X-shaped Radical Offshore wind Turbine for Overall cost of energy Reduction

D7.9

Review of species-specific collision risks for sea birds

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About X-ROTOR

X-ROTOR: "X-shaped Radical Offshore wind Turbine for Overall cost of energy Reduction" is a Horizon 2020 funded project which aims to develop a disruptive new offshore wind turbine concept.

The X-ROTOR project is led by University of Strathclyde (UK) in partnership with Norwegian University of Science and Technology (Norway), Delft University of Technology (Netherlands), University College Cork (Ireland), Fundacion Cener National Renewable Energy Centre (Spain) and GE Renovables España (Spain).

As the effects of climate change are becoming ever more visible, Europe has raised its target for the amount of energy it consumes from renewable sources from the previous goal of 27% to 32% by 2030. Offshore wind energy can play a key role in achieving the EU target and contribute to the required 40% reduction in CO_2 emissions. However, to achieve the previously mentioned targets the cost of offshore wind must be reduced. The X-ROTOR concept provides a direct route to drastically reducing both capital and operating costs of energy from offshore wind.

The project runs for three years from January 2021, during which time, the concept will be developed through a holistic consideration of technical, cost, environmental and socio-economic impact aspects.

If proven feasible, X-ROTOR will, as a disruptive new offshore wind turbine concept, create new opportunities for the European wind energy industry and play an important role maintaining the EU's position as global technological leader in renewable energy, reducing greenhouse gas emissions and decarbonising the EU economy.

For more information see **https://XROTOR-project.eu**

Description of the deliverable and its purpose

Environmental Impact Assessments (EIA) conducted during pre-construction phase of offshore wind farms clearly identified interactions between turbines and marine wildlife, especially seabirds, as a concern requiring further investigation. Mortality associated with collision could lead to negative impacts on seabird populations, and needs to be assessed on a case-by-case basis.

Within environmental impact assessments, the Collision Vulnerability Index is frequently used to assess collision risk, and is based on several vulnerability factors among which flight height is the most critical. We therefore conducted a comprehensive literature review possible for the 82 species, including breeding and migrating birds, focusing on flight height and three others collision risk factors. We calculated an Uncertainty Level associated with flight height to take into account its reliability when calculating the Collision Vulnerability index. For approx. 20 species, the available information is satisfactory to assess flight heights. However, we identified 60 species for which further data collection is necessary to reduce uncertainty about vulnerability to wind turbine collisions, and identified existing GPS data which may facilitate further work.

Within X-ROTOR, collision risk factors will be coupled with habitat use and conservation status into the Collision Vulnerability Index. This index will be applied to seabird distribution data to aid identification of suitable areas for the development of the X-ROTOR turbines.

List of acronyms and abbreviations

CRM	Collision Risk Models
CVI	Collision Vulnerability Index
EIA	Environmental Impact Assessment

1 Introduction

1.1 Background

Following the increasingly concerning IPCC climate predictions (Masson-Delmotte et al., 2021) and in order to reach the Paris Agreement Objectives (UNFCCC, 2015), the European Union must dramatically decrease its greenhouse gas emissions. Renewable energy has a fundamental part to play in global decarbonisation, and in 2018, targets of the European Union Renewable Energy Directive were revised upward, aiming for at least a 32% share of renewable energy (European Parliament, 2018). In response, many countries are turning to wind energy, with short terms EU targets driving expansion of onshore/offshore wind farms.

To ensure the lowest environmental cost per kW produced, effects of wind farms on ecosystems need to be carefully assessed (May et al., 2017). Environmental Impact Assessments (EIA) conducted during pre-construction clearly identified interactions between turbines and marine wildlife, especially seabirds, as a concern (Bergström et al., 2014). Seabirds are among the most threatened of all bird groups (Dias et al., 2019), with effects of offshore wind farm including population declines (Searle et al., 2014), habitat loss due to barrier effect (Masden et al., 2010), displacement (Welcker & Nehls, 2016) and mortality by collision (Desholm, 2006). Assessment of collision risk is often a requirement of consenting, and its over or underestimation could have profound effects on the sustainability of populations. Because of the unique design of the X-ROTOR concept turbine, there is a need to reassess seabird vulnerability, accounting for differences between traditional turbine designs and the X-ROTOR design.

1.2 Seabird flight height

Numerous studies developed collision risk models (CRM), such as the Band model, predicting the probability for a bird to collide with the blade (Band, 2012) or calculated collisions vulnerability index (Certain et al., 2015; Critchley & Jessopp, 2019) during EIA prior to the installation of wind turbines.

Collisions risk is dependent on the proportion of time spent flying within the rotor sweep area, and its calculation requires detailed knowledge of four collision risk factors: 1) the percentage of time spent flying, 2) the flight manoeuvrability, 3) the nocturnal flight activity and 4) the percentage time spent/proportion of birds flying at blade height for the species considered (Furness, Wade, & Masden, 2013).

Within offshore wind farm EIA, flight height information has come from different sources such as at-sea/sea-watches survey conducted with binoculars (Rothery, Newton, & Little, 2009), laser rangefinder (Harwood, Perrow, & Berridge, 2018) or ornithodolite (Hedenström & Åkesson, 2016), radar (Alerstam & Gudmundsson, 1999), photogrammetry (Prinsloo et al., 2021) or bird-borne devices (Cleasby et al., 2015). Each method has advantages and limitations (see Table 1). Data is often expressed as percentage of time spent at blade height rather than providing raw flight height measurements, making it difficult to apply to turbine designs with different characteristics. However, for some species, distributions of bird density in relation to altitude have been recently generated from flight height data originally collected in height bands during at-sea surveys (e.g. Cook et al., 2012; Johnston et al., 2014) allowing such extrapolation.

Table 1. Summary of advantages and disadvantages of methods used to estimate birds flight heights. Adapted from Thaxter, Ross-Smith, & Cook, 2015 and Largey et al., 2021.

<table>
<tr><th colspan="2">Method</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td rowspan="3">Visual and Boat-based survey</td><td>Binoculars</td><td>1. Well-established protocols.
2. Very high rate of species identification.</td><td>1. Generic flight height bands used rather than individual flight estimates.
2. Survey restricted to good weather conditions and daylight hours.
3. Disturbance by vessel affecting the birds.
4. Imprecise relative to sensor methods.</td></tr>
<tr><td>Laser rangefinder and inclinometer</td><td>1. Useful additional method or verification to aid where disadvantages of some methods become an issue (such as close ground observations and radar scatter)
2. Can identify individual species.</td><td>1. Restricted to daytime use through human observers.
2. Greater tendency to miss targets at higher altitude further from the observer.
3. In the marine environment, likely unsuitable for use on an unstable platform.
4. Does not provide 3D data.</td></tr>
<tr><td>Ornithodolite</td><td>1. Can record detailed flight height and behavioural information at lower altitudes
2. Good for targeted investigation to assess detailed flight behaviour in relation to extrinsic factors.
3.Useful additional verification method.
4.Individual species identification possible.
5. Can give three-dimensional flight height information.</td><td>1. Restriction to lower altitude range, and spatial range away from the observer.
2. Requires targeted effort and could potentially miss other birds moving through.
3. Restricted to daylight hours and conditions in which observations can be conducted.
4. Greater distance from observer increases potential error of measurement.
5. Applicability over a wider area is uncertain. Typically used from land, and likely not suitable on an unstable platform.</td></tr>
<tr><td rowspan="2">Digital high definition imagery</td><td>Aerial stills and video</td><td>1. More cost effective than boat surveys.
2. Data can be stored and re-analysed at a later date-valuable to further analytical advances and quality assurance.
3. Flight altitude of the survey plane is high enough to cause no disturbance issues to birds below.</td><td>1. Imperfect species identification for older dataset.
2. Survey restricted for some systems in clear conditions.
3.Problems of glare for some systems.
4. Data collection restricted to daytime but further infrared improvements may overcome this.
5. Do not measure flights parameters directly.</td></tr>
<tr><td>Spectro-graphic techniques</td><td>1. Same as above.
2. Not limited by daylight.
3. Three-dimensional tracks of animals can be obtained.</td><td>1. Same as above.
2. Limited to a range from turbines up to 500 m.</td></tr>
<tr><td>Radar</td><td>Weather surveillance Doppler</td><td>1. Wide ranging spatial area coverage (up to 200 km).
2. Nocturnally functioning.</td><td>1. Coarse resolution (ca. 250 m).
2. Generally expensive but can be cheap if making use of existing weather surveillance networks.
3. Poor low-altitude coverage, but with careful analysis can be used to extract</td></tr>
</table>

Method		Advantages	Disadvantages
			altitude profiles of birds (Dokter et al., 2010).
	Tracking radar	1. Same as above although less wide ranging. 2. Altitude profiles more refined and 3D movement can be identified in a similar manner to the ornithodolite method (Pennycuick, 2008).	1. Narrow coverage (10-20 km range), but greater than that obtained under boat-based and digital aerial survey methods. 2. Potential legal/Strategic defence issues as the system can track aircraft. 3.Expensive, not widely available.
	Marine X-Band	1. Flight height accurately measured (e.g., ±1 m). 2. Good for specific location studies. 3. Superior use in different weather conditions (i.e., not influenced by number of satellites and cloud cover, and greater penetration compared to lasers). 4. Inexpensive, off- the-shelf.	1. Underestimations of flight heights close to the sea. 2. Radar may detect larger flocks than smaller ones. 3. Species identification often not possible for some taxon groups. 4. Restricted in wider spatial coverage (e.g., <12 km). 4. Potentially expensive. 5. Can obtain vertical or horizontal measurements, not both at the same time (i.e., not 3D), compared to tracking radar and telemetry methods. 6. Use restricted to general vertical distribution over a single horizontal space.
Telemetry	Bird-borne altimeter	1. Wider spatial focus obtained. 2. Can give specific flight height distributions linked to particular breeding colonies and protected sites. 3. Not restricted to hospitable weather conditions and can monitor throughout the day and night. 4. Potentially smaller error in altitude measurements than GPS-PTT's. 5. Future altimeters will be lighter and could be packaged in the same device with other sensors, allowing a wider range of species to be tracked locally in 3D space within and far away from a wind farm.	1. Potential to alter the behaviour of animals. 2. Sample sizes smaller for telemetry raising questions of population-level representativeness. 3. Shorter-life devices restrict temporal focus, restriction potentially on capture and re-capture of some species. 4. Limited continuous use across the year for some species due to potential attachment constraints. 5. Previous devices were heavy, preventing use on lighter species, and dual deployment alongside other positional devices wasn't possible. 6. Requires calibration with local pressure, but species can range widely, hence increasing potential for error.
	Plane-based altimetry	1. Useful as a verification method for other techniques. 2. Direct observing of birds at height also possible.	1. Potential disturbance to animals. 2. Restricted use and spatio-temporal coverage. 3. Expensive.
	GPS	1. Same as point 1 to 3 for Bird-borne altimeter. 2. Requires no additional devices. 3. Localised 3D data can be obtained. 4. Increasingly capable of tracking smaller species using lighter GPS devices than previously possible using altimeters. 5. Sampling rate and modelling techniques can be used to understand and account for potential error on estimations. 5. Combining with PTT or GSM transmission systems, allows study of birds away from breeding colonies.	1. Same as point 1 to 4 for Bird-borne altimeter. 2. High estimation factor due to mathematical earth representation hence greater potential for error surrounding estimates, requiring validation.

Method		Advantages	Disadvantages
		6. Could be used to describe flight behaviour and spatial overlap with WF.	
Others	LiDAR	1. 3D data could theoretically be obtained. 2. Could be operated far offshore (if aircraft-mounted) where the use of radar may not be feasible.	1. Not deployable in inclement weather or nocturnally.
	Audible microphones	1. Useful additional verification to other methods. 2. Can identify individual species.	1. Interference with ambient sound. 2. Small range, restricted to vertical usage. 3. Do not measure flight parameters directly.
	Thermal/ Night vision infrared imaging	1. Useful additional verification to other methods. 2. Detailed local behavioural data can be gathered. 3. Thermal imagery has been used up to high altitudes. 4. Can identify individual species.	1. Coarse altitude resolution if calibrated with vertical radar and then used alone (Kunz et al., 2007). 2. Affected by cloud cover and other atmospheric conditions. 3. Do not measure flights parameters directly.
	Moon-watching, artificial light & Ceilometer	1.Useful additional verification to other methods. 2. Relatively inexpensive. 3. Can identify individual species.	1. Limited vertical range. 2. Restricted period of observation to full moon and clear conditions. 3. Light attraction bias if artificial light source used. 4. May not be applicable in an offshore context. 5. Only of use at night.

