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Population vulnerability of two sympatric gull species to offshore windfarm developments

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Abstract

Offshore wind farm developments are one of many renewable energy sources increasing in popularity due to the current demand for alternatives to fossil fuels. However, despite the benefits of offshore wind power, studies suggest that collision mortality and the consequences of avoidance in seabirds are causes for concern. Few studies have looked at the long-term consequences of collision risk, therefore the potential impacts on a population level are largely unknown. This study aimed to determine the vulnerability of two sympatric gull populations, herring gulls and lesser black-backed gulls, to offshore windfarm developments. Estimates for mortality risk were calculated by applying Band's model to a test model system comprised of a population of each species breeding sympatrically at South Walney in proximity to existing offshore renewable energy developments (OREDs). Population viability analysis software 'VORTEX' was used to estimate the impact of the calculated mortality risk on the size and trajectory of each population. The impact of using national average data rather than site specific data was assessed by altering productivity and mortality by plus and minus one standard deviation and observing the impact this had on the calculated growth rate of both bird populations. The results indicate that herring gulls appear to be more vulnerable to mortality from offshore wind farm developments than lesser black-backed gulls. This collision mortality could cause the South Walney herring gull population to decline dramatically within the next 50 years, possibly by 78 %. Using national average productivity and mortality data can have a large impact on the calculated population growth rate so there is a need for site specific data. In conclusion, there needs to be more consideration to population level impacts when developing offshore wind farms.

Introduction

The search to find alternative forms of energy to fossil fuels is critical. Not only is the carbon dioxide released as a result of the combustion of fossil fuels harmful to both the environment and the health of the public (Herzog *et al*, 2001), but they are finite, meaning they will eventually run out (Höök,2013), possibly as soon as 2040 for oil, 2042 for gas and 2112 for coal, according to Shafiee and Topal (2009). Therefore, in recent years, there has been an increase in the demand for energy from renewable sources such as wind power, which increased in supply by three and a half times in Europe between 2005 and 2015, and solar PV power which increased by fifty times (Arantegui and Jäger-Waldau, 2017). This shift towards renewables is likely to be further fuelled in upcoming years by the signing of the 2015 Paris Agreement, as countries strive towards meeting the target of limiting global temperature change to less than 2°C above preindustrial levels (UNFCC, 2015). Among renewable sources of energy, there is increasing popularity surrounding offshore renewable energy developments (OREDs), such as wind, tidal and wave energy, due to their vast energy potential (Pelc and Fujita, 2009). According to Esteban and Leary (2012), it is possible that 7% of the world's electricity could be supplied by these technologies by 2050.

Despite these benefits, like most anthropogenic developments, current research indicates that ORED construction, operation and decommissioning can have impacts on marine ecosystems and the species within them. According to Gill (2005), the seabed is disrupted by the construction of ORED foundations and underwater power-cables, and the disturbed sediment can cover and crush habitats. Furthermore, the noise created by drilling and construction piling, as well as the sound they produce when operating, can impair the acoustic system of organisms and impact their communication and echolocation of predators and prey (Gill, 2005). Additionally, decommissioning OREDs involves removing a structure from under the sea, reducing habitat heterogeneity and possibly causing indirect effects such as altering the food chain and the availability for organisms to find suitable habitats (Kaiser and Jennings, 2002).

Collision and avoidance is an issue that numerous researchers believe can arise due to OREDs, particularly offshore wind farms. According to Garthe and Huppop (2004), this is a problem for species both in the air and under the water. This view is supported by Dadswell and Rulifson (1994), who state that some migrating marine species are affected by submerged turbines. According to Wilson *et al* (2007), cetaceans are at risk of being struck by blades of ocean current and tidal devices. Furthermore, cetaceans and pinnipeds may be at risk of becoming entangled in the cables and moorings of some ORED devices (Boehlert and Gill, 2010), particularly if the devices attract their prey species, as some studies indicate that man-made structures can act as artificial reefs, attracting fish and invertebrates (Jensen, 2002; Helvey, 2002; Wilhelmsson and Malm, 2008). Collision mortality of birds in particular, is an issue that studies suggest is a cause for concern (Drewitt and Langston, 2006). According to Furness *et al* (2013), among seabirds, the species most at risk of collision include herring gulls *Larus argentatus*, great black-backed gulls *Larus marinus*, lesser black-backed gulls *Larus fuscus*, white tailed eagles *Haliaeetus albicilla* and northern gannets *Morus bassanus*. This is due to a combination of their flight percentage at blade height, flight agility, percentage of time flying, night flight and conservation importance which in combination makes the species more likely to collide with turbines and the consequences more severe. The paper proposes a collision risk index which combines these factors and incorporates their 'conservation importance' to propose a vulnerability score for a range of marine bird species.

