept areas of a wind farm.

1.2 Assignment

The aim is to provide an overview of the current knowledge and knowledge gaps concerning:

- The flight height distribution of seabirds
- The major factors influencing the flight height
- The possible implications of flight height distributions and influencing factors for the seabird collision risk for offshore wind farms

The information is collected by literature search.

This study is part of the BO project Vervolg Uitvoering Masterplan (VUM) Ecologische effectmeting windenergie op zee.

2 Detection methods

Flight height of birds can be detected by several methods. Johnston et al. (2014) mention that the most important methods for determination of flight heights of seabirds comprise visual observations, tagging, high-definition imagery and radar. Tagging data may overcome some bias associated with weather conditions and nocturnal behaviour (Bridge et al., 2011; Stumpf et al., 2011; Klaassen et al., 2012), but offers a restrictive sample size and is not suitable for all species (Burger & Shaffer, 2008). High-definition digital imagery is increasingly common in aerial surveys of offshore windfarms (Buckland et al., 2012), but data are hard to use on a species specific basis and restricted to lower air space. Radar may positively bias estimates of flight altitudes as low-flying birds are under-recorded due to reflections from the sea surface (Hüppop et al., 2006) and species specific information is sparse (Schmaljohann et al., 2008). Consequently, migrants which may fly above 1000 m are not usually seen by visual observers, either on the ground or in aeroplanes but are included in radar data sets (Hüppop et al., 2006; Krijgsveld et al., 2011), and different methods might bias estimates of flight height in different ways. Studies using radar and visual observations suggest that most seabird movements occur at lower altitudes, while observations at higher altitudes are migrating passerines or waders (Krijgsveld et al., 2011).

Hüppop et al. (2006) applied several methods for observation of bird migration, including flight altitudes, and discussed the advantages and disadvantages of these methods. These methods comprise sea watching, ship-based surveys, ship radar, thermal imaging, video camera and microphone, searching collision victims.

There are limitations to all methods applied to determine flight heights. Most data discussed by Hüppop et al. (2006) were collected during ship-based surveys, and issues associated with observer safety and the detectability of birds limited the data collection to hours of daylight, with moderate winds and good visibility. Information about variation in flight behaviour during different conditions is therefore limited. However, many of the studied species are considered less likely to forage during the night than during the day (e.g. Garthe & Hüppop, 2004). A key concern about the use of visual observations to estimate flight altitudes is that the data will be negatively biased as recording birds at higher altitudes is difficult (Johnston et al., 2014).

3 Flight height

Information on flight height values of seabirds is found in many publications, but only a few provide (semi) quantitative values for many seabird species over the entire relevant altitude range (up to approx. 300 meter above sea level). We therefore focus on the latter publications comprising Krijgsveld et al. (2005, 2011), Cook et al. (2012), Furness et al. (2013), Bradbury et al. (2014) and Johnston et al. (2014).

Krijgsveld et al. (2011) recorded flight activity of local seabirds (such as gulls, divers, gannets, scoters, guillemots and auks), migrating seabirds (such as divers and scoters) and migrating non-marine birds (such as thrushes and geese) at a broad altitude band (measured up to 1385 m high). The research was carried out for the Offshore Wind farm Egmond aan Zee (OWEZ) between April 2007 and June 2010, following a baseline study at Meetpost Noordwijk that took place between 2003 and 2005 (Krijgsveld et al., 2005). Flight altitudes were obtained by vertical radar observations both during the day and at night and with visual observations during daytime. Gulls flew mostly below 50m, occasionally higher up to 200m. Seabirds (alcids, divers, sea ducks, skuas and tubenoses) flew mostly low above the sea, at altitudes up to 50 m, and mostly below 15 m. Most cormorants flew up to 100 m, occasionally higher. The average flight altitudes for these and other seabird groups are shown in Table 1.

Table 1 Average altitude of seabirds flying near Meetpost Noordwijk (Krijgsveld et al., 2005)

Species group	Average altitude (m)
Gulls	36.8
Terns	27.6
Gannets	25.6
Cormorants	23.8
Divers	19.0
Sea ducks	18.5
Skuas	16.2
Alcids	11.9
Tubenoses	11.3

Cook et al. (2012) reviewed and modelled flight heights of seabirds. They used studies that applied three different methodologies to the calculation of seabird flight heights:

- Assignment to flight classes during boat-based surveys undertaken to inform EIAs;
- Estimation of height during land-based sea-watching;
- Measurement by radar.