Although flight height is crucial in CRM (Certain et al., 2015), it is subject to many uncertainties depending on the measurement methods used (Wade et al., 2016), the sample size available (Thaxter et al., 2017), the species, sex, season (breeding *vs* migration) and flights type (foraging *vs* commuting), as well as weather and/or the period of the year (Lane et al., 2020; Thaxter et al., 2015 for example). CRM's conclusions on vulnerability are very sensitive to such uncertainties (Masden et al., 2021), which should be taken into account during modelling (Wade et al., 2016) and decision-making.

1.3 Aims and objectives

This report forms part of the Environmental Impact Assessment activities of the X-ROTOR project building a robust Collision Vulnerability Index. The report provides a comprehensive review of the following collision risk factors for a range of seabird species either breeding or migrating through European waters:

1. Percentage of time spent flying

2. Flight agility

3. Percentage of time spent flying at night

4. Flight height.

From the values obtained, a percentage of time spent within turbine's swept area will be calculated once more technical information about the X-ROTOR turbines is available. The degree of uncertainty associated with this variable is also presented.

2 Methods

According to BirdLife (http://datazone.birdlife.org/species/search), we listed species present in European waters throughout the year before conducting, for each one, a thorough literature review using Google Scholar. We paid particularly attention to comprehensive and recent reviews on flight height and flight behaviours (see for example Furness et al., 2013; Thaxter, Ross-Smith, & Cook, 2015; Willmott, Forcey, & Kent, 2013) to identify relevant studies. We augmented the references obtained in existing reviews using keywords targeting each species considered and representing the main subject matter such as "flight", "height", "altitude", "time activity budget", "night flight" as well as known methodologies investigated as part of this review such as "GPS", "tracking", "survey", "radar", "altimeter", "rangefinder", and "LiDAR". Once studies were compiled, they were sorted according to the measurement method used. Studies modelling seabird flight height distributions were classified according to the method used to obtained flight data. Further, using MoveBank online database and literature review (using Google Scholar and a review conducted by Bernard and colleagues (2021)) we identified example of existing GPS data set that could be analysed to determine flight height of our species of interest.

We followed the method developed by Wade and colleagues (2016) to calculate for each species an Uncertainty Score that we transformed in an Uncertainty Level (very low to very high) for the flight height variable. This score is a sum of the number of sites and studies from which flight height data were obtained, the mean period of years over which data were collected, the level of uncertainty associated with the method used to collect data and a score taken into account if data sources referred to the target species or higher taxonomic groupings. In this calculation we considered data obtained by LiDAR as having the same accuracy as those from radar.

3 Results

According to BirdLife International, 82 species are present in European waters across the year. The studies dealing with flight height (expressed in meters above sea level) of each species are listed, according to the measurement method used, in Table 2. Some studies (see Leopold et al., 2004 and Krijgsveld et al., 2011 for example) are conducted year round and distinguished flight height recorded during or outside migration periods. Flight height distributions have been modeled for 25 species by 5 studies: two relying on boat/land-based surveys, two on GPS data and one on data obtained through LiDAR measurements. For clarity, boat/land-based surveys studies from which data were used in the two former are not presented in Table 2 but are available in Table 6. They were however considered when calculating Uncertainty Score. We identified only one study using plane-based survey (Perkins et al., 2004: common terns were recorded at or near sea level, but 31 were flying between 91-152m) to record seabirds' flight altitude.

Table 2. Flight height studies listed by methodology used. Uncertainty Level was calculated following Wade et al., 2016.

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
Arctic jaeger *Stercorarius parasiticus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median height between 10-20m Paton et al., 2010: n=1, <10m Christensen et al., 2004: n=1, 49m	Paton et al., 2010: n=19, 63.2% <10m, 10<15.8%<25m, 25<27.1%<125m	Krijgsveld et al., 2011: All skuas observed flew at rather low height, but are known to use a wide array of flight height, both during day and night.		**Moderate**
Arctic loon *Gavia arctica*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: n=2, median height between 5-10m Paton et al., 2010: n=5, 0m Borkenhagen et al., 2018: n=23, med=19m, max=69m, min=4m, 0<87%30m, 30<13%<150m	Paton et al., 2010: Loon spp, n=615, 58.9% <10m, 10<23.4%<25m, 25<14.8%<125m, 2.9%>125m Fly higher during migration	Krijgsveld et al., 2011: Divers species observed up to 30m. Wind dependent. Migration flights are higher than foraging ones.		**High**
Arctic tern *Sterna paradisaea*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m Borkenhagen et al., 2018: Common and Arctic terns n=28, med=9m, max=39m, min=1m,	Paton et al., 2010: Terns spp, n=1293, 29.9% <10m, 10<58.6%<25m, 25<11.4%<125m Hedenström & Åkesson, 2016: 10 flocks at 17.9±13.5m, 4 at 6±2.5m, 8 at 6.1±2.3m, 72 at 22.1±34.4m, 13 at 14.4±18.9m and 109 at 34.6±49.6m	Alerstam & Gudmundsson, 1999: n=1, 522m during migration		**Moderate**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	0<96.4%30m, 30<3.4%<150m Harwood et al., 2018: n=12, between 3.6 and 23.1m				
Atlantic puffin *Fratercula arctica*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Paton et al., 2010: n=5, 0m Borkenhagen et al., 2018: Alcids spp, n<20, <30m Harwood et al., 2018: n=3, between 0.9 and 12.1m	Paton et al., 2010: Alcids spp, n=166, 100% <5m	Krijgsveld et al., 2011: Alcids fly at very low altitude, often <5m and hardly reach 50m.		**Moderate**
Audouin's gull *Larus audouinii*	Cristensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m, 25<39.7%<125m, 58.6%>125m Rosén & Hedenström, 2001: Flying close to sea level	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m 10<22.5%<25m 25<10.3%<125m 0.7%>125m	Cook et al., 2018: modelled flight height distribution for gulls spp Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m		**Very high**
Audubon's shearwater *Puffinus lherminieri*	Paton et al., 2010: Unidentified shearwaters, n=27, 48.1% at 0m, 51.9%<10m Haney, Fristrup, & Lee, 1992: Rarely above 2m	Paton et al., 2010: Shearwaters spp, n=1525, 100% <10m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**
Balearic shearwater *Puffinus mauretanicus*	Paton et al., 2010: Unidentified shearwaters, n=27, 48.1% at 0m, 51.9%<10m	Paton et al., 2010: Shearwaters spp, n=1525, 100% <10m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level Mateos-Rodríguez & Bruderer, 2012: >90% of shearwaters below 20m		**Very high**
Band-rumped storm petrel *Hydrobates castro*		Paton et al., 2010: Storm petrels spp, n=1, 100% <10m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
Barrow goldeneye *Bucephala islandica*					**Very high**
Black guillemot *Cepphus grylle*	Paton et al., 2010: Unidentified alcids, n=27, 13.3% at 0m, 86.7%<10m	Paton et al., 2010: n=1, <10m			**Very high**
Black tern *Chlidonias niger*	Cook et al., 2012: n=6, <20m Garthe &Hüppop, 2004: median <5m Borkenhagen et al., 2018: Terns spp, n=28, med=9m, max=39m, min=1m, 0<96.4%30m, 30<3.4%<150m Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m	Paton et al., 2010: n=15, 73.3% <10m, 10<26.7%<25m, Van Der Winden, 2002: During migration, birds ascend in the evening to high altitudes (>500m)			**Very high**
Black-headed gull *Larus ridibundus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median between 10-20m with 10% above 100m Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m, 25<39.7%<125m, 58.6%>125m Christensen et al., 2004, Gulls spp, n=42, mean=71.2±67.9m, range=2-395m Borkenhagen et al., 2018: n=22, med=12m, max=47m, min=4m,	Day et al., 2003: 29m (range 1-200m) Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m 10<22.5%<25m 25<10.3%<125m 0.7%>125m	Cook et al., 2018: modelled flight height distribution for gulls spp Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m Parnell et al., 2005; Walls et al., 2004:29m (range 1-200m)		**Low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	0<95.5%<30m, 30<4.5%<150m				
	Harwood et al., 2018: n=43, between 1.5-52.9m				
Black-legged kittiwake *Rissa tridactyla*	Johnston et al., 2014: modelled flight height distribution	Paton et al., 2010: n=56, 76.8%<10m 10<23.2%<25m	Cook et al., 2018: modelled flight height distribution		**Very low**
	Cook et al., 2012: modelled flight height distribution	Day et al., 2003: n=36 flocks, mean=6.4±1.3m, range=1-30m	Alerstam & Gudmunsson, 1999: during migration, n=3, mean=293.7m, range=92-542m		
	Garthe &Hüppop, 2004: median between 5-10m		Walls et al., 2004; Parnell et al., 2005: 7.4m (range 5-20m)		
	Paton et al., 2010: n=55, 91% at 0m, 32.7%<10m 10<47.3%<25m, 25<10.9%<125m		Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m		
	Christensen et al., 2004, Gulls spp, n=42, mean=71.2±67.9m, range=2-395m				
	Borkenhagen et al., 2018: n=68, med=16m, max=81m, min=0m, 0<83.3%<30m, 30<16.2%<150m				
	Harwood et al., 2018: n=539, between -3.1-36.3m				
	Mendel et al., 2014: n=36, median= 16.6m boxplot whisker range: 1-34.8m, max: 80m				
Black-necked grebe *Podiceps nigricollis*					**Very high**
Bulwer's Petrel *Bulweria bulwerii*	Paton et al, 2010: Shearwaters spp n=27: 48.1% at 0m, 51.9%< 10m	Paton et al 2010: Shearwater spp n=1525 100%<10m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**
Caspian gull *Larus cachinnans*	Christensen et al., 2004, Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Paton et al 2010: Gulls spp, n=22808 66.6%<10m, 10<22.5%<25m, 25<10.3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Very high**
	Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m,		Krijgsveld et al., 2011: Gulls<50m when foraging but		

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	25<39.7%<125m, 58.6%>125m		up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
Caspian tern *Hydroprogne caspia*	Paton et al.,2010: Terns spp, n=12, 33.3%<10m, 10<66.7%<25m	Paton et al., 2010: n=2, 10<100%<25m			**Very high**
	Christensen et al., 2004, Terns spp, n=11, mean=21.2±5.3m, range=16-33m	Hedenström & Akesson 2016: 3 flocks at 20.9±6.9m			
	Borkenhagen et al., 2018: Terns spp, n=28, med=9m, max=39m, min=1m, 0<96.4%<30m, 30<3.4%<150m				
	Cuthbert & Wires, 1999: 3<100%<30m				
Common eider *Somateria mollissima*	Johnston et al., 2014: modelled flight height distribution	Paton et al., 2010: n=24195, 92.9%<10m 10<6.9%<25m, 25<0.2%<125m	Desholm, 2003: n=2384, mean=10.9m, max=95.8m, min<5m		**Moderate**
	Cook et al., 2012: modelled flight height distribution	Day et al., 2003: n=17 flocks, mean=1.4±0.1m, range=1-3m	Petersen et al., 2006: flight distribution inside and outside wind farms (p.106)		
	Garthe &Hüppop, 2004: median <5m	Pettersson, 2005: highly variable but mainly between 10-40m			
	Paton et al., 2010: n=294, 8.8% at 0m, 90.8%<10m 10<0.3%<25m				
	Harwood et al., 2018: n=12, between 3.6-23.1m				
	Sadoti et al., 2005: n=84, mean= 4.1±1.2m, min=4m, max=15m				
Common goldeneye *Bucephala clangula*		Paton et al., 2010: n=336, 50.6%<10m 10<38.1%<25m, 25<11.3%<125m	Dirksen, Spaans, & van der Winder, 2000: <30m		**Very high**
Common gull-billed tern *Gelochelidon nilotica*	Paton et al.,2010 : Terns spp, n=12, 33.3%<10m, 10<66.7%<25m	Paton et al., 2010: Terns spp, n=1293, 29.9% <10m, 10<58.6%<25m, 25<11.4%<125m			**Very high**
	Christensen et al., 2004, Terns spp, n=11, mean=21.2±5.3m, range=16-33m				