Band (2012) created the Collision Risk Model, which when applied to relevant data allows researchers to estimate the mortality rate of bird populations caused by turbines in offshore windfarm developments. The model is now used as standard in the windfarm EIA process and the most frequently used avian collision risk model in the UK (Masden, 2015). This model has been applied by researchers such as May *et al* (2010), who used it to gain an estimate of collision risk in white-tailed eagles. The study concluded that the avoidance rate of white-tailed eagles was 97.8 and 97.9 % for turbines rotating at 11 and 16 RPM, respectively. Avoidance can be on either a 'micro' or a 'macro' scale. Micro-avoidance is when birds fly through the windfarm, avoiding individual turbines (Cook *et al*, 2012), whereas macro-avoidance is when birds alter their flight path to fly around the whole wind farm (Desholm and Kahlert, 2005). The band model is not perfect. For example, it does not account for oblique approach angles and windspeed (Christie, 2015). Despite this, the Band model is legally required and recognised as it is considered the best model currently available (Masden, 2015).

The Band model calculates the predicted number of collisions per annum and per month of bird species to windfarms, taking into account avoidance rates. However, despite its widespread use and adoption, there are uncertainties regarding what impact these collisions may have on the population in the future. Seabirds are long-lived and have a reasonably long breeding lifespan along with a low annual reproductive output, making populations vulnerable to adult mortality (Erikstad *et al*, 1998). However, despite the prevalence of collision risk modelling and the known short-term impacts of offshore wind farms, not many studies have looked at the longer-term consequences for bird populations of this collision risk, therefore the potential impacts on a population level are largely unknown.

The aim of the present study is to determine the vulnerability of two sympatric gull populations, herring gulls and lesser black-backed gulls, which are named by Furness *et al* (2013) as some of the most at risk species to offshore windfarm developments. The objectives are to calculate an estimate for mortality risk by applying Band's model to a test model system comprised of a population of each species breeding sympatrically at South Walney in proximity to existing OREDs, and then to use the population viability analysis software 'VORTEX' in order to estimate the impact of the calculated mortality risk on the size and trajectory of each population. The impact of using national average data rather than site specific data will also be assessed by altering the national average productivity and mortality by plus and minus one standard deviation and observing the impact this has on the calculated growth rate of both bird populations.