The modelling was carried out by estimating continuous distributions of flight heights for each bird species, assuming the same distribution across all sites. These distributions were fitted with a flexible curve, not constrained to any specific distributional form. This was based on boat-based data primarily because information on flight heights was required at a species-specific level. Digital aerial surveys and video imagery techniques on flight heights are therefore not used although they have potential and might offer a future alternative to data from boat surveys. Digital aerial surveys have been widely used in recent years to inform the EIA process for offshore wind farms. These methods have the potential not only to inform on baseline numbers of birds, but also on flight heights. Cook et al. (2012) found only two radar studies that recorded flight heights, one focussing on Common Eider in Alaska (Day et al., 2004) and a second considering migrating Black-headed and Lesser Black-backed Gulls in in the Netherlands (Shamoun-Baranes et al., 2006). They conclude that the sample sizes involved in these studies are presently too small to make generalizations about species flight behaviour. It should be noticed that there are other radar studies on seabirds available from which flight height information may be derived (Myres, 1963; Alerstam et al., 1974a; Alerstam et al., 1974b; Zhalakevicius, 1977; Dirksen et al., 1998; Dirksen et al., 2005).

The flight height data presented by Cook et al. (2012) should be considered in relation to sites which are used by birds on a daily basis only. Attempts to model flight heights at sites where a significant proportion of birds is likely to be passing through as part of their migration were unsuccessful as the models failed to converge. This may imply that flight heights at these sites can be highly variable, and that they should be considered on an individual basis, or modelled within specific seasons. It is also worth noting that no data were available covering species flight heights at night. This is of concern given that several key seabird species, such as Northern Fulmar and Black-legged Kittiwake, are believed to be fairly active at night (Garthe & Hüppop, 2004).

For each of the 25 seabird species, Cook et al. (2012) modelled all available flight height data assigned to height bands during boat-based surveys of offshore wind farms in the UK, the Netherlands, Denmark, Belgium and Germany. They applied a spline function, which fits a curve to the data. They assumed that for each species, flight heights would follow a similar distribution across all study sites. For each bootstrap the proportion of birds flying at each height between 0 and 300 m above sea-level, in 1 m intervals, was calculated. The final results presented are the median of all of these values, and the associated 95 % confidence intervals calculated from the bootstrap values. For most species, tight confidence limits indicated that data were reasonably consistent between sites. Exceptions were found for Common Eider and Great Cormorant as models for these two species failed to converge. Distinguishing between sites where Common Eiders were likely to be recorded during migration and those where they were resident, had no impact on model performance. The authors conclude that this may indicate that flight behaviour in Common Eiders and Great Cormorant is highly variable between sites.

In order to derive the potential exposure OWF, for each species the proportion of birds flying within a generic collision risk window, defined as covering a range from 20 m to 150 m above sea-level, was calculated.

The Band collision risk model (Band 2012) also uses the data on flight height distributions, as produced by the modelling presented by Cook et al. (2012). For collision risk modelling, Cook et al. (2012) recommend that consideration should be given to results using both the site-specific and their modelled flight height data.

Furness et al. (2013) estimated the percentage of flight at turbine height (ca. 20-150 above sea level). They based their evaluation on an extensive literature review. Their results on flight height are less detailed than those of Johnston et al. (2014) but are also interesting to present here. Furness et al. (2013) ranked 37 seabird species on the flight percentage at wind turbine blade height. Flight altitude includes birds in all activities (such as foraging, commuting, migrating). It may vary seasonally, but there are too few data available at present to test this possibility. The percentage of a species' flight altitude at turbine blade height (20-150 m a.s.l.) ranged from values of 0 to 35. Bradbury et al. (2014) updated and extended the flight height data of Furness et al. (2013) to 54 seabird species.

Johnston et al. (2014) provide data from visual surveys of the flight height of 25 marine bird species on 32 potential offshore wind farm development sites carried out by observers mainly on boats, but also on offshore platforms and shore. This publication is mainly based on the extensive work reported by Cook et al. (2012). These data are very detailed and the generic flight height distributions of seabirds are currently used in the Band models for risk of bird collision risks for offshore wind farms (Band, 2012). For 25 seabird species the modelled flight height distributions are shown in Figure 1. A clear difference among these species can be seen. Most species fly within 20 meter height above sea level for more than 90% of their flying time (Figure 2). The species with relative high flight altitudes are large gulls and Common Eider. However in The Netherlands high flying Common Eiders are not observed at sea and along the coast (Mardik Leopold, IMARES, pers. com.).

For 25 bird species the flight height percentages from Johnston et al. (2014) were compared with those from Bradbury et al. (2014) (see Figure 3). There is a high correlation (R2=0.92) between the flight height percentages at rotor blade height in case the Common Eider is left out the dataset. The flight height percentages of both datasets differ less than a factor 2 for 17 of the 25 bird species (see Table 2).