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Borkenhagen et al., 2018: Terns spp, n=28, med=9m, max=39m, min=1m, 0<96.4%<30m, 30<3.4%<150m				
Common loon *Gavia immer*	Cook et al., 2012: n=14, <20m Sadoti et al., 2005: In 2003, n=8, mean=24.4±15.7m, min=10m, max=60m. In 2004, n=27, mean=31.6±30m, min=4, max=100m	Paton et al., 2010: n=2762, 58.0%<10m 10<19.2%<25m, 25<20.1%<125m, 2.7m>125m	Krijgsveld et al., 2011: Divers species observed up to 30m. Wind dependent. Migration flights are higher than foraging ones.		**Very high**
Common guillemot *Uria aalge*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Paton et al., 2010: n=131, 55% at 0m, 45%<10m Borkenhagen et al., 2018: Alcids spp, n<20, <30m Harwood et al., 2018: n=25, between -2.7-9.9m	Day et al., 2003: n=4 flocks, mean=1.3±0.3m, range between 1-2m Paton et al., 2010: Guillemots spp, n=1, <10m	Krijgsveld et al., 2011: Alcids fly at very low altitude, often <5m and hardly reach 50m.		**Low**
Common scoter *Melanitta nigra*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Paton et al., 2010: Unidentified scoter, n=4, 10<100%<25m Christensen et al., 2004: n=2, mean=4±5.2m, range=0-8m Sadoti et al., 2005: Scoters spp, n=218, mean=7.3±11.3m, min=4m, max=100m	Paton et al., 2010: Scoters spp, n=34373, 92.2%<10m, 10<7%<25m, 25<0.7<125m Day et al., 2003: n=1 flock, 2m	Kahlert et al., 2012: Diurnal migration at 183m in average. Range=115-165m		**Moderate**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
Common tern *Sterna hirundo*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median between 5-10m Paton et al., 2010: n=61, 4.9% at 0m, 36.1%<10m, 10<47.5%<25m, 25<11.5%<125m, Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m Sadoti et al., 2005: In 2003 n=130, mean=29.6±33m, min=5m, max=250m. In 2004, n=163, mean=23.8±21.8m, min=4m, max=100m Borkenhagen et al., 2018: Common and Arctic terns n=28, med=9m, max=39m, min=1m, 0<96.4%30m, 30<3.4%<150m	Paton et al., 2010:n=3644,53.5%<10 m, 10<42.7%<25m, 25<3.8%<125m Hedenström & Åkesson, 2016: 32 flocks at 12.5±12.1m, 5 at 5.2±1.4m, 22 at 12.9±15.2m, 70 at 20.3±27.2m	Krijgsveld et al., 2011: General foraging altitude range up to 20m. Terns migrate at night at higher altitude.		**Low**
Cory's shearwater *Calonectris borealis*	Paton et al., 2010: n=520 21.7% at 0m, 78.3%<10m. Rosén & Hedenström, 2001: Close to sea level	Paton et al., 2010:n=2229, 99.6%<10m, 10<0.4%<25m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**
Desertas petrel *Pterodroma deserta*	Paton et al, 2010: Shearwaters spp n=27: 48.1% at 0m, 51.9%< 10m	Paton et al 2010: Shearwater spp n=1525 100%<10m	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**
European herring gull *Larus argentatus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median	Paton et al., 2010: n=51036, 51.9%<10m, 10<33.2%<25m, 25<14.7<125m, 0.3%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration	Ens et al., 2008: 90%<25m, 3.7%>75m	**Low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	between 5-10m with 10% above 50m Paton et al., 2010: n=1652, 7.6% at 0m, 64.7%<10m, 10<13.9%<25m, 25<12.8%<125m, 1%>125m Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395 Sadoti et al., 2005: In 2003 n=31, mean=50.2±55.9m, min=1m, max=175m. In 2004, n=32, mean=24.6±35.7m, min=4m, max=150m Borkenhagen et al., 2018: n=233, med=31m, max=180m, min=-2m, 0<45.5%<30m, 30<54.1%<150m, 0.4%>150m Harwood et al., 2018: n=43, range between 1.5-52.9m Mendel et al., 2014, n=25, Boxplot whisker range 0-74.2m, med=32.4m		on land recorded at 380m in average but up to 750m		
European shag *Gulosus aristotelis*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution				**Very high**
European-Storm-petrel *Hydrobates pelagicus*	Cook et al., 2012: n=52, 20<2%<130m	Paton et al., 2010: Storm petrel spp, 100%<10m	Krijgsveld et al., 2011: All tubenoses fly near sea level		**Very high**
Glaucus gull *Larus hyperboreus*	Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m,	Paton et al 2010: Gulls spp, n=22808 66.6%<10m,	Cook et al., 2018: Gulls spp, modelled		**Very high**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	25<39.7%<125m, 58.6%>125m	10<22.5%<25m, 25<10.3%<125m, 0.7%>125m	flight height distribution		
	Cook et al., 2012: n=1, <20m	Day et al., 2003: n=99 flocks. mean=52.1±4.9m, range=1-200 m	Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
	Christensen et al., 2004, Gulls spp, n=42, mean=71.2±67.9m, range=2-395m				
Goosander *Mergus merganser*		Paton et al 2010: n=2 25<100%<125m	Dirksen et al., 2000: <30m		**Very high**
Great black-backed gull *Larus marinus*	Johnston et al., 2014: modelled flight height distribution	Paton et al 2010: n=8610, 65.8%<10m, 10<25.8%<25m, 25<8.0%<125m, 0.8%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Low**
	Cook et al., 2012: modelled flight height distribution		Walls et al., 2004; Parnell et al., 2005: 22m (range 1-300m)		
	Garthe &Hüppop, 2004: median between 10-20m but few above 50m		Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
	Paton et al., 2010: n=1001, 15.8% at 0m, 67.3%<10m, 10<8.1%<25m, 25<8%<125m, 0.8%>125m				
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m				
	Sadoti et al., 2005: In 2003 n=86, mean=52.7±60.9m, min=1m, max=250m. In 2004, n=77, mean=43.1±65m, min=4m, max=500m				
	Borkenhagen et al., 2018: n=67, med=32m, max=85m, min=5m, 0<44.8%<30m, 30<55.2%<150m				
	Harwood et al., 2018: n=19, range between 6.8-42.9m				

Species	**Boat based survey**	**Land based seawatches**	**Radar/LiDAR**	**Telemetry**	**Uncertainty Level**
Great cormorant *Phalacrocorax carbo*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Paton et al., 2010: n=15, 13.3% at 0m, 80%<10m, 10<6.7%<25m Christensen et al., 2004: n=6, mean=58.3±8.4m, range=46-70m	Paton et al 2010: n=2014, 79.8%<10m, 10<12.9%<25m, 25<5.8%<125m, 1.5%>125m	Walls et al., 2004; Parnell et al., 2005; Petersen et al., 2006: mean=8.3 m, range=1-150m Krijgsveld et al., 2011: majority of birds flew <5m and not >75m		**Moderate**
Great crested grebe *Podiceps cristatus*	Leopold et al., 2004: n=32, 40%<2m, 2<60%<10m Cook et al., 2012: n=82, <20m Garthe &Hüppop, 2004: median between 5-10m		Krijgsveld et al., 2011: Grebes spp, up to 50m. Nocturnal migration probably higher		**Very high**
Great shearwater *Ardenna gravis*	Paton et al., 2010: n=239, 9.6% at 0m, 90.4%<10m	Paton et al., 2010:n=14, 100%<10m	Krijgsveld et al., 2011: All tubenoses fly near sea level		**Very high**
Great skua *Catharacta skua*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median between 10-20m but few above 50m Harwood et al., 2018: n=1, 21.9m		Krijgsveld et al., 2011: All skuas observed flew at rather low height, but are known to use a wide array of flight height, both during day and night.	Ross-Smith et al., 2016: modelled flight height distribution	**Moderate**
Greater scaup *Aythya marila*	Paton et al., 2010: Unidentified scaups, n=55, 10<45.5%<25m, 25<54.5%<125m	Paton et al., 2010: n=143, 65.7%<10m, 10<31.5%<25m, 25<2.8%<125m	Dirksen et al., 2000: <50m during day and <75m during night		**Very high**
Harlequin duck *Histrionicus histrionicus*		Paton et al., 2010: n=291, 99.3%<10m, 10<0.7%<25m			**Very high**
Horned grebe *Podiceps auritus*		Paton et al., 2010: n=85, 76.5%<10m, 25<23.5%<125m	Zhao et al., 2019: migration at 927m Krijgsveld et al., 2011: Grebes spp,		**Very high**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
			up to 50m. Higher at nigh.		
Iceland gull *Larus glaucoides*	Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Very high**
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Moorhouse, 2021: Between 1-25m at low tide, <1m at high tide	Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
Ivory gull *Pagophila ebrunea*	Paton et al., 2010: Gulls spp, n=58, 10<1.7%<25m, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution	Frederiksen, Gilg, & Yannic, 2021: up to 4000m during migration. Flight height during the journey available in Fig 3	**Very high**
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m		Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
King eider *Somateria spectabilis*		Paton et al., 2010: n=1, <10m			**Very high**
		Day & Rose, 2000: Eiders spp, mean=12m, range=0-70m			
		Day et al., 2003: n=4 flocks. mean=1.3±0.3m, range=1-2m			
Leach's storm-petrel *Hydrobates leucorhous*		Paton et al., 2010: n=1, <10m	Krijgsveld et al., 2011: All tubenoses fly near sea level		**Very high**
Lesser black-backed gull *Larus fuscus*	Johnston et al., 2014: modelled flight height distribution	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution	Ross-Smith et al., 2016: modelled flight height distribution	**Very low**
	Cook et al., 2012: modelled flight height distribution		Walls et al., 2004; Parnell et al., 2005: mean=170m, range=20-200m	Thaxter et al., 2019: modelled collision vulnerabilit using GPS data	
	Garthe &Hüppop, 2004: median		Krijgsveld et al., 2011: Gulls<50m when foraging but	Corman & Garthe, 2014: 89%<20m	