Methodology

Study Site and Species

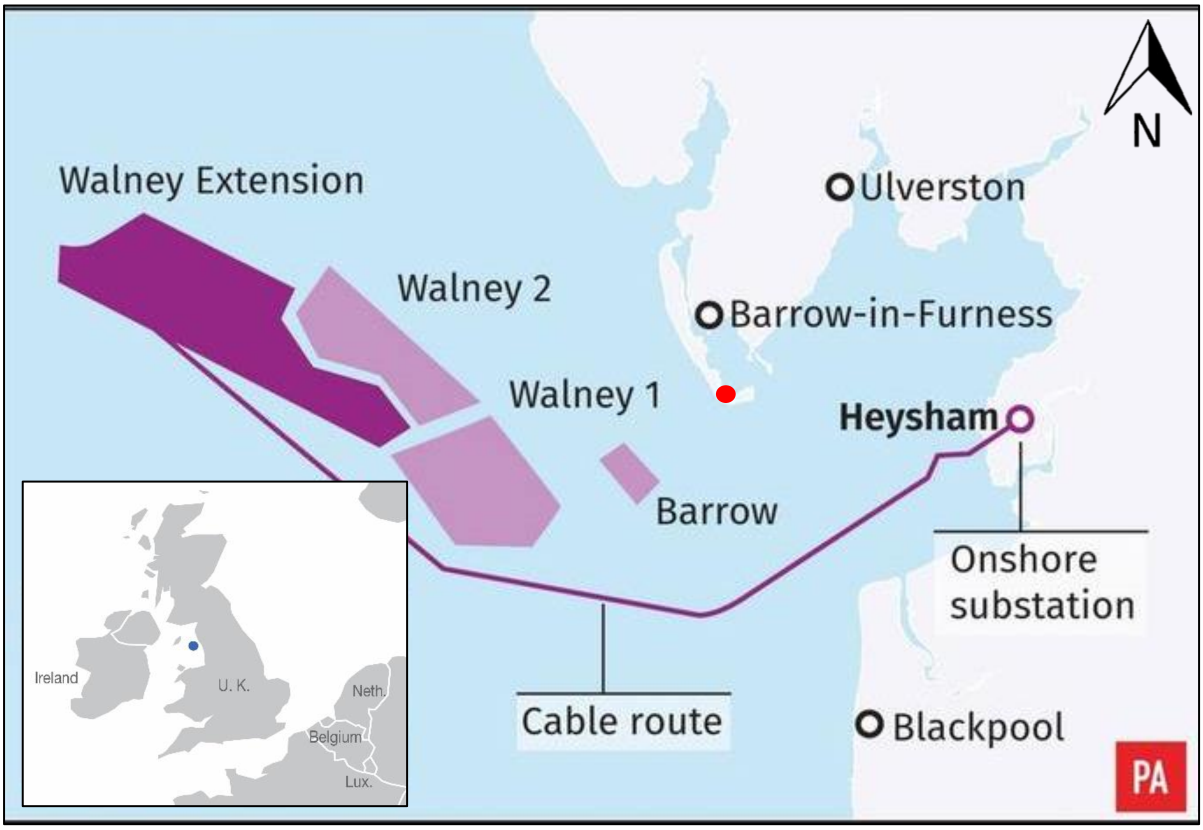

Figure 1. Location of Walney Extension Offshore Wind Farm and South Walney Herring Gull and Lesser Black-Backed Gull breeding site (ITV News, 2018; ABB, 2015). The red circle indicates location of the South Walney Herring Gull and Lesser Black-Backed Gull breeding site.

The study required a wind farm development located within proximity to populations of birds known to show vulnerability to wind farm mortality. For this reason, Walney Extension Offshore Windfarm, located in the Irish Sea approximately 19km west of Barrow-in-Furness in Cumbria, was used as the study site (Figure 1). Inaugurated in 2018, it is the largest offshore wind farm in the world, powering almost 600,000 homes (Orsted, 2018).

The populations chosen to be studied were herring gull and lesser black-backed gull populations breeding at South Walney. The species were chosen as they are known to be some of the most vulnerable bird species to wind turbine collision. Furness *et al* (2013) ranked herring gulls as the most vulnerable and lesser-black backed gulls as the third most vulnerable species out of the 38 listed in their collision index. Furthermore, these populations are known to make use of the area in and surrounding Walney Extension (Thaxter *et al*, 2017; Thaxter *et al*, 2018).

Collision Risk Modelling

Collision mortality estimates of herring gulls and lesser black-backed gulls to Walney Extension offshore wind farm were generated using a collision risk model (CRM) (Band, 2012). Bird data, bird survey data, windfarm data and turbine data were input into the spreadsheet created by Band (2012) which calculates the proportion of birds flying at rotor height, the potential bird transits through rotors, the number of collisions assuming no avoidance and the average collision risk for a single rotor transit. Figures are also calculated which account for a range of possible avoidance rates. The spreadsheet gives estimates of the number of collisions of birds with wind farms per month and per annum.