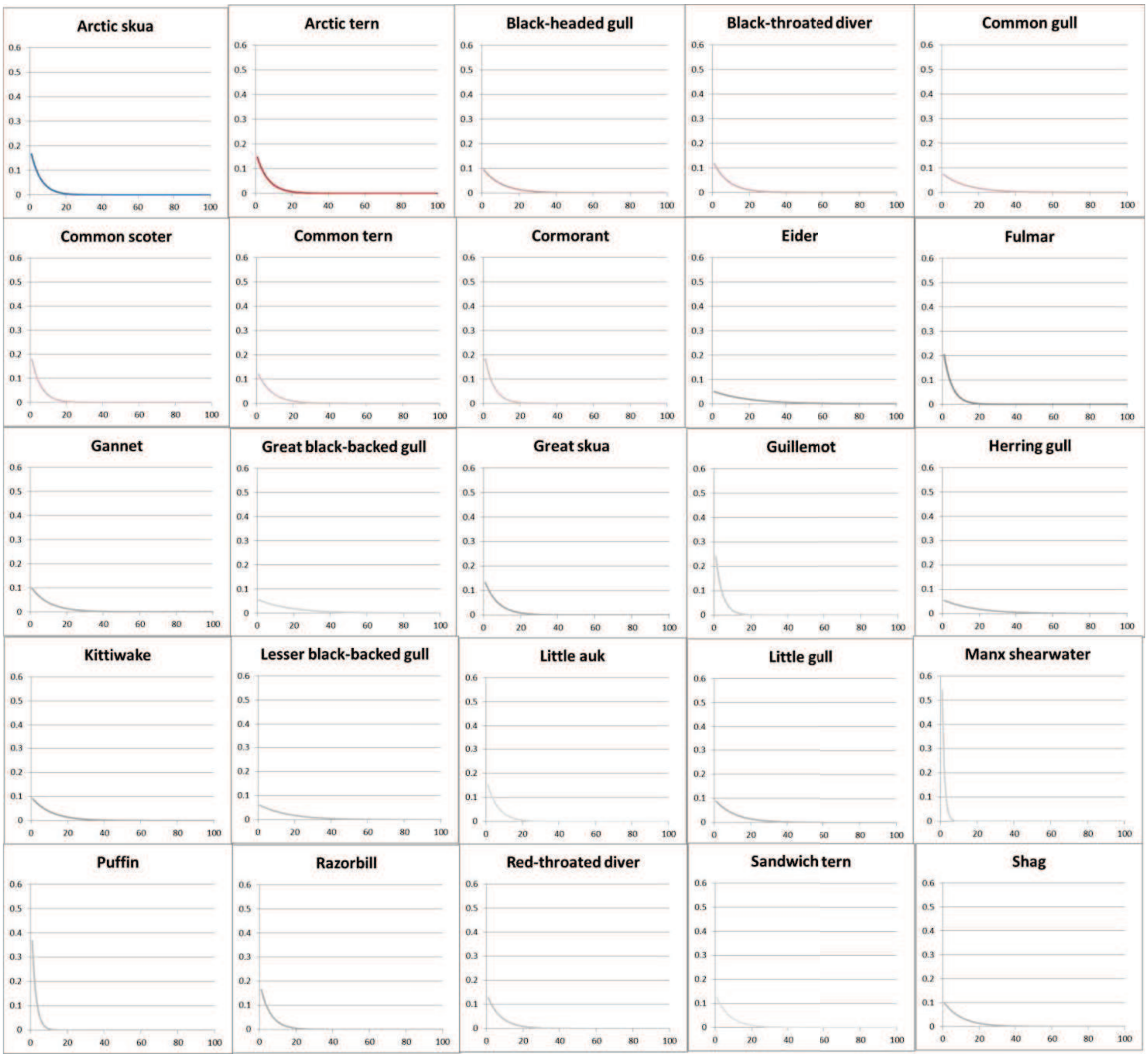

Figure 1 Modelled flight height distributions of 25 seabird species. Source of data: Johnston et al. (2014)