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	between 10-20m with 10% above 50m Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m Borkenhagen et al., 2018: n=1785, med=21m, max=431m, min=-2m, 0<70%<30m, 30<29.6%<150m, 0.4%>150m Harwood et al., 2018: n=19, range between -0.5-40.4m Mendel et al., 2014, n=637, Boxplot whisker range 0-69.6m, med=26.3m		up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.	Klaassen et al., 2011: >70% <250m Ens et al., 2008: 90%<25m, 3.7%>75m Borkenhagen et al., 2018: n=705, med=8m, max=735m, min=-10m, 0<59.3%<30m, 30<17%<150m, 5.7%>150m	
Lesser crested tern *Thalasseus bengalensis*	Paton et al.,2010: Terns spp, n=12, 33.3%<10m, 10<66.7%<25m Christensen et al., 2004, Terns spp, n=11, mean=21.2±5.3m, range=16-33m Borkenhagen et al., 2018: Terns spp, n=28, med=9m, max=39m, min=1m, 0<96.4%<30m, 30<3.4%<150m	Paton et al., 2010: Terns spp, n=1293, 29.9% <10m, 10<58.6%<25m, 25<11.4%<125m			**Very high**
Little auk *Alle alle*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010: n=125, 77.6% at 0m, 22.4%<10m Borkenhagen et al., 2018: Alcids spp, n<20, <30m	Paton et al., 2010: Alcids spp, n=106, 100%<10m	Krijgsveld et al 2011: Alcids <5m, rarely >50m but some pers. obs. (R. Fijn) of little auks above.		**High**
Little gull *Hydrocoloeus minutus*	Johnston et al., 2014: modelled flight height distribution	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m,	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median <5m Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m Borkenhagen et al., 2018: n=25, med=19m, max=39m, min=-2m, 0<96%<30m, 30<4%<150m, Mendel et al., 2014: n=17, med= 18.8m, Boxplot whisker range: 8.6-24.5m, max=48m	25<10,3%<125m, 0.7%>125m	Walls et al., 2004; Parnell et al., 2005: mean=67m, range=4-250m Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
Little tern *Sternula albifons*	Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m Borkenhagen et al., 2018: Terns spp, n=28, med=9m, max=39m, min=1m, 0<96.4%<30m, 30<3.4%<150m	Paton et al., 2010: Terns spp, n=1293, 29.9%<10m, 10<58.6%<25m, 25<11.4%<125m Hedenström & Åkesson, 2016: 12 flocks fly at 4.6±2.2m, 10 at 14.4± 17.7m, 2 at 12.2m ±6.6, 3 at 6.1± 2.8m, 7 at 6.3± 2.7m Everaert & Stienen, 2007: In 2004, n=1749, 0<86%<15m, 16<12%<50m, 2% >50m. In 2005, n=375, 0<35%<15m, 16<64%<50m, 1%>50m.	Krijgsveld et al., 2011: General foraging altitude range up to 20m. Terns migrate at night at higher altitude.		**Very high**
Long-tailed duck *Clangula hyemalis*	Cook et al 2012: n=114 <20m, mean= 1.9m range=0-10m Paton et al., 2010: n=21, 9.5% at 0m, 76.2%<10m, 10<14.3<25m, Sadoti et al., 2005: n=4, 4m	Paton et al 2010: n=259 90.3%<10m, 10<9.7%<25m, Day et al., 2003: n=108 flocks. mean=1.9±0.1m, range=1-10 m	Kahlert et al., 2012: Diurnal migration mean=133m, range=107-166m		**Vey high**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
Long-tailed jaeger *Stercorarius longicaudus*	Paton et al., 2010: n=1, 100% at 0m	Paton et al., 2010: Jaegers spp n=3, 100%<10m Galbraith et al.,2013: one individual collided with a plane at 4084m during migration.	Alerstam & Gudmunsson 1999: During migration, n=2, mean=908m, range=734-1081m Krijgsveld et al., 2011: All skuas observed flew at rather low height, but are known to use a wide array of flight height, both during day and night.		**Very high**
Manx shearwater *Puffinus puffinus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010: n=2, 100% at 0m Harwood et al., 2018: n=1 at 18.1m	Paton et al., 2010: n=7, 50%<10m, 10<50%<25m	Krijgsveld et al., 2011: All tubenoses are flying near sea level		**High**
Mediterranean gull *Larus melanocephalus*	Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		**Very high**
Mew gull *Larus canus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Garthe &Hüppop, 2004: median between 10-20m but few above 50m Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution Walls et al., 2004; Parnell et al., 2005: mean= 45m, range=10-150m Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		**Low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m Harwood et al., 2018: n=36, range between 1.3-46.1m Borkenhagen et al., 2018: n=105, med=18m, max=117m, min=2m, 0<82.9%<30m, 30<17.1%<150m,				
Monteiro's storm petrel *Hydrobates monteiroi*		Paton et al., 2010: Storm petrel spp n=1, <10m,	Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Very high**
Northern fulmar *Fulmarus glacialis*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010:, n=5, 20% at 0m, 80%<10m Garthe &Hüppop, 2004: median <5m Borkenhagen et al., 2018: n<20, <30m Harwood et al., 2018: n=30, range between -5.5-5.5m		Krijgsveld et al., 2011: All tubenoses species are flying near sea level		**Low**
Northern gannet *Morus bassanus*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010: n=1278, 9% at 0m, 46.1%<10m, 10<38.1%<25m, 25<6.7m<125m, 0.2%>125m Garthe &Hüppop, 2004: median between 10-20m but few above 50m Borkenhagen et al., 2018: n=79, med=14m, max=52m, min=-3m, 0<87.3%<30m, 30<12.7%<150m	Paton et al., 2010: n=8560, 54.6<10m, 10<35.4<25m, 25<9.9%<125m, 0.1%>125m	Cook et al., 2018: modelled flight height distribution Walls et al., 2004; Parnell et al., 2005: mean= 10m, range=0-200m	Cleasby et al., 2015: distribution of estimated flight height Fig5	**Very low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Harwood et al., 2018: n=350, range between -8.1-49.5m Mendel et al., 2014: n=24, med= 18.8m, Boxplot whisker range: 1.7-40.5m Sadoti et al., 2005: In 2003 n=4, mean=16.3±10.3m, min=5m, max=30m. In 2004, n=81, mean=23.7±16.6m, min=4m, max=60m				
Pallas's gull *Larus ichthyaetus*	Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution Krijgsveld et al., 2011: Gulls<50m when foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
Pomarine jaeger *Stercorarius pomarinus*	Paton et al., 2010: n=1, <10m	Paton et al., 2010:n=2, 100%<10m	Krijgsveld et al., 2011: All skuas observed flew at rather low height, but are known to use a wide array of flight height, both during day and night. Alerstam & Gudmunsson 1999: During migration, n=13, mean=452m, range=2-1932m		**Very high**
Razorbill *Alca torda*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010: n=93, 41.9% at 0m, 58.1%<10m Garthe &Hüppop, 2004: median <5m Borkenhagen et al., 2018: Alcids spp, n<20, <30m	Paton et al., 2010: n=135, 100%<10m	Krijgsveld et al 2011: Alcids <5m, rarely >50m.		**Moderate**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Harwood et al., 2018: n=20, range between -0.7-12.5m Sadoti et al., 2005: In 2004, n=3, mean=14.7±9.2m, min=4m, max=20m				
Red phalarope *Phalaropus fulicarius*		Day et al., 2003: Unidentified phalarope, n=2 flocks at 1m	Alerstam & Gudmunsson 1999: During migration, n=8, mean=530m, range=34-1231m		**Very high**
Red-billed tropicbird *Phaeton aetherus*		Lee & Walsh-Mcgehee, 1998: White-tailed tropicbird plunge from 15-20m			**Very high**
Red-breasted merganser *Mergus serrator*	Paton et al., 2010: n=2, 10<100%<25m	Paton et al., 2010: n=2245, 78.2%<10m, 10<16.4<25m, 25<5.4%<125m	Dirksen et al., 1998: Merganser spp, <30m		**Very high**
Red-necked grebe *Podiceps grisegena*	Cook et al., 2012: n=1, <20m Paton et al., 2010: n=1 at 0m Garthe &Hüppop, 2004: median between 5-10m	Paton et al., 2010: n=24, 91.7%<10m, 10<8.3<25m	Krijgsveld et al., 2011: up to 50m. Nocturnal migration at higher latitude		**Very high**
Red-necked phalarope *Phalaropus lobatus*	Paton et al., 2010: n=24, 95.8% at 0m, 4.2%<10m	Day et al., 2003: Unidentified phalarope, n=2 flocks at 1m	Alerstam & Gudmunsson 1999: During migration, n=1 at 283m		**Very high**
Red-throated loon *Gavia stellata*	Johnston et al., 2014: modelled flight height distribution Cook et al., 2012: modelled flight height distribution Paton et al., 2010: n=106, 5.7% at 0m, 30.2%<10m, 10<35.8%<25m, 25<21.7%<125m, 6.6>125m Garthe &Hüppop, 2004: median between 5-10m Borkenhagen et al., 2018: Divers spp, n=23, median=19m, max=69m, min=4m, 0<87%<30m, 30<13%<150m	Paton et al., 2010: n=1226, 80.5%<10m, 10<12.4<25m, 25<6%<125m, 1.1>125m	Walls et al., 2004; Parnell et al., 2005: 4.5m, range=1-21m Kahlert et al., 2012: Red or Black throated divers. Diurnal migration at 73m in average, range=66-81m Krijgsveld et al., 2011: Divers species observed up to 30m. Wind dependent. Migration flights are higher than foraging ones.		**Low**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	Sadoti et al., 2005: In 2003 n=2, mean=5.5± 6.4m, min=1m, max=10m. In 2004, n=28, mean=20.5±19.1m, min=4m, max=70m				
Roseate tern *Sterna dougallii*	Paton et al., 2010: n=8, 37.5%<10m, 10<50%<25m, 25<12.5%<125m	Paton et al., 2010: n=125, 40%<10m, 10<60%<25m	Krijgsveld et al., 2011: General foraging altitude range up to 20m. Terns migrate at night at higher height.		**Very high**
	Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m				
	Borkenhagen et al., 2018: Terns spp, n=28, median=9m, max=39m, min=1m, 0<96.4%<30m, 30<3.4%<150m				
	Sadoti et al., 2005: Common and Roseate terns, in 2003 n=130, mean=29.6± 33m, min=5m, max=250m. In 2004, n=163, mean=23.8±21.8m, min=4m, max=100m				
	Perkins et al., 2004: Terns spp, n=250, mean=8.8±9.4, median=7.62m and range=1.5-76.2m				
Ross's gull *Rhodostethia rosea*	Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Very high**
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Densley, 1979: 3m above sea level when searching for food	Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
	Hedenström, 1998: n=29, mean=29m, range=40-50m				
Sabine's gull *Xema sabini*	Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m,	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Very high**

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
		25<10,3%<125m, 0.7%>125m			
	Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m	Day et al., 2003: n=5, mean=10.6±4.2m, range=3-25m	Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
	Hedenström, 1998: n=7, 2<5m, 1=10m, 1=15m, 1=20m, range=16-33m				
Sandwich tern *Thalasseus sandvicensis*	Johnston et al., 2014: modelled flight height distribution	Paton et al., 2010: Terns spp, n=1293, 29.9%<10m, 10<58.6%<25m, 25<11.4%<125m,	Krijgsveld et al., 2011: General foraging altitude range up to 20m. Terns migrate at night at higher altitude.		**Low**
	Cook et al., 2012: modelled flight height distribution	Hedenström and Åkesson 2016: 20 flocks flight at 11.2±3.2m, 6 at 72.1±84.3m, 8 at 13.2±2.6m, 21 at 14.1±14.1m	Walls et al., 2004; Parnell et al., 2005: mean=20m, range=8-80m		
	Garthe &Hüppop, 2004: median between 10-20m but few above 50m				
	Christensen et al., 2004: Terns spp, n=11, mean=21.2±5.3m, range=16-33m				
	Borkenhagen et al., 2018: Divers spp, n=49, median=17m, max=66m, min=4m, 0<95.9%<30m, 30<4.1%<150m				
	Perkins et al., 2004: Terns spp, n=250, mean=8.8±9.4m, median=7.62m and range=1.5-76.2m				
	Perrow, Skeate, & Gilroy, 2011: n=117, 48%>20m				
Scopoli's shearwater *Calonectris diomedea*		Paton et al., 2010: Shearwater spp, n=1525, 100%<10m	Krijgsveld et al., 2011: All tubenoses are flying near sea level		**Very high**
Slender-billed gull Larus genei	Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m	Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m	Cook et al., 2018: Gulls spp, modelled flight height distribution		**Very high**
	Christensen et al., 2004: Gulls spp, n=42,	Day et al., 2003: n=5, mean=10.6±4.2m, range=3-25m	Krijgsveld et al., 2011: Gulls<50m foraging but up to		

Species	Boat based survey	Land based seawatches	Radar/LiDAR	Telemetry	Uncertainty Level
	mean=71.2±67.9m, range=2-395m		250m looking for food. Migration on land recorded at 380m in average but up to 750m.		
Sooty shearwater *Ardenna grisea*	Cook et al., 2012: n=2, <20m, 1 around 1m Paton et al., 2010: n=16, 100%<10m	Paton et al., 2010: n=5, 100%<10m	Krijgsveld et al., 2011: All tubenoses are flying near sea level		**Very high**
Steller's eider *Polysticta stelleri*		Day & Rose, 2000: Eiders spp, mean=12m, range=0-70m Day et al., 2003: n=4 flocks. mean=1.3±0.3m, range=1-2m	Alerstam & Gudmunsson 1999: During migration, n=1 at 369m		**Very high**
Thick-billed murre *Uria lomvia*	Paton et al., 2010: n=3, 33.3% at 0m, 66.7%<10m Borkenhagen et al., 2018: Alcids spp, n<20, <30m	Paton et al., 2010: Murre spp, n=1, 100%<10m	Krijgsveld et al 2011: Alcids <5m, rarely >50m		**Very high**
Velvet scoter *Melanitta fusca*	Cook et al., 2012: n=20, <20m Paton et al., 2010: Unidentified scoter, n=4, 10<100%<25m Garthe & Hüppop, 2004: median <5m Sadoti et al., 2005: n=218, 7.3±11.3m, min=4m, max=100m	Paton et al., 2010: Scoter spp, n=34373, 92.2%<10m, 10<7%<25m, 25<0.7%<125m Day et al., 2003: Unidentified scoter, n=1 flock at 2m	Kahlert et al., 2012: Diurnal migration at 128m in average, range=101-162m		**Very high**
White-faced storm petrel *Pelagodroma marina*		Paton et al., 2010: Storm petrel spp n=1, <10m,	Krijgsveld et al., 2011: All tubenoses fly near sea level		**Very high**
Wilson's storm petrel *Oceantites oceanicus*	Paton et al., 2010: n=1511, 49.8% at 0m, 50.2%<10m Sadoti et al., 2005: In 2003, n=12 2.9±1.9m, min=1m, max=5m. In 2004, n=10, 9.2±6.1m, min=3m, max=15m	Paton et al., 2010: n=1240, 100%<10m	Krijgsveld et al., 2011: All tubenoses are flying near sea level		**Very high**
Yelkouan shearwater Puffinus yelkouan	Paton et al., 2010: Shearwater unidentified, n=27, 48.1% at 0m, 51.9%<10m	Paton et al., 2010: Shearwater spp, n=1525, 100%<10m	Krijgsveld et al., 2011: All tubenoses are flying near sea level		**Very high**
Yellow billed loon	Paton et al., 2010: Loon spp n=5, 100% at 0m	Paton et al., 2010: Loon spp, n=615, 58.5%<10m, 10<23.4%<25m,	Krijgsveld et al., 2011: Divers species observed up		**Very high**

<table>
<tr><th>Species</th><th>Boat based survey</th><th>Land based seawatches</th><th>Radar/LiDAR</th><th>Telemetry</th><th>Uncertainty Level</th></tr>
<tr><td rowspan="2">Gavia adamsii</td><td></td><td>25<14.8%<125m, 2.9>125m</td><td rowspan="2">to 30m. Wind dependent. Migration flights are higher than foraging ones.</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Sadoti et al., 2005: Loon spp, In 2004, n=18 14.2±15.5m, min=4m, max=50m.</td><td>Day et al., 2003: Unidentified loons, n=11 flocks. Mean=3.5±1.7m, range=1-20m</td></tr>
<tr><td rowspan="2">Yellow billed gull Larus michahellis</td><td>Paton et al., 2010: Gulls spp, n=58, 25<39.7%<125m, 58.6%>125m</td><td>Paton et al., 2010: Gulls spp, n=22808, 66.6%<10m, 10<22.5%<25m, 25<10,3%<125m, 0.7%>125m</td><td>Cook et al., 2018: Gulls spp, modelled flight height distribution</td><td rowspan="2"></td><td rowspan="2">Very high</td></tr>
<tr><td>Christensen et al., 2004: Gulls spp, n=42, mean=71.2±67.9m, range=2-395m</td><td>Day et al., 2003: n=5, mean=10.6±4.2m, range=3-25m</td><td>Krijgsveld et al., 2011: Gulls<50m foraging but up to 250m looking for food. Migration on land recorded at 380m in average but up to 750m.</td></tr>
<tr><td>Zino's petrel Pterodroma madeira</td><td></td><td>Paton et al., 2010: Storm petrel spp n=1, <10m,</td><td>Krijgsveld et al., 2011: All tubenoses fly near sea level</td><td></td><td>Very high</td></tr>
</table>

Flight characteristics are presented for each species in Table 3 and are mainly taken from the review conducted by Garthe & Hüppop (2004) and Furness and colleagues (2013). Opportunistic observations or tracking studies added information regarding nocturnal activity and time spent flying.