Bird Data

Table 1 summarises the species biometric parameters and sources used as input data in the bird data section of the CRM, including body length, wingspan, flight speed and nocturnal activity. Collision rates were calculated separately using both flight types (flapping and gliding) since both herring gulls and lesser black-backed gulls are known to perform both flying techniques. Flapping was shown to have a slightly greater impact on mortality rate, therefore these data were used in the results to show a worst-case scenario.

Table 1. Species biometrics used in the collision risk modelling of Walney Extension offshore wind farm

Species	Body Length (m)	Wingspan (m)	Flight Speed (m/sec)	Nocturnal Activity
Herring Gull	0.6 [1]	1.44 [1]	13.4 [2]	3 [3]
LBB Gulls	0.58 [1]	1.42 [1]	14.4 [2]	3 [3]

[1] Robinson (2018)

[2] Pennycuick (2018)

[3] Garthe and Hüppop (2004)

Bird Survey Data

Daytime bird density data in the Walney Extension area (Table 2), derived from boat-based surveys taken from June 2011 to November 2012, were sourced from Ellis and Hazelton (2013). The proportion of birds flying at rotor height (Table 3) was calculated in the spreadsheet using the proportion of birds of each species at 1m flight height intervals (Johnston, 2018). Proportion of flights upwind is also used in the calculations and was set to 50% as it is advised in the Band model guidance that this should be set to 50% "unless survey indicates a predominant direction relative to wind e.g. for large-scale migration flights" which was not the case in this study based on GPS tracking data (Thaxter *et al*, 2017; Thaxter *et al*, 2018).

Table 2. Daytime flying bird density (birds/km^2) in Walney Extension site

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Herring Gull	0.1	0.09	5.54			0	0	0.04	0.04	0.12	0.13	
LBB Gull	0.04	0	6.08		0.34	0.99	0.85	0.08	0.36	2.15	0.52	

- Blanks represent no data collected. Zeros represent data collected but no birds observed.

Table 3. Proportion of birds at collision risk height at Walney Extension (Figures were calculated for the two different sized turbines used in the wind farm)

Species	Proportion at rotor height	
	7.0 MW turbines	8.25 MW turbines
Herring Gull	0.714	0.949
LBB Gull	0.688	0.945

Windfarm Data

The latitude of the Walney Extension (54.088 degrees) was taken from 4C Offshore (2018), as was the number of turbines (87). The latitude is used to calculate the daylight hours for each month, used in determining the daytime activity of the birds. A tidal offset of 2.5 m was used as this data was unavailable for the location and the Band (2012) guidance recommends that 2 to 3 m is typical.

Turbine Data

Table 4 displays the input parameters for the wind farm specifications used within the Band model. The time operational was set to a theoretical maximum as the only information available was the proportion of time operational based on windspeed alone (85%) (Cumbria.gov.uk, 2018). Therefore, the mortality rate calculated does not account for turbine maintenance and downtime. Walney Extension makes use of two different models of wind turbine (40 x MHI-Vestas 8.25 MW turbines and 47 x Siemens Gamesa 7 MW turbines), therefore collision risk models were run for both turbine types and then the end collision rates were calculated based on the findings from of each model and the ratio of turbines installed.

Table 4. Wind turbine specifications for Walney Extension

Input Parameter	8.25 MW turbines	7.0 MW turbines
No. of blades	3	3
Rotation speed (rpm)	10.5 [1]	10.5 [2]
Rotor radius (m)	82 [3]	77 [4]
Hub height (m)	105 [5]	105 [5]
Max. blade width (m)	5.4 [6]	5 [7]
Pitch	30° [8]	30° [8]

[1] Walney Extension Newsletter (2016)
[2] No data available so same value as 8.25 MW turbines used
[3] MHI Vestas Offshore (2018)
[4] Siemens gamesa (2018)
[5] 4C Offshore (2018)
[6] Vestas Wind Systems (2011)
[7] Nader (2016)
[8] No data available. Band guidance recommends that 25-30 degrees is typical (Band, 2012)

Avoidance Rates

The CRM calculates the number of collisions based on various avoidance rates of the birds to the turbines (95%, 98%, 99%, 99.5%). According to Cook *et al* (2014), the recommended avoidance rate for both herring gulls and lesser black-backed gulls is 99.5% as there is evidence of micro-avoidance of turbines in these species.