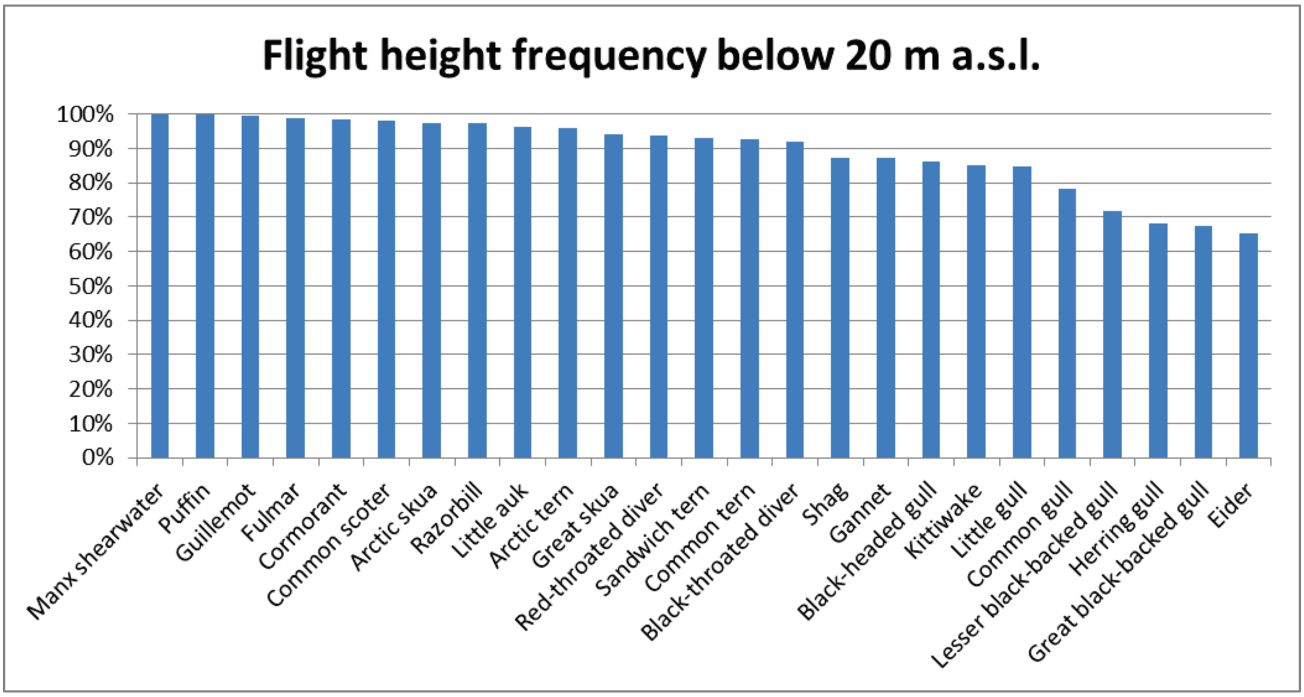

Figure 2: Flight height frequency below 20 meter above sea level of 25 seabird species. Source of data: Johnston et al. (2014)

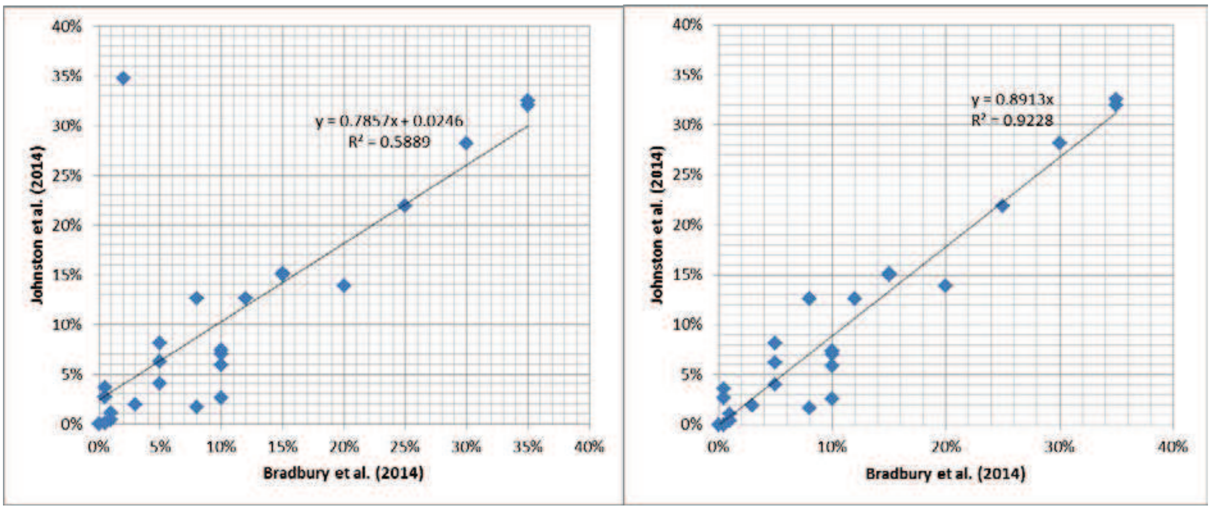

Figure 3: The percentage birds flying at wind turbine blade height (20-150 m a.s.l.) according to the Bradbury method and the Band model (data from Johnston et al., 2014). The line depicts the relationship between the methods. Left figure: for 25 seabird species (including Eider). Right figure for 24 seabird species (without Eider because of the enormous deviation).

Table 2: The percentage birds flying at wind turbine blade height (20-150 m a.s.l.) according to the Bradbury method and the Band model (data from Johnston et al., 2014).