Table 3. Summary of collision risk factors by species.

<table>
<tr><th>Species</th><th>% of time spend flying</th><th>Nocturnal flight activity</th><th>Flight manoeuvrability</th></tr>
<tr><td rowspan="2">Arctic jaeger Stercorarius parasiticus</td><td rowspan="2">Garthe &Hüppop, 2004: 81-100% Unchanged in Furness et al., 2013</td><td>Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013</td><td rowspan="2">Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013</td></tr>
<tr><td>Bryant & Furness, 1995: Inactive during night</td></tr>
<tr><td rowspan="2">Arctic loon Gavia arctica</td><td rowspan="2">Garthe &Hüppop, 2004: 41-60% Unchanged in Furness et al., 2013</td><td>Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013</td><td rowspan="2">Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013</td></tr>
<tr><td>Krijgsveld et al., 2011: Migration mainly at night</td></tr>
<tr><td rowspan="2">Arctic tern Sterna paradisaea</td><td rowspan="2">Garthe &Hüppop, 2004: 81-100% Unchanged in Furness et al., 2013</td><td>Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013</td><td rowspan="2">Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013</td></tr>
<tr><td>Gudmundsson et al., 1992; Johansson & Jakobsson, 1997; Lensink et al., 2002; Van Der Winden, 2002: Terns migrate mainly at night at rather high altitudes</td></tr>
<tr><td rowspan="3">Atlantic puffin Fratercula arctica</td><td>Garthe &Hüppop, 2004: 0-20% Unchanged in Furness et al., 2013</td><td>Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013</td><td rowspan="3">Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013</td></tr>
<tr><td>Shoji et al., 2015: 5.71% during breeding period</td><td rowspan="2">Krijgsveld et al., 2011: Alcids migrate mainly at night</td></tr>
<tr><td>Fayet et al., 2021: 5.8 ± 0.83% for birds from Whales, 4.1± 1.7% for those coming from</td></tr>
</table>

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
	Norway and 7.5 ± 5% and 1.6 ± 0.42% for South and North Iceland respectively		
Audouin's gull *Larus audouinii*	No information found	MaÑosa, Oro, & Ruiz, 2004: Some nocturnal activity recorded Christel et al., 2012: 32% of active locations between 19h and 1h.	No information found
Audubon's shearwater *Puffinus lherminieri*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Balearic shearwater *Puffinus mauretanicus*	Aguilar et al., 2003: 28.3 ± 9.6% Meier et al., 2015: 46.6 ± 8.9%	Meier et al., 2015: Crepuscular and nocturnal activity recorded Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Band-rumped storm petrel *Hydrobates castro*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Barrow goldeneye *Bucephala islandica*	No information found	No information found	No information found
Black guillemot *Cepphus grylle*	Furness et al., 2013: 0-20%	Furness et al., 2013: Very low Hildén, 1994: During summer, maximum colony attendance increased during the night and is reached just before sunrise.	Furness et al., 2013: Low
Black tern *Chlidonias niger*	Garthe &Hüppop, 2004: 81-100%	Garthe &Hüppop, 2004: Very low Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der Winden 2002: Terns migrate mainly at night at high altitudes	Garthe &Hüppop, 2004: Very high
Black-headed gull *Larus ridibundus*	Garthe &Hüppop, 2004: 0-20% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013 Indykiewicz, Jakubas, & Gerke, 2021: Some nocturnal flights happened	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
Black-legged kittiwake *Rissa tridactyla*	Garthe &Hüppop, 2004: 41-60% Unchanged in Furness et al., 2013 McKnight et al., 2011: 11.8% in winter	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
Black-necked grebe *Podiceps nigricollis*	No information found	No information found	No information found
Bulwer's Petrel *Bulweria bulwerii*	Dias et al., 2016: 90% at night and 73% during the day	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night Dias et al., 2016: Mainly nocturnal	No information found
Caspian gull *Larus cachinnans*	No information found	No information found	No information found
Caspian tern *Hydroprogne caspia*	No information found	Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der	No information found

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
		Winden 2002: Terns migrate mainly at night at rather high altitudes	
Common eider *Somateria mollissima*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013
	Pelletier et al., 2007: 0.7% of the day excluding migration period	Merkel & Mosbech, 2008 and Pelletier et al., 2007: Some nocturnal activity recorded	
Common goldeneye *Bucephala clangula*	Furness et al., 2013: 21-40%	Furness et al., 2013: Moderate	Furness et al., 2013: Moderate
Common gull-billed tern *Gelochelidon nilotica*	No information found	Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der Winden 2002: Terns migrate mainly at night at rather high altitudes	No information found
		Fasola & Canova, 1993: Diurnal	
Common loon *Gavia immer*	Furness et al., 2013: 21-40%	Furness et al., 2013: Very low	Furness et al., 2013: Very low
Common guillemot *Uria aalge*	Garthe &Hüppop, 2004: 0-20% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013
	Fort et al., 2013: 5% during winter when not migrating. 15% during migration	Krijgsveld et al., 2011: Alcids migrate mainly at night	
	Burke & Montevecchi, 2018: <5% during winter	Regular, Hedd, & Montevecchi, 2011: Some nocturnal activity recorded	
	Cairns, Bredin, & Montevecchi, 1987: 10% during breeding season		
Common scoter *Melanitta nigra*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013
Common tern *Sterna hirundo*	Garthe &Hüppop, 2004: 81-100% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
		Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der Winden 2002: Terns migrate mainly at night at rather high altitudes	
Cory's shearwater *Calonectris borealis*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Desertas petrel *Pterodroma deserta*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
		Lobato, 2017: According to the moon cycle phase, up to 90% of the night time spent flying during the breeding season and up to 62% during the non-breeding period.	
		Ramos et al., 2016: Some nocturnal activity	

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
European herring gull *Larus argentatus*	Garthe &Hüppop, 2004: 61-80% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: High Unchanged in Furness et al., 2013
European shag *Gulosus aristotelis*	Furness et al., 2013: 21-40% Grémillet, et al., 2020: 20% of time spend commuting during breeding season	Furness et all, 2013: Low Grémillet et al., 2020: Foraging activity occurred between 9-17h	Furness et al., 2013: Moderate
European-Storm-petrel *Hydrobates pelagicus*	Furness et al., 2013: 41-60%	Furness et al., 2013: High del Hoyo, Elliott, & Sargatal, 1996 and personal observation: highly nocturnal	Furness et al., 2013: Very high
Glaucus gull *Larus hyperboreus*	No information found	No information found	No information found
Goosander *Mergus merganser*	No information found	Dirksen et al., 2000: Roost during night Marquiss & Duncan, 1994; Sjöberg, 1985: Activity peak at sunrise/sunset but some males have nocturnal activity during incubation	No information found
Great black-backed gull *Larus marinus*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013 Garthe &Hüppop, 1996: Some nocturnal activity recorded	Garthe &Hüppop, 2004: High Unchanged in Furness et al., 2013
Great cormorant *Phalacrocorax carbo*	Garthe &Hüppop, 2004: 61-80% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013 Grémillet et al., 2005: Diving and foraging during polar night	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013
Great crested grebe *Podiceps cristatus*	Garthe &Hüppop, 2004: 41-60% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013 Krijgsveld et al., 2011: Migrate mainly at night	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013
Great shearwater *Ardenna gravis*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Great skua *Catharacta skua*	Garthe &Hüppop, 2004: 61-80% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013 Votier et al., 2006: Some nocturnal activity recorded	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
Greater scaup *Aythya marila*	Furness et al., 2013: 21-40%	Furness et al., 2013: Very high Beynon et al.,1981: Some nocturnal activity recorded Dirksen et al., 2000: Active during night and roost during day time	Furness et al., 2013: Low
Harlequin duck *Histrionicus hitrionicus*	Inglis, Lazarus, & Torrance, 1989: 0.6%	Rizzolo et al., 2005: no nocturnal activity recorded	No information found
Horned grebe *Podiceps auritus*	Furness et al., 2013: 21-40%	Furness et al., 2013: Low	Furness et al., 2013: Low
Iceland gull *Larus glaucoides*	No information found	Lensink et al., 2002: Gulls migrate nocturnally	No information found
Ivory gull *Pagophila ebrunea*	No information found	Zurowski, 2007: some nocturnal activity recorded	No information found

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
King eider *Somateria spectabilis*	No information found	Systad, Bustnes, & Erikstad, 2000: Usually diurnal but can feed at low light level Oppel, Powell, & Butler, 2011: Active during the night in Alaska during Arctic summer (no obscurity)	No information found
Leach's storm-petrel *Hydrobates leucorhous*	Furness et al., 2013: 41-60%	Furness et al., 2013: High del Hoyo et al., 1996: Nocturnal activity recorded	Furness et al., 2013: very high
Lesser black-backed gull *Larus fuscus*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013 Garthe & Hūppop, 1996: Some nocturnal activity recorded	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
Lesser crested tern *Thalasseus bengalensis*	No information found	Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der Winden 2002: Terns migrate mainly at night at rather high altitudes	No information found
Little auk *Alle alle*	Furness et al., 2013: 0-20% Fort, Porter, & Grémillet, 2009: 9% during winter	Furness et al., 2013: Very low Berge et al., 2015; Ostaszewska et al., 2017: Some nocturnal activity recorded during winter	Furness et al., 2013: Moderate
Little gull *Hydrocoloeus minutus*	Garthe &Hüppop, 2004: 41-60%	Garthe &Hüppop, 2004: Low Lensink et al., 2002: Gulls migrate nocturnally	Garthe &Hüppop, 2004: Very high
Little tern *Sternula albifons*	Furness et al., 2013: 81-100% Perrow et al., 2006: 55.8± 3.4% in 2003 and 71.8±9.5% in 2004	Furness et al., 2013: Very low Gudmundsson et al. 1992; Johansson & Jakobsson 1997; Lensink et al. 2002; van der Winden 2002: Terns migrate mainly at night at rather high altitudes	Furness et al., 2013: Very high
Long-tailed duck *Clangula hyemalis*	Furness et al., 2013: 21-40%	Furness et al., 2013: Moderate	Furness et al., 2013: Moderate
Lon-tailed jaeger *Stercorarius longicaudus*	No information found	Krijgsveld et al., 2011: Skuas could be active and migrate at night	No information found
Manx shearwater *Puffinus puffinus*	Furness et al., 2013: 41-60%	Furness et al., 2013: Moderate Krijgsveld et al., 2011: All tubenoses species are active and migrate at night Personal observations: Come back at the colony during the night	Furness et al., 2013: Moderate
Mediterranean gull *Larus melanocephalus*	No information found	Cama et al., 2011: In winter, birds roost at sea during the night Lensink et al., 2002: Gulls migrate nocturnally	No information found
Mew gull *Larus canus*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013 Lensink et al., 2002: Gulls migrate nocturnally	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
Monteiro's storm petrel *Hydrobates monteiroi*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Northen Fulmar *Fulmarus glacialis*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: High Unchanged in Furness et al., 2013 Berge et al., 2012: Some nocturnal activity recorded Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013
Northern gannet *Morus bassanus*	Garthe &Hüppop, 2004: 41-60% Unchanged in Furness et al., 2013 Furness et al., 2018: 8% during the breeding season and 3% during winter	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013 Furness et al., 2018: Inactive at night Garthe, Benvenuti, & Montevecchi, 2003: Inactive at night	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013
Pallas's gull *Larus ichthyaetus*	No information found	Lensink et al., 2002: Gulls migrate nocturnally	No information found
Pomarine jaeger *Stercorarius pomarinus*	No information found	Krijgsveld et al., 2011: Skuas could be active and migrate at night	No information found
Razorbill *Alca torda*	Garthe &Hüppop, 2004: 0-20% Unchanged in Furness et al., 2013 Shoji et al., 2015: 20.4±5.8% Dall'Antonia et al., 2001: During breeding season, 9.5± 2.9% in 1997 and 5.4± 2.9% in 1998	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013 Benvenuti et al., 2001: Some nocturnal activity recorded Dall'Antonia et al., 2001: No flight and dive activity recorded during breeding season Isaksson et al., 2019: Some dives recorded at night during breeding season	Garthe &Hüppop, 2004: Low Unchanged in Furness et al., 2013
Red phalarope *Phalaropus fulicarius*	No information found	Mcneill et al., 1992: Some nocturnal activity recorded	No information found
Red-billed tropicbird *Phaethon aethereus*	Sommerfeld & Hennicke, 2010: Red-tailed tropicbird spent 90% (daylight) of their short trips flying during chick rearing and 62.4% during incubation Mejías et al.,2017: White-tailed tropicbirds spent 6.5% of time flying at night and 41.5% during the day during winter	Sommerfeld & Hennicke, 2010: Red-tailed tropicbird spent 80% of the night on the water surface Mejías et al.,2017: White-tailed tropicbirds hunt by day during the non breeding season	No information found
Red-breasted merganser *Mergus serrator*	No information found	Dirksen et al., 1998: Fly during day and roost during night Sjösberg 1985: Activity peak at sunrise/sunset but some males have nocturnal activity during incubation	No information found
Red-necked grebe *Podiceps grisegena*	Garthe &Hüppop, 2004: 0-20%	Garthe &Hüppop, 2004: Very low Krijgsveld et al 2011: Grebes are known to migrate mainly at night	Garthe &Hüppop, 2004: Low