Population Viability Analysis Modelling

Population viability analysis (PVA) models of herring gulls and lesser black-backed gulls to mortality from the Walney Extension offshore wind farm were carried out using the software VORTEX (Version 10.3.5.0) (Lacy and Pollak, 2017) which simulates survival and reproductive events in sequential years for every individual in a population (Lacy, 2000).

Firstly, demographic information was input into VORTEX to calculate the rate the population is predicted to grow or decline in the next 50 years for both species of birds in the absence of turbines. These were used as baseline scenarios. Secondly, to simulate the impact of mortality from Walney Extension, the percentage mortality (based on an avoidance rate of 99.5%) derived from the collision risk modelling, along with the initial population size, was converted into a reduction in survival rate and added to these models to enable visualisation of the potential impact of the collisions of birds to Walney Extension on the populations. It was assumed that the proportion of birds which were killed remained the same and was independent of population size. The number of iterations used in the modelling was 100. Means ± SD were used in the calculations.

Life History and Population Attributes Data

Tables 5 summarises the parameters and sources used in the PVA for both bird species. The maximum lifespan for herring gulls is for the population in the Netherland and the figure for LBB gulls is for Great Britain and Ireland as data for the South Walney population specifically was unavailable. Maximum age of reproduction for males and females of both species of birds was set to the same as the maximum lifespan as no literature was found which suggested otherwise. The percentage of females breeding was set to 100% which represents a worst-case scenario in terms of the impact of the collisions, but a best-case scenario for the population. The figures used for productivity (offspring per female) are the UK national averages due to a lack of South Walney specific data. The mortality rates shown in Table 5 were converted from survival rates found in the literature and figures for apparently occupied nests in South Walney were doubled to provide an estimate for initial population size of mature individuals of both herring gulls and lesser black-backed gulls.

Table 5. Life history parameters of Herring Gulls and Lesser Black-Backed Gulls used in the Population Viability Analysis

Parameter	Herring Gull Value	LBB Gull Value
Breeding system	Long-term monogamous [1]	Long-term monogamous [2]
Age of first offspring	4 [3]	4 [3]
Maximum lifespan	34 years 9 months [4]	34 years 10 months [4]
Maximum number of broods per year	1 [3]	1 [3]
Maximum number of progeny per brood	3 [3]	3 [3]
Sex ratio at birth (% males)	50	50
Maximum age of reproduction	34 years 9 months	34 years 10 months
Offspring per female ± SD	0.920 ± 0.477 [5]	0.530 ± 0.325 [5]
Mortality (from age 0-1) ± SD	20.2 ± 0.092 [5]	18.0 [5]
Annual Mortality (age > 1) ± SD	16.6 ± 0.034 [5]	11.5 ± 0.022 [5]
Initial population size	5594 [6]	19638 [6]

[1] Fitch (1980)
[2] Dockery and Reiss (1999)
[3] Robinson (2018)
[4] Fransson *et al* (2010)
[5] Horswill and Robinson (2015)
[6] Sellers and Shackleton (2011)

UK National Average Data

UK national average data for productivity and mortality, sourced from Horswill and Robinson (2015), was used in the population viability analysis due to a lack of site specific data. To determine the impact of using this data, the deterministic growth rate of the herring gull and lesser black-backed gull populations without and with wind farm mortality was calculated for: mean productivity, mean productivity plus 1 standard deviation (SD), mean productivity minus 1 SD, mean annual adult mortality, mean adult annual mortality plus 1 SD, mean annual adult mortality minus 1 SD. Standard deviations were unavailable for lesser black-backed gull juvenile mortality therefore only the deterministic growth rate of herring gulls was calculated for: mean juvenile mortality, mean juvenile mortality plus 1 SD, mean juvenile mortality minus 1 SD.