Species	**Bradbury et al. (2014)**	**Johnston et al. (2014)**
Herring Gull	35%	32.0%
Great Black-backed Gull	35%	32.5%
Lesser Black-backed Gull	30%	28.2%
Common Gull	25%	21.9%
Black Headed Gull	20%	13.9%
Little Gull	15%	15.1%
Kittiwake	15%	15.0%
Gannet	12%	12.6%
Arctic Skua	10%	2.6%
Great Skua	10%	5.9%
Sandwich Tern	10%	7.0%
Common Tern	10%	7.4%
Cormorant	8%	1.7%
Shag	8%	12.6%
Red-throated Diver	5%	6.2%
Black-throated Diver	5%	8.1%
Arctic Tern	5%	4.0%
Common Scoter	3%	1.9%
Eider	2%	34.7%
Fulmar	1%	1.0%
Guillemot	1%	0.4%
Razorbill	0.5%	2.7%
Little Auk	0.5%	3.6%
Puffin	0.5%	0.0%
Manx Shearwater	0%	0.0%

4 Factors affecting flight height

Flight height of seabirds can potentially be influenced by many factors, both environmental and anthropogenic:

- Wind speed
- Wind direction
- Rain and other precipitation
- Time of the day/Day-Night
- Season
- Distance to coast
- Foraging
- Habitat type and spatial arrangement
- Migration
- Offshore wind farms
- Other factors

These factors are dealt within the following sections. A synthesis is elaborated in section 5.2. It should be noted that the studies often greatly differ in the level of detail, time and spatial scale and the scope; some focussing on specific seabird species and other on seabirds in general.

4.1 Wind speed

Birds may avoid areas of heavy wind and rain or spend more time at or under the water surface in these conditions (Johnston et al., 2014), although Procellariiformes (such as Northern Fulmar *Fulmarus glacialis* and Manx Shearwater *Puffinus puffinus*) may have higher flight altitudes during strong winds (Spear & Ainley, 1997). Consequently, the absence of data collected during poor weather may bias estimates of the proportion of birds at risk, both when using the modelled distributions and existing methods. Data were also summarized across the year as a whole, again reflecting how they are currently used. Consequently, these data may include observations of migrating birds.

Ainley et al. (2015) evaluated the effect of wind speed and wind direction on two key characteristics of seabird behaviour, flight height and flight behaviour. They used cluster analysis to partition 104 seabird species into morphological groupings based on degree of divergence in morphology from Pennycuick’s “standard seabird,” with subgroups evident among and within flappers, glide-flappers, and flap-gliders (Pennycuick, 1989). Seabird flight height and behavior varied among groups and subgroups and changed as a function of wind speed and direction relative to travel, with the probability of more gliding and flying above 10 m increasing as wind speed increased.

A detailed experiment with tagged Lesser Black-backed Gulls revealed that the flight height of these birds was unaffected by wind (Corman & Garthe, 2014).

From this information it can be concluded that the response of flight height to increasing wind speed is variable depending on bird species.

4.2 Wind direction

In general headwinds result in a lower flight altitude.

A detailed experiment with tagged Lesser Black backed Gulls revealed that the flight height of these birds was unaffected by wind (Corman & Garthe, 2014). However, gulls flying from sea to their colonies have been seen to fly very low over the waves (Mardik Leopold, IMARES, pers. com.).

Spear & Ainley (1997) studied the influence of wind direction and wind speed on migrating seabirds. Extensive low-altitude transoceanic migration by seabirds may be related to opportunistic foraging along the migration route, which would require consistent low-altitude flight. If this is true, migrating seabirds should respond to the wind in a way that would result in a compromise between optimal foraging and efficient flight. Consistent with this idea, Arctic Terns migrating in the Antarctic flew mostly into headwinds (a flight direction similar to that of terns and skuas we observed over a much wider geographic range, many of which were in migration) and foraged along the migration route. This finding suggests that headwind flight is acceptable or even preferred during migration.

Flight altitudes of Common Eiders during migration in Alaska were significantly lower during headwinds than during crosswinds and tailwinds (Day et al., 2004). The flight altitude of divers is dependent on wind direction, with mostly low-altitude flights in headwind conditions and higher flight altitudes during tailwind situations (Krijgsveld et al., 2011).

Overall we can conclude that flight height is lower in headwind, and higher in tailwind but dropping with higher tailwind speed, whereas for some species no influence of wind direction is found.

4.3 Rain and precipitation

Little information is found on the influence of rain and precipitation on flight height. In general precipitation results in a lower flight altitude (Hüppop et al., 2006). Seabirds may avoid areas of rain or spend more time at or under the water surface in these conditions (Johnston et al., 2014), however specific information is lacking. Migrating birds fly at lower altitudes at rainy nights because Hüppop et al. (2006) noticed that the percentage of birds migrating under 200 m was distinctly higher in rainy nights than in nights without rain.