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
Red-necked phalarope *Phalaropus lobatus*	No information found	No information found	No information found
Red-throated loon *Gavia stellata*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013 Krijgsveld et al 2011: Migrate mainly at night	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013
Roseate tern *Sterna dougallii*	Furness et al., 2013: 81-100%	Furness et al., 2013: Very low Pratte et al., 2021: 3/42 trips happened at night during breeding season	Furness et al., 2013: Very high
Ross's gull *Rhodostethia rosea*	No information found	Lensink et al., 2002: Gulls migrate nocturnally	No information found
Sabine's gull *Xema sabini*	No information found	Lensink et al., 2002: Gulls migrate nocturnally	No information found
Sandwich tern *Thalasseus sandvicensis*	Garthe &Hüppop, 2004: 81-100% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very low Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Very high Unchanged in Furness et al., 2013
Scopoli's shearwater *Calonectris diomedea*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night Rubolini et al., 2015: Active at night	No information found
Slender-billed gull Larus genei	Veen et al., 2019: 10.8% flying during daytime	Lensink et al., 2002: Gulls migrate nocturnally Veen et al., 2019: not active during the night	No information found
Sooty shearwater *Ardenna grisea*	Furness et al., 2013: 41-60%	Furness et al., 2013: Moderate Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	Furness et al., 2013: Moderate
Steller's eider *Polysticta stelleri*	No information found	Systad & Bustnes, 2001: nocturnal activity recorded	No information found
Thick-billed murre *Uria lomvia*	Falk et al., 2000: 7.1 % during the breeding season	Regular et al., 2011: nocturnal activity recorded	No information found
Velvet scoter *Melanitta fusca*	Garthe &Hüppop, 2004: 21-40% Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013	Garthe &Hüppop, 2004: Moderate Unchanged in Furness et al., 2013
White-faced storm petrel *Pelagodroma marina*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found
Wilson's storm petrel *Oceantites oceanicus*	No information found	Obst & Nagy, 1993: Birds come back at night to feed their chick	No information found
Yelkouan shearwater Puffinus yelkouan	Péron et al., 2013: 68% of the day time spend travelling or foraging	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night Péron et al., 2013: 80% of the night spend resting on water	No information found
Yellow-billed loon *Gavia adamsii*		Earnst, 2004: Some nocturnal activity recorded	

Species	% of time spend flying	Nocturnal flight activity	Flight manoeuvrability
Yellow legged gull *Larus michahellis*		Lensink et al., 2002: Gulls migrate nocturnally	
Zino's petrel *Pterodroma madeira*	No information found	Krijgsveld et al., 2011: All tubenoses species are active and migrate at night	No information found

More than 70% of the species considered had "Very high" or "High" Uncertainty Level (see Table 4). Although several of those species are related to species for which flight height has been more studied, their own flight height assessment will benefit of existing GPS data that could potentially be used in the future to model flight height distribution (see Table 5).

Table 4. Uncertainty criteria, score and level.

Species	Species score	Number of sites	Number of studies	Mean years	Method score	Uncertainty score	Uncertainty level
Arctic jaeger *Stercorarius parasiticus*	3	16	20	2.98	62	103.98	**Moderate**
Arctic loon *Gavia arctica*	3	10	13	3.45	40	69.45	**High**
Arctic tern *Sterna paradisaea*	3	16	20	2.69	62	103.69	**Moderate**
Atlantic puffin *Fratercula arctica*	3	13	27	3.14	81	127.14	**Moderate**
Audouin's gull *Larus audouinii*	2	5	5	0.68	17	29.68	**Very high**
Audubon's shearwater *Puffinus lherminieri*	2	3	3	1.55	9	18.55	**Very high**
Balearic shearwater *Puffinus mauretanicus*	2	3	3	1.55	12	21.55	**Very high**
Band-rumped storm petrel *Hydrobates castro*	2	2	2	1.55	7	14.55	**Very high**
Barrow goldeneye *Bucephala islandica*	1	0	0	0	0	1	**Very high**
Black guillemot *Cepphus grylle*	3	1	1	1.1	2	8.1	**Very high**
Black tern *Chlidonias niger*	3	7	7	3.79	17	37.79	**Very high**
Black-headed gull *Larus ridibundus*	3	26	30	2.69	101	162.69	**Low**
Black-legged kittiwake *Rissa tridactyla*	3	35	43	2.56	136	219.56	**Very low**

Species	Species score	Number of sites	Number of studies	Mean years	Method score	Uncertainty score	Uncertainty level
Black-necked grebe *Podiceps nigricollis*	1	0	0	0	0	1	**Very high**
Bulwer's Petrel *Bulweria bulwerii*	2	2	2	1.55	7	14.55	**Very high**
Caspian gull *Larus cachinnans*	2	4	4	0.84	15	25.84	**Very high**
Caspian Tern *Hydroprogne caspia*	3	6	5	1.73	10	25.73	**Very high**
Common eider *Somateria mollissima*	3	19	21	2.17	63	108.15	**Moderate**
Common goldeneye *Bucephala clangula*	3	3	2	1.2	7	16.2	**Very high**
Common gull-billed tern *Gelochelidon nilotica*	2	4	3	2,11	7	18,11	**Very high**
Common loon *Gavia immer*	3	7	8	2.15	24	44.15	**Very high**
Common guillemot *Uria aalge*	3	27	34	2.91	101	167.91	**Low**
Common scoter *Melanitta nigra*	3	23	30	2.33	89	147.33	**Moderate**
Common tern *Sterna hirundo*	3	27	33	2.73	97	162.73	**Low**
Cory's shearwater Calonectris borealis	3	3	3	1.05	9	19.05	**Very high**
Desertas petrel *Pterodroma deserta*	2	2	2	1.5	7	14.5	**Very high**
European herring gull *Larus argentatus*	3	30	36	2.78	11	182.78	**Low**
European shag *Gulosus aristotelis*	3	4	7	2.3	23	39.3	**Very high**
European-Storm-petrel *Hydrobates pelagicus*	3	4	4	2.28	13	26.28	**Very high**
Glaucus gull *Larus hyperboreus*	2	6	6	1.1	20	35.1	**Very high**
Goosander *Mergus merganser*	3	2	2	1.2	7	15.2	**Very high**
Great black-backed gull	3	30	37	2.67	116	188.67	**Low**

Species	Species score	Number of sites	Number of studies	Mean years	Method score	Uncertainty score	Uncertainty level
Larus marinus							
Great cormorant *Phalacrocorax carbo*	3	18	26	2.44	86	135.44	**Moderate**
Great crested grebe *Podiceps cristatus*	3	5	6	3.9	19	36.9	**Very high**
Great shearwater *Ardenna gravis*	3	2	2	1.55	7	15.55	**Very high**
Great skua *Catharacta skua*	3	16	20	3.04	64	106.04	**Moderate**
Greater scaup *Aythya marila*	3	2	2	1.2	7	15.2	**Very high**
Harlequin duck *Histrionicus histrionicus*	3	1	1	1.1	2	8.1	**Very high**
Horned grebe *Podiceps auritus*	3	3	3	1.55	12	22.55	**Very high**
Iceland gull *Larus glaucoides*	2	5	5	0.86	17	29.86	**Very high**
Ivory gull *Pagophila ebrunea*	2	5	5	0.8	20	32.8	**Very high**
King eider *Somateria spectabilis*	3	3	3	0.63	7	16.63	**Very high**
Leach's storm-petrel *Hydrobates leucorhous*	3	2	2	1.55	7	15.55	**Very high**
Lesser black-backed gull *Larus fuscus*	3	41	47	2.37	159	252.37	**Very low**
Lesser crested tern *Thalasseus bengalensis*	2	4	3	2.11	7	18.11	**Very high**
Little auk *Alle alle*	3	7	10	2.85	32	54.85	**High**
Little gull *Hydrocoloeus minutus*	3	25	29	2.85	94	153.85	**Low**
Little tern *Sternula albifons*	2	7	6	1.99	17	33.99	**Very high**
Long-tailed duck *Clangula hyemalis*	3	5	7	0.5	20	35.5	**Very high**
Long-tailed jaeger *Stercorarius longicaudus*	3	4	4	1.1	13	25.1	**Very high**
Manx shearwater	3	13	15	2.2	47	80.2	**High**

Species	Species score	Number of sites	Number of studies	Mean years	Method score	Uncertainty score	Uncertainty level
Puffinus puffinus							
Mediterranean gull *Larus melanocephalus*	2	4	4	0.84	15	25.84	**Very high**
Mew gull *Larus canus*	3	30	34	2.79	108	177.79	**Low**
Monteiro's storm petrel *Hydrobates monteiroi*	2	2	2	1.55	7	14.55	**Very high**
Northen Fulmar *Fulmarus glacialis*	3	26	32	2.94	96	159.94	**Low**
Northern gannet *Morus bassanus*	3	37	44	2.62	137	223.62	**Very low**
Pallas's gull *Larus ichthyaetus*	2	4	4	0.86	15	25.86	**Very high**
Pomarine jaeger *Stercorarius pomarinus*	3	3	3	1.12	12	22.12	**Very high**
Razorbill *Alca torda*	3	24	29	2.94	86	144.94	**Moderate**
Red phalarope *Phalaropus fulicarius*	3	2	2	0.245	7	14.245	**Very high**
Red-billed tropicbird *Phaethon aethereus*	2	1	1		1	5	**Very high**
Red-breasted merganser *Mergus serrator*	3	2	2	1.2	7	15.2	**Very high**
Red-necked grebe *Podiceps grisegena*	3	4	4	3.625	12	26.625	**Very high**
Red-necked phalarope *Phalaropus lobatus*	3	3	3	0.53	9	18.53	**Very high**
Red-throated loon *Gavia stellata*	3	25	32	2.57	102	164.57	**Low**
Roseate tern *Sterna dougallii*	2	6	6	1.54	16	31.54	**Very high**
Ross's gull *Rhodostethia rosea*	2	6	6	0.72	18	32.72	**Very high**
Sabine's gull *Xema sabini*	2	6	6	0.63	19	33.63	**Very high**
Sandwich tern *Thalasseus sandvicensis*	3	30	36	2.61	110	181.61	**Low**
Scopoli's shearwater	2	2	2	1.55	7	14.55	**Very high**

Species	Species score	Number of sites	Number of studies	Mean years	Method score	Uncertainty score	Uncertainty level
Calonectris diomedea							
Slender-billed gull *Larus genei*	2	4	4	0.84	15	25.84	**Very high**
Sooty shearwater *Ardenna grisea*	3	4	4	2.03	13	26.03	**Very high**
Steller's eider *Polysticta stelleri*	2	3	3	0.25	9	17.25	**Very high**
Thick-billed murre *Uria lomvia*	2	4	3	2.7	9	20.7	**Very high**
Velvet scoter *Melanitta fusca*	3	8	8	2.77	22	43.77	**Very high**
White-faced storm petrel *Pelagodroma marina*	2	2	2	1.55	7	14.55	**Very high**
Wilson's storm petrel *Oceantites oceanicus*	3	3	3	1.25	9	19.25	**Very high**
Yelkouan shearwater *Puffinus yelkouan*	2	2	2	1.55	7	14.55	**Very high**
Yellow billed loon *Gavia adamsii*	2	4	4	0.98	12	22.98	**Very high**
Yellow billed gull *Larus michahellis*	2	4	4	0.84	15	25.84	**Very high**
Zino's petrel Pterodroma madeira	2	2	2	1.55	7	14.55	**Very high**

Table 5. Potential sources of additional flight height data obtained by tracking studies.