Results

Collision Risk Modelling

Table 6 shows estimates for the number of birds colliding with Walney Extension per year for a range of avoidance rates based on the current population size. The data indicates that the avoidance rate used has a significant impact on the number of collisions per annum for both herring gulls and lesser black-backed gulls, for example, an increase in avoidance by 3% from 95 to 98% causes and reduction in the number of collisions by almost 2.5 times for both bird species. The recommended avoidance rate for both herring gulls and lesser black-backed gulls is 99.5% (Cook *et al*, 2014) which was used for further modelling.

Table 6. Estimated number of birds colliding with Walney Extension wind turbines per year under different avoidance rate scenarios

Avoidance Rate (%)	Collisions per annum	
	Herring Gull	LBB Gull
95	2568	4411
98	1027	1769
99	513	884
99.5	257	442

Table 7 shows the estimated number of birds colliding with Walney Extension per month. For both bird species, most collisions occur in March. Between June and November, the number of lesser black-backed gull collisions is higher than that of herring gulls.

The number of collisions appears to be much higher for lesser black-backed gulls than herring gulls (Table 6 and Table 7). However, the estimated population size of lesser black-backed gulls in South

Walney is over 3.5 times higher than herring gulls, yet the number of collisions for each avoidance rate is on average only 1.7 times higher for lesser black-backed gulls which shows that the wind farm has more than twice the impact on the herring gull population than on the lesser black-backed gull population. The calculated mortality rate of herring gulls is 5.6%, yet the mortality rate for lesser black-backed gulls is 2.6%.

Table 7. Estimated number of birds colliding with Walney Extension wind turbines per month using an avoidance rate of 99.5%

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Herring Gull	4	3	236			0	0	2	1	5	5	
LBB Gull	1	0	233		15	42	36	3	14	80	18	

– Blanks represent no data collected. Zeros represent data collected but no birds observed.

The data displayed in both Table 6 and Table 7 are maximum values based on 85% operation and flapping flight, therefore the true values may be lower.

Population Viability Analysis

Table 8 shows how the number of collisions of both bird species with Walney Extension Offshore wind farm affects the growth rate of the population. It can be seen that the impact upon the herring gull population is estimated to be far greater than the impact on the lesser black-backed gull population growth rate, with the wind farm mortality resulting in a negative growth rate of the herring gull population. Figure 2 further highlights the impact that the wind farm collisions are estimated to have on the herring gull population size in the next 50 years. The influence of the wind farm mortality is estimated to reduce the population size from 5594 to 1216 within 50 years (Figure 2B), a decline of 78 %. The baseline scenarios illustrated by Figure 2A and 3A show steady population growth. Figure 3 illustrates that the influence of collision mortality will cause little impact upon the population size of lesser black-backed gulls in the next 50 years.

Table 8. Deterministic growth rate of Herring Gulls and Lesser Black-Backed Gulls without and with wind farm mortality

	Deterministic growth rate (r)	
	Without wind farm mortality	With wind farm mortality
Herring Gull	0.0287	-0.0289
LBB Gull	0.0237	0.0234