4.4 Time of the day/Day-night

Lesser Black-backed Gulls flew lower at night than during the day. Foraging trips during the day might be conducted at higher altitudes than those at night because of better visibility (Corman & Garthe, 2014).

During migration, time of day has an effect on flight altitude (Hüppop et al., 2006). Whatever the time of day or season of the year, the highest percentage of flights was almost exclusively registered in the lowest 100 m. This is particularly evident in the daytime and to a lesser extent also in the morning and evening periods. At night, most birds also migrate at altitudes below 200 m in a seasonally varying proportion. Altitude distribution differences between nights may be due to a different range of species. Many diurnally migrating species of seabirds and waterfowl migrate mostly at very low altitudes. Krijgsveld et al. (2011) found that especially at night the flight activity of migrating birds occurred at both higher and lower altitudes.

From this information it can be concluded that the flight altitude is generally lower at night, lower but sometimes higher during migration.

4.5 Season

In the literature we did not find information on the influence of season on the flight height of seabirds. For pooled migrating birds (combination of occurring bird species) flight activity varies highly between seasons (Krijgsveld et al., 2011). In the winter and summer season flight altitudes were low, reflecting the dominance of gulls and to a lesser extent other local seabirds that fly at low altitudes. In the spring some species like arctic waders migration to their breeding grounds fly at very high altitudes (Hüppop et al., 2006), using high-altitude tailwinds (Alerstam, 1978; Liechti & Bruderer, 1998; Green & Piersma, 2003).

From this we can conclude that the flight altitude is lower in summer and winter (dominance of local seabirds), higher in spring and autumn (dominance of migrating birds). There is a lack of species specific information for seabirds.

4.6 Distance to coast

Camphuysen (2011) registered the flight height of Lesser Black-backed Gulls with GPS loggers and found a distinct pattern. This was a broad zone of 5-25m altitude along the coast, followed by a nearly equally wide zone of distinctly lower altitudes and more extreme altitude values at the far end of the feeding range. The low flight altitude zone is seen as a zone of more frequent water contact. This is an area which is used by large beam trawlers and therefore also used by gulls forging on discards. The zone nearby and parallel to the coast is less used for foraging at the water surface. This is interpreted as the commuting zone to and from the colony where the gulls fly at higher altitudes. Water depth and distance to the coast probably are the key factors for this flight pattern. This is not completely in line with the findings of Corman & Garthe (2014) that the outbound and inbound flights of Lesser Black-backed Gulls occurred at similar heights.

In general the flight altitude of low migrating birds can be seen to be distinctly lower offshore than on the coast or inland (Hüppop et al., 2006). This was also found by Stumpf et al. (2011) for Marbled Murrelets (*Brachyramphus marmoratus*) using radar to quantify flight heights.

From this information it can be concluded the effect of distance to coast on the flight height is variable (lower and higher) depending on the bird species.

4.7 Foraging

The flight height is also influenced by foraging behaviour. This is demonstrated by Camphuysen (2011) and Corman & Garthe (2014) for Lesser Black-backed Gulls equipped with specifically programmed GPS data loggers to ensure accurate flight-height measurements in the southern North Sea during the incubation period. Foraging Lesser Black-backed Gulls vary their flight heights according to their destination, time of day, and flight type. Straight flights represented commuting between different foraging sites and/or the breeding colony, while tortuous flights probably indicated active foraging. Straight commuting flights were made at higher altitudes than tortuous flights. For orientation of Lesser Black-backed Gulls flight height is higher. The lower flight altitude somewhat further from the coast and the colony is probably connected with the foraging strategy. Here most foraging will occur, with more frequent water contact of the birds and the presence of trawlers providing a chance for scavaging on discards.

From this information it can be concluded that foraging behaviour as compared with not foraging behaviour (commuting, migrating) requires lower flight height.

4.8 Habitat type and spatial arrangement

Corman & Garthe (2014) found that GPS-logged Lesser Black-backed Gulls flew lower over the sea than over land.

Hüppop et al. (2006) mentioned that the greater unevenness of the landscape creates turbulence – more or less depending on the exact topography of the land surface – which are hardly ever encountered at sea. Low stratum winds reach speeds that are greater and more constant over sea than they do over land. Accordingly, tailwinds at low altitudes are more favourable at sea than over land, which could be one reason for the lower flight altitudes at sea.

Stumpf et al. (2011) used radar to quantify flight heights, passage rates and flight behaviour of Marbled Murrelets between nesting sites and feeding sites on the Olympic Peninsula, Washington. They concluded that flight height likely varies with the topography and the spatial arrangement (including elevation) of suitable habitat, next to other factors like distance from the ocean and weather. Another example can be given for Manx Shearwaters, flying very low above the sea surface (Figure 2) and often breeding at high coastal altitudes, like the highlands of Wales and Scotland up to 1000 m altitudes (Mardik Leopold, IMARES, pers. com.).