Species	References
Arctic tern *Sterna paradisaea*	Seward et al., 2021: 10 individuals from Skerries Island during the breeding season.
Atlantic puffin *Fratercula arctica*	This study: 10 individuals from Skellig Michael equipped with Nanofix (PathTrack) in July 2021.
	Harris et al., 2012: 7 individuals from Isle of May equipped with IGotU-GT 120 during the breeding season.
	Fayet etal, 2021: 34 individuals (280 trips) from Norway, Whales and Iceland equipped with NanoFix (PathTrack) during the breeding season 2018.
	Delord et al., 2020: 6 individuals from Saint Pierre and Miquelon equipped with NanoFix (PathTrack) during the breeding season 2016.
	Bennison et al., 2019: 12 individuals (102 trips) from Little Saltee equipped with Uria GPS (Ecotone) and NanoFix (PathTrack).
Audouin's gull *Larus audouinii*	Bécares et al., 2015; García-Tarrasón et al., 2015: 37 individuals from Ebro Delta equipped with CatTraq GPS during the breeding season 2011.
	Christel et al., 2012: 8 birds from EbroDelta equipped with PTT during the breeding season 2006.
	Jurinović et al., 2019: 5 individuals from Ebro Delta equipped with GPS-GSM devices.

Species	References
Balearic shearwater *Puffinus mauretanicus*	Louzao et al., 2012: 6 individuals equipped with Argos PTT in May 2011.
	Meier et al., 2015: 61 individuals equipped.
Barrow goldeneye *Bucephala islandica*	Robert, Benoit, & Savard, 2002: 18 individuals from Saint Lawrence river estuary equipped with Argos PTT-100 implants.
Black guillemot *Cepphus grylle*	Owen, 2014: 23 individuals (19 tracks) from Orkney equipped during the breeding seasons 2013-2014.
	Shoji et al., 2015: 1 individual from Northern Ireland equipped with GPS during summer 2013.
Black-headed gull *Larus ridibundus*	Indykiewicz et al., 2021: 10 individuals equipped with PinPoint GPS (Lotek) during the breeding seasons 2016-2019.
	Jakubas et al., 2020: 37 individuals equipped with PinPoint-10 GPS (Lotek) during the breeding season 2018.
Black-legged kittiwake *Rissa tridactyla*	Kotzerka, Garthe, & Hatch, 2010: 14 individuals from Middelton Island equipped with GiPSy GPS (TechnoSmart) in 2007.
	Ponchon et al., 2017: 36 individuals from 3 French colonies equipped with Uria-68S GPS (Ecotone).
	Chivers et al., 2012: 14 individuals from two Irish colonies equipped with IGoTU-GT100 during the breeding season 2009-2010.
	Ponchon et al., 2015: 16 individuals from two Norwegian colonies equipped with MiniGPS-100 (Earth&OCEAN) during the breeding seasons 2010-2011.
	Christensen-dalsgaard, May, & Lorentsen, 2018: 314 individuals from two Norwegian colonies equipped with mGPS2 (Earth&OCEAN) and IGoTU-GT120 during the breeding seasons 2011-2014.
Bulwer's petrel *Bulweria bulwerii*	Rodríguez et al., 2013: 5 individuals from Alegranza equipped with PTT during the breeding season 2010
	Dataset provided by Gonzalez-Solis and Paiva in BirdLife DataZone portal.
Caspian tern *Hydroprogne caspia*	Rueda-Uribe et al., 2021: 69 individuals from 7 colonies in the Baltic Sea equipped with Ornitela GPS-GSM during the breeding seasons 2017-2019.
	Dataset provided by Dossa in BirdLife DataZone portal.
Common gull-billed tern *Gelochelidon nilotica*	Goodenough & Patton, 2019: 11 individuals from Californian colonies equipped with PTT during the breeding seasons 2012-2016.
Common guillemot *Uria aalge*	Delord et al., 2020: 6 individuals from Saint Pierre and Miquelon equipped with Cat-Log and IGoTU during the breeding season 2016.
	Peschko, Mercker, & Garthe, 2020: 12 individuals from Helgoland equipped with Uria GPS (Ecotone) during the breeding seasons 2016-2017.
	Evans et al., 2013: 7 individuals from Salgo Island equipped with GPSD (Mobile Action Technology).
Cory's shearwater *Calonectris borealis*	Paiva et al., 2010: 33 individuals from Berlangas equipped with CR2 GPS during the breeding season 2006. Data used in Haug et al., 2015
	Dell'Ariccia et al., 2010: 22 individuals from Linosa equipped during breeding season 2007.
	Rodríguez et al., 2015: Individuals from Tenerife equipped with CatTraq GPS during the breeding season 2013-2014.
Desertas petrel *Pterodroma deserta*	Ventura et al., 2020: 20 individuals from Madeira during the 2015-2015 breeding seasons.
European herring gull *Larus argentatus*	Stienen et al., 2016: 26 individuals from the southern North Sea coast equipped with Uva-BiTS GPS during the breeding seasons 2013-2015.
	Shlepr et al., 2021: 31 individuals from Brier Island equipped with IGoTU and Ecotone GPS during the breeding season.
European shag *Gulosus aristotelis*	Grémillet et al., 2020: 29 individuals from Chausey and Saint Marcouf equipped with Harrier-L GPS (Ecotone) during the breeding season.
	Kogure et al., 2016: 14 individuals from Isle of May equipped with ORI400-D3GT GPS during the breeding season.

Species	References
	Lorentsen et al., 2019: 308 individuals equipped with mGPS-2 (Earth&OCEAN) and IGoTU-GT120 during the breeding seasons 2011-2016.
	Soanes et al., 2014: 84 individuals from Puffin Island equipped with IGoTU-GT120 during the breeding seasons 2010-2012.
European-Storm-petrel *Hydrobates pelagicus*	Bolton, 2021: 42 tracks from UK birds during the breeding season.
	Rotger et al., 2020: 22 foraging tracks from Mediterranean subspecies during the breeding season.
Great black-backed gull *Larus marinus*	Maynard & Ronconi, 2018: 3 individuals from Devil's Island equipped with Harrier-M GPS (Ecotone) during the breeding season 2016.
	Borrmann et al., 2019: 7 individuals from Foehr equipped with OrniTrack 30 GPS/GSM (Ornitela) during the breeding season 2016.
Great cormorant *Phalacrocorax carbo*	Yoda et al., 2012: 4 individuals (15 trips) equipped with GiPSy (TechnoSmart) during the breeding season 2012.
Great shearwater *Ardenna gravis*	Schoombie et al., 2018: 25 foraging trips of birds from Gough Island equipped during the breeding season.
Great skua *Catharacta skua*	Wade et al., 2014: 20 individuals equipped in a wind turbine context with UVA-BiTS GPS during the breeding season 2014.
Harlequin duck *Histrionicus histrionicus*	Brodeur et al., 2002: 25 individuals from Quebec and Hudson Bay equipped with PTT-100 during the breeding seasons 1996-1998.
	Chubbs et al., 2008: 11 individuals from Central Labrador equipped with satellite telemetry during the breeding season 2001-2002.
	Robert et al., 2008: 8 individuals from Isle au Haut equipped with satellite telemetry during the breeding season 2001.
Ivory gull *Pagophila ebrunea*	Gilg et al., 2016: 104 individuals from several colonies in High Arctic equipped with PTT during breeding seasons 2010-2013.
King eider *Somateria spectabilis*	Oppel & Powell, 2010: 53 individuals from Alaska equipped with PTT during the breeding seasons 2006-2008.
Lesser black-backed gull *Larus fuscus*	Baert et al., 2018: Some data included in Stienen et al., 2016 and Vanermen et al., 2020. 107 individuals from 3 colonies (Belgium and Dutch coasts) equipped with Uva-BiTS GPS during the breeding seasons 2013-2017. It's specifically mentioned that altitude was recorded but unused in the analysis.
Little auk *Alle alle*	Mosbech's team: ALLE GPS (Ecotone) deployed in East Greenland during the breeding season 2019.
	Amélineau et al.,2016: 15 complete tracks from birds equipped in East Greenland with EP3.3 and ALLE GPS (Ecotone) during the breeding seasons 2012-2014.
	Jakubas's team: GPS data used in Jakubas et al., 2016; 2012 and 2020
Little tern *Sternula albifons*	Perrow et al., 2006: 13 individuals equipped during the breeding seasons 2003-2004.
Long-tailed duck *Clangula hyemalis*	Mallory et al., 2006: 3 individuals equipped with Argos transmitters in March 2003-2004.
	Allison et al., 2009: 8 individuals equipped during winter 2007-2008.
Long-tailed jaeger *Stercorarius longicaudus*	BirdLife DataZone: Gilg's dataset (4 tracks between 2006-2007, obtained with PTT).
Manx shearwater *Puffinus puffinus*	This study: individuals from Little Saltee equipped with CatLog and Nanofix (PathTrack) during summer 2021.
	Jessopp's team: GPS data used in Arneill et al., 2020 for example
	Gilford's team: GPS data used in Dean et al., 2015; Freeman et al., 2013; Gibb et al., 2017; Richards et al. , 2019; Shoji et al., 2015 for example.
Mediterranean gull *Larus melanocephalus*	Picardi et al., 2019: 29 tracks

Species	References
Monteiro's storm petrel *Hydrobates monteiroi*	BirdLife Datazone: Rodrigues Costa Neves's dataset from Azores (n=72 GPS tracks between 2018-2020).
Northen Fulmar *Fulmarus glacialis*	Mallory et al.,2008: 5 individuals from Canada equipped with PTT100 (Microwave) during the breeding season 2004.
	Edwards et al., 2013: 22 individuals from Eynhallow equipped with IGoTU-GT120 during the breeding season 2012.
Northern gannet *Morus bassanus*	This study: 25 individuals from Great Saltee equipped with IGoTU and AxyTreck (TechnoSmart) during summer 2021.
	Numerous studies! Jessopp's team (Bennison et al., 2018 for example) + among others, Amélineau et al., 2014; Bodey et al., 2014; Carter et al., 2016; Clark et al., 2020 (altitude recorded but unused); Lane, Spracklen, & Hamer, 2019; Peschko et al., 2021 (in a wind farm context); Pettex et al., 2012; Votier et al., 2010.
Pallas's gull *Larus ichtyaetus*	Guo-Gang et al., 2014: 5 individuals equipped with PTT.
	Muzaffar et al., 2008: 6 individuals from Qinghai Lake equipped with PTT in 2007.
Razorbill *Alca torda*	Shoji et al., 2015: 7 individuals equipped with IGoTU during the breeding season.
	Delord et al., 2020: 5 individuals from Saint Pierre and Miquelon equipped with Cat-Log/IGoTU GPS during the breeding season 2016.
	Chimienti et al., 2017: 5 individuals equipped with IGoTU-GT120 during the breeding seasons 2014-2015.
	Isaksson et al., 2019: 5 individuals equipped with IGoTU-GT120 during the breeding season.
	Kuepfer, 2012: 90 individuals equipped with IGoTU-GT120 during the breeding season 2011.
Red-billed tropicbird *Phaeton aethereus*	BirdLife Datatzone: Numerous GPS datasets provided by Oppel, Gonzalez-Solis, Soanes, Green and Paiva.
Red-throated loon *Gavia stellata*	Heinänen et al., 2020: 3 individuals from German bright equipped in a wind farm context with Argos PTT from Telonics (IMPTAV-2635, 2640, 2645) and Siltrack (K3I 171A) in March 2015-2017.
Roseate tern *Sterna dougallii*	Pratte et al., 2021: 7 individuals equipped with NanoFix (PathTrack) during the breeding season 2016.
Species	**References**
Ross's gull *Rhodostethia rosea*	Gilg et al., 2016: 2 individuals from Kolyna Delta equipped with PTT during the breeding season 2013.
Sandwich tern *Thalasseus sandvicensis*	Fijn et al., 2017: 21 individuals (151 trips) equipped with ALLE-55 (Ecotone) during the breeding seasons 2012-2015.
Scopoli's shearwater *Calonectris diomedea*	BirdLife DataZone: Numerous GPS datasets provided by Gonzalez-Solis, Arcos, Metzger, Cecere and Gaibani, Raine and Garcia.
	Grémillet et al., 2014: 19 individuals from Zembra equipped with CatTraqQM during the breeding seasons 2012-2013.
	Péron & Grémillet, 2013: 24 individuals from 3 Mediterranean Islands equipped with PTT or GPS during the breeding seasons 2011-2012
Slender-billed gull *Larus genei*	Veen et al.,2019: 3 individuals from Saloum Delta equipped with UvA-BiTS GPS during the breeding season 2014.
Sooty shearwater *Ardenna grisea*	Bonnet-Lebrun et al., 2020: 20 individuals equipped.
Steller's eider *Polysticta stelleri*	Martin et al., 2015: 14 individuals from Alaska equipped with PTT during the breeding season 2000-2001
Thick-billed murre *Uria lomvia*	Gaston et al., 2013: 34 individuals from Coats and Digges Islands equipped with CatTraq during the breeding seasons 2010-2012
	Brisson-Curadeau et al., 2018: 93 individuals from Coats Island equipped with AxyDepth during the breeding season 2017.
	Linnebjerg et al., 2013: 6 individuals from South Greenland equipped with IGoTU GT-120, TM-TAG and EP-3.1 during the breeding seasons 2009-2011.
White-faced storm petrel	BirdLife Datazone: GPS datasets provided by Gonzalez-Solis, Catry, Granadeiro and Alho

Species	References
Pelagodroma marina	
Yelkouan shearwater Puffinus yelkouan	BirdLife Datazone: GPS datasets provided by Kapelj, Metzger, Raine and Lago
	Péron et al., 2013: 29 individuals equipped with GPS and 6 with PTT in Port-Cros and Porquerolles Islands during the breeding seasons 2011-2012.
	Pezzo et al., 2021: 21 individuals equipped in Sardinia
Yellow-billed loon *Gavia adamsii*	Ford, 2014: 14 individuals from Canadian Arctic with PTT.
	Schmutz et al., 2019 :Argos raw data from Alaska
Zino's petrel *Pterodroma madeira*	BirdLife Datazone: Datasets provided Catry, Silva, Granedeiro.

Table 6. Flight height data sources used in Johnston et al., 2014 and Cook et al., 2012.

Wind Farm	Years	Months	Method	References
Argyll Array		All Year	Boat	Scottish Power Renewables. *unpublished data.*
Barrow		All Year	Boat	DONG Energy. 2006. *Barrow Offshore Wind Farm Environmental Statement*, DONG Energy, Essex
Blyth	1998-2000	All year	Shore	Rothery, p., Newton, I. & Little, B. 2009. Observations of seabirds at offshore wind turbines near Blyth in northeast England. *Bird Study*, 56, 1-14
Burbo Bank	2001-2002	Dec-Feb	Boat	Seascape Energy. 2008. *Burbo Bank Offshore Wind Farm Environmental Statement.* Available from [http://www.dongenergy.com/Burbo/Environment/statement/Pages/statement.aspx accessed 21/05/2013]
Docking Shoal		All Year	Boat	Centrica Energy. 2008. *Docking Shoal Offshore Wind Farm Environmental Statement. Centrica Renewables, Windsor*
Dogger Bank	2010-2011	All Year	Boat	Forewind Ltd. *unpublished data*
Dudgeon	2007-2008	All Year	Boat	Econ. 2009. *Ornithological assessment of the Dudgeon Offshore Wind Farm: Technical Report*, ECON Ecology, Norwich
Egmond aan Zee	2003 - 2004	All Year	Boat	Leopold, M. F., Camphuysen, C. J., van Lieshout, S. M. J., ter Braak, C. J. F., Dijkman, E. M. 2004. *Baseline studies North Sea Wind Farms: Lot 5 Marine Birds in and around the future site Nearshore Windfarm (NSW).* Alterra-rapport 1047, Alterra, Wageningen
Gunfleet Sands	2005-2007	All Year	Boat	DONG Energy. 2005. *Gunfleet Sands 1 Environmental Statement*, DONG Energy, Essex DONG Energy. 2007. *Gunfleet Sands 2 Environmental Statement*, DONG Energy, Essex
Gwynt Y Mor	2002-2005	All Year	Boat	N Power Renewables. 2005. *Gwynt y Mor Offshore Wind Farm Environmental Statement*. N Power Renewables, Swindon
Horns Rev	2005-2006	Mar-May, Sept - Nov	Boat	Blew, J., Hoffmann, M., Nehls, G. & Hennig, V. 2008. *Investigations of the bird collision risk and the responses of harbour porpoises in the offshore wind farms Horns Rev, North Sea and Nysted, Baltic Sea, in Denmark Part 1: Birds.* University of Hamburg, Hamburg, Germany.
Humber Gateway	2003-2005	All Year	Boat	IECS. 2007. *Seabird Survey Programme Findings, Humber Gateway Windfarm*. Report to E.ON Renewables. IECS, Hull
Islay		All Year	Boat	SSE Renewables. *unpublished data*

Kentish Flats	2001-2002	All Year	Boat	Environmentally Sustainable Systems Ltd. 2008. *Kentish Flats Ornithological Monitoring Report*. Environmentally Sustainable Systems Ltd., Edinburgh available from [http://www.vattenfall.co.uk/en/file/2_Kentish_Flats_Bird_Monitoring.pdf_16360530.pdf accessed 21/05/13]
Lincs	2004-2006	All Year	Boat	Centrica Energy. 2007. *Lincs Offshore Wind Farm Environmental Statement.*
London Array	2002-2005	All Year	Boat	Dong Energy. 2005. *Environmental Statement Volume 1: Offshore Works London Array Limited*. Dong Energy, Essex
Lynn & Inner Dowsing	2001-2005	All Year	Boat	RPS. 2008. *Lynn & Inner Dowsing Offshore Wind Farm Boat-based Ornithological Monitoring Report*. RPS, Glasgow
Meetpost Nordwijk	2003 - 2004	All Year	Offshore Platform	Krijgsveld, K. L., Lensink, R., Schekkerman, H., Wiersma, P., Poot, M. J. M., Meesters, E. H. W. G., Dirksen, S. 2005. *Baseline studies North Sea wind farms: fluxes, flight paths and altitudes of flying birds 2003-2004*. Alterra, Wageningen
Moray Firth	2010-2012	All Year	Boat	Moray Offshore Renewables Ltd. 2012. *Developing Wind Energy in the Outer Moray Firth Environmental Statement Telford, Stevenson and MacColl Wind Farms and Associated Transmission Infrastructure*. Available [http://morayoffshorerenewables.com/Document-Library.aspx?path=environmental+statement&page=1 accessed on 21/05/13]
Neart na Gaoithe	2009-2011	All Year	Boat	Mainstream Renewable Power Ltd. 2012. *Offshore Environmental Statement.* Available [http://www.neartnagaoithe.com/environmental-statement1.asp accessed on 21/05/13]
North Hoyle	2001	All Year	Boat	Innogy. 2002. *North Hoyle Environmental Statement.* Available from [http://www.rwe.com/web/cms/en/312146/rwe-innogy/sites/wind-offshore/in-operation/north-hoyle/environment/environmental-statement/ accessed 21/05/2013]
Nysted	2005-2006	Mar-May, Sept - Nov	Boat	Blew, J., Hoffmann, M., Nehls, G. & Hennig, V. 2008. *Investigations of the bird collision risk and the responses of harbour porpoises in the offshore wind farms Horns Rev, North Sea and Nysted, Baltic Sea, in Denmark Part 1: Birds.* University of Hamburg, Hamburg, Germany. Desholm, M. & Kahlert, J. 2005. Avian collision risk at an offshore wind farm. *Biology Letters* 1: 296-298.
Race Bank	2005-2007	All Year	Boat	Centrica Energy. 2009. *Race Bank Offshore Wind Farm Environmental Statement*. *Centrica Renewables, Windsor*
Rampion	2010-2012	All Year	Boat	E.ON Climate and Renewables. *unpublished data*
Sheringham Shoal	2004-2006	All Year	Boat	Scira Offshore Energy Ltd. 2006. *Sheringham Shoal Environmental Statement*, Scira Offshore Energy Ltd. [http://www.scira.co.uk/downloads/_Environmental%20Statement%20-%20main%20text.pdf accessed 21/05/2013]
Thorntonbank	2005-2007	All Year	Boat	Vanermen, N. & Stienen, E. W. M. 2008. *Seabirds & Offshore Wind Farms: Monitoring Results 2008.* INBO, Brussels
Tuno Knob	1998	Feb-Mar	Offshore Platform	Larsen, J.K. & Guillemette, M. 2007. Effects of wind turbines on flight behaviour of wintering Common Eiders: implications for habitat use and collision risk. *Journal of Applied Ecology* 44: 516-522.
Wangerooge	1999	Sept - Nov	Shore	Kruger, T. & Garthe, S. 2001. Flight altitudes of coastal birds in relation to wind direction and speed. *Atlantic Seabirds*, 3, 203-216
Westernmost Rough	2004-2006	All Year	Boat	DONG Energy. 2009. *Westernmost Rough Environmental Statement*. DONG Energy, Essex

West of Duddon Sands	2004-2005	All Year	Boat	Morecambe Wind Ltd. 2006. *West of Duddon Sands Offshore Wind Farm Environmental Statement*. Morecambe Wind Ltd., Morecambe
Zeebrugge	2004-2005	Jun-Jul	Shore	Everaert, J. & Stienen, E. W. M. 2007. Impact of wind turbines on birds in Zeebrugge. *Biodiversity and Conservation*, 16, 3345-3359
Greater Gabbard	2004-2005	All Year	Boat	Banks, A. N., Burton, N. H. K., Austin, G. E., Carter, N., Chamberlain, D. E., Holt, C., Rehfisch, M. M., Wakefield, E., Gill, P. 2005. *The potential effects on birds of the Greater Gabbard Offshore Wind Farm Report for February 2004 to March 2005*. BTO Research Report No. 419, Thetford.

4 Conclusions and perspectives

This report constitutes the first essential step in the calculation of a robust Collision Vulnerability Index (Certain et al., 2015) for the X-ROTOR Project in European waters. The review of existing literature highlights some species as extensively studied while others require further flight height data collection to reduce the uncertainty that will bias vulnerability indices. Although tracking studies (with GPS and/or altimeter) suffer from some limitations (see Table 1) and inaccuracies (Péron et al., 2020), large amounts of existing data available through published studies and online databases such as MoveBank (https://www.movebank.org/cms/webapp?gwt_fragment=page=search_map) and BirdLife International (http://www.seabirdtracking.org) see (see Table 5), provide arguably the most comprehensive and comparable data across species. Furthermore, such existing data represent good sources for future flight height analysis.

With on-going miniaturization of tracking devices, those species with poorly known at-sea flying behaviour can be equipped. Under X-ROTOR project, three seabird species (Atlantic puffin, Manx shearwater and Northern Gannet) with “Moderate”, “High” and “Very low”, flight height Uncertainty Level respectively, were tracked during the 2021 breeding season to provide knowledge on parameters needed to increase certainty within collision risk models. These data will be analysed within the Environmental Impact work package throughout the X-ROTOR project.

Finally, to calculate a Collision Vulnerability Index within the X-ROTOR project, we will need to assess two further factors (Critchley & Jessopp, 2019): habitat use and conservation status. The first one describes the extent to which seabirds may use areas suitable for offshore windfarm development as well as their sensitivity to disturbance by turbines, vessels and helicopters disturbances (Thaxter et al., 2018). The conservation status further describes the susceptibility of populations to increased mortality associated with offshore developments, and is influence by adult survival rate and the percentage of the biogeographical populations occurring in areas of interest. Combining Collision Vulnerability Index with seabird distribution data (e.g. ObSERVE project, Rogan et al., 2018), will enable production of Vulnerability maps, useful in identifying areas suitable for offshore development while minimising potential impacts on biodiversity.

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