From this information it can be concluded that flight height of seabirds above sea is lower than flight height above land.

4.9 Migration

The influence of several types of circumstances during migration on the flight heights of birds has already been described above. However it is important to discriminate migration from daily use of sea habitat by local birds in order to find possible general patterns for flight height. Therefore the influence of migration is briefly treated in this paragraph. During migration, birds are likely to fly at greater altitudes than when foraging or commuting between sites (Garthe & Hüppop, 2004; Krijgsveld et al., 2011). Birds try mostly to fly in the altitude stratum in which their energy costs are lowest. The choice of stratum may also be influenced by a variety of other parameters, such as the length of the intended flight and the experience of the bird (Hüppop et al., 2006).

Hüppop et al. (2006) investigated year-round bird migration over the North Sea with regard to offshore wind farms. The authors investigated the potential risks of birds endangered by offshore wind farms and their behaviour when facing wind farms (flight distances, evasive movements, influence of light, collision risk). There exists a comprehensive literature on bird migration over the North Sea but with respect to questions regarding environmental effects and impacts connected with the construction of offshore wind turbines, severe knowledge gaps became obvious, including the proportion of birds flying in altitudes up to 200 m (as high as the future wind energy plants) and the influence of weather, wind, precipitation and visibility on the flight altitude.

4.10 Offshore wind farms

Radar studies at Horns Rev and Nysted showed that many birds entering the wind farm reorientate to fly through the empty “lanes” between turbine rows, minimising collision risk. The Nysted Thermal Animal Detection System (TADS, a remote infrared video monitoring system) and radar studies confirmed that waterbirds (mostly Eider) reduced their flight altitude within the wind farm, flying more often below rotor height than they did outside the wind farm (Petersen et al., 2006).

Camphuysen (2011) investigated the possible effects of windfarms on the flight altitude of Lesser Black-backed Gulls with GPS loggers and visual observations. On average the flight altitude inside the windfarm was slightly higher than outside the wind farm.

The difference between the findings of Petersen et al. (2006) and Camphuysen (2011) means that different seabird species may react differently concerning the direction of the adjustment of flight height.

Krijgsveld et al. (2011) found that seabird species adjusted their flight altitude when approaching the windfarm. Large gulls, small gulls and gannets tended to increase their flight altitude, whereas terns tended to lower their flight altitude inside the wind farm. Cormorants did not alter their flight altitude.

From the available information it can be concluded that the influence of a windfarm on flight height of seabirds is variable (lower, higher, no change) depending on the species of concern.

4.11 Other factors

In this study a limited number of factors influencing flight height are discussed. There may be other factors that need attention, for instance the presence of fishing boats providing discards. Large numbers of gulls follow fishing boats and fly at lower altitudes as compared to the situation without fishing boats. Another relevant factor may be the autumn passage of skuas chasing fish eating bird like gulls and terns to higher flight altitudes (Mardik Leopold, IMARES, pers. com.).

5 Discussion and conclusion

In this chapter the available information relevant to the three questions addressed in this study will be discussed. This will be done by integrating the information collected and analysed in the previous chapters, and discussing the current knowledge status and gaps concerning:

- The flight height distribution of seabirds
- The major factors influencing flight height
- The possible implications of flight height distributions and influencing factors for the seabird collision risk for offshore wind farms

5.1 Flight height

At present a rough insight in the flight height distribution of seabirds on the North Sea exists. Cook et al. (2012) and Johnston et al. (2014) collected experimental site observation data and modelled this to produce generic flight height distributions for 25 seabird species. Bradbury et al. (2014) and Furness et al. (2013) provided useful flight height data in relation to dangerous offshore wind turbine altitudes (between 20 and 150 meter above sea level).

Cook et al. (2012) mentioned that flight heights are often recorded during boat-based surveys prior to construction, with flying birds assigned to height bands. This existing methodology for recording flight heights is limited in as far as the wide bands typically used make it impossible to discern whether a species is exploiting the full height of the band or merely a narrow section at the lower or upper end. There is an urgent need for further research into the flight heights of seabirds. Ideally, this would include direct measurements of flight height through the tagging of individual birds and the monitoring of movements at a broader scale through the use of technologies such as radar, as well as through visual observations. This would produce means and the variation around flight height values, also during adverse weather conditions and at night (when collisions are more likely to occur) and could be used to express the probabilities of birds occurring in particular flight bands.

Shamoun-Baranes et al. (2006) also mentioned that detailed measurements of the vertical distribution of different species of birds are sparse in scientific literature. The main reason is the technical difficulty in collecting such data. Measurements of flight altitudes of birds require special equipment, for example, radar, tracking devices such as GPS loggers placed on individual birds, or following birds with aircraft. Studies that have collected data on the flight altitudes of particular species are either highly focused on one species or group of birds, or on birds flying in the lowest air layers where flight altitudes can be estimated visually. Most of these studies have concentrated on migrating birds rather than local movements of seabirds.

5.2 Factors influencing flight height

A summary of the factors affecting flight height of seabirds as analysed in chapter 4 is given in Table 3. It should be noticed that the drawing of conclusions is hampered by many knowledge gaps. In general flight heights can be influenced by any of the factors considered in this study. Flight height is reduced by 5 factors (rain/precipitation, time of day (night), foraging, above sea (as opposed to above land), presence of fishing boats, raised by 2 factor (migration, orientation), and variable (either reduced or raised) by 5 factors (wind speed, wind direction, season, distance to coast, offshore wind farm) depending on the seabird species.

These findings reveal that many factors may influence the flight altitudes of birds. However, few studies focused on the dynamics of flight altitudes of several species of seabirds and terrestrial birds during their local flights over sea or land, outside the migration seasons, in relation to weather conditions.
The timing within the daily and annual routine of the bird probably plays an important role in influencing flight altitudes, because of changing adaptive pressures during the day and year (Shamoun-Baranes et al. 2006).

Individual birds may alter their flight height behaviour according to weather conditions (wind speed, wind direction, precipitation), time of day, foraging strategy and whether commuting, migrating, foraging, presence of offshore wind farms (Garthe & Hüppop, 2004; Petersen et al., 2006; Shamoun-Baranes et al., 2006; Krijgsveld et al., 2011; Stumpf et al., 2011; Corman & Garthe, 2014; Ainley et al., 2015). The response is not always generic for seabirds because interspecies differences do also occur.

Table 3: Summary of the factors affecting flight height and their major effect

Factor	**Situation to compare**	**Flight height change**
Wind speed	High wind speed versus low wind speed	Variable (lower, higher, no change) depending on bird species
Wind direction	Headwind, tailwind, crosswind	Lower in headwind; higher in tailwind but dropping with higher tailwind speed
Rain/precipitation	Rain versus no rain	Lower in rain, birds may settle on the water during heavy rain or hail
Time of the day	Night versus day	Lower at night, lower but sometimes higher during migration
Season	More options (spring, summer, autumn, winter, migration period)	Lower in summer and winter (dominance of local seabirds), higher in spring and autumn (dominance of migrating birds)
Foraging	Foraging versus not foraging (commuting, migrating)	Lower
Distance from the coast	Increasing distance	Variable (lower and higher) depending on bird species
Habitat type and spatial arrangement	Sea versus land	Lower above sea
Migration	Migration versus non migration (habitat use)	Higher
Offshore wind farms	Presence of OWP versus absence of OWP	Variable (Lower, higher, no change) depending on bird species
Fishing boat	Presence of fishing boat versus absence of fishing boat	Lower for discards eating bird species

5.3 Implications for the seabird collision risk for offshore wind farms

In general seabirds fly relatively low above the sea surface (see Figure 2), compared to landbirds migrating over the sea. The majority of the seabird species therefore will have a low risk for collision to offshore wind turbines because they fly almost exclusively under the rotor swept altitude. A few species are considered at relatively high potential collision risk with considerable flight height percentages in the height range of 20 to 150 m a.s.l.. These are mainly the gull species, the Northern Gannet and the Common Eider. For instance Corman & Garthe (2014) measured that 89% of recorded flight heights for Lesser Black-backed Gulls were below 20 m above sea level, indicating an overlap of 11% with the rotor swept area of most operating wind turbines. Johnston et al. (2014) and Bradbury et al. (2014) found even higher overlap values amounting to 28% and 30% respectively.

It should be kept in mind that apart from flight height there are more factors determining the collision risk: flight manoeuvrability, percentage of time flying, nocturnal activity and avoidance (Bradbury et al., 2014). Ainley et al. (2015) suspected that most of the gliders among the seabirds, would be highly vulnerable to offshore wind farms due to their flight height behaviour when winds are strong and their smaller manoeuvrability as compared to the flappers among the seabirds.

Factors that raise the flight height of seabirds to rotor height will probably also increase the collision risk for wind turbines, whereas the opposite will be expected for factors reducing flight height. As described in paragraph 5.2, the factors raising the flight height are migration, season, wind speed, wind direction (tail wind), distance to coast, offshore wind farm, depending on the seabird species. This means that more seabird species than the ones already mentioned above may become at risk. The extent of the effects is not known.

6 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Dr. Mardik F. Leopold
Senior researcher

Signature:

Date: 25 maart 2016

Approved: Dr. ir. T.P. Bult
Business Unit Manager

Signature:

Date: 25 maart 2016