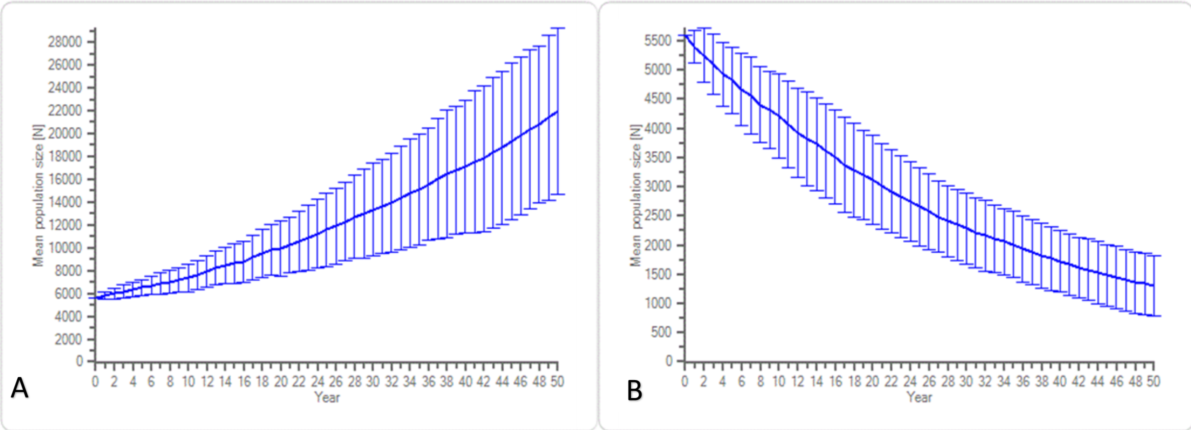

Figure 2. Population growth of Herring Gulls at South Walney (A) without the influence of collisions with Walney Extension Offshore wind farm (B) with the influence of collision with Walney Extension Offshore wind farm

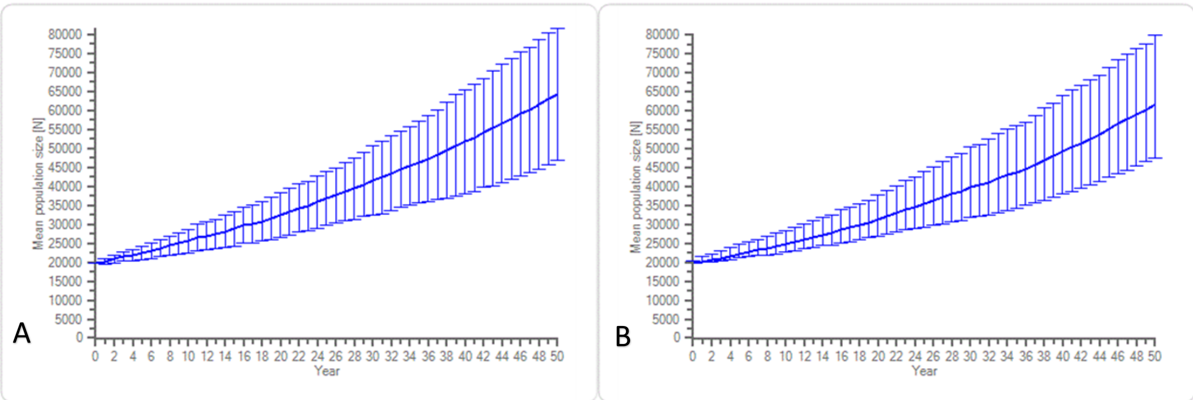

Figure 3. Population growth of Lesser Black-Backed Gulls at South Walney (A) without the influence of collisions with Walney Extension Offshore wind farm (B) with the influence of collision with Walney Extension Offshore wind farm

UK National Average Data

Tables 9, 10 and 11 show that changing the productivity or mortality by just one standard deviation has a large impact on the predicted deterministic growth rates of herring gull and lesser black-backed gull populations breeding at South Walney both without and with wind mortality from wind turbines. Increasing the productivity or mortality by 1 SD causes an increase in the growth rate of the populations, whereas decreasing productivity by 1 SD caused a decrease in the growth rate of the populations. In some cases (highlighted in Tables 9, 10 and 11) changing the mortality or productivity by 1 SD makes the difference between positive a negative growth of the populations.

Table 9. Deterministic growth rate (r) of Herring Gull and Lesser Black-Backed Gull populations without and with wind farm mortality for different productivity figures

	Herring Gull			LBB Gull		
Scenario	Productivity	r without wind farm mortality	r with wind farm mortality	Productivity	r without wind farm mortality	r with wind farm mortality
-1SD	0.443	-0.0499	-0.1075	0.205	-0.0559	-0.0562
Mean	0.92	0.0287	-0.0289	0.53	0.0237	0.0234
+1SD	1.397	0.0827	0.0251	0.855	0.0755	0.0752

Table 10. Deterministic growth rate of Herring Gull population without and with wind farm mortality for different juvenile mortality figures

		Deterministic growth rate (r)	
Scenario	Juvenile mortality (0-1 year)	without wind farm mortality	with wind farm mortality
-1SD	11	0.0422	-0.0154
Mean	20.2	0.0287	-0.0289
+1SD	29.4	0.0141	-0.0435

Table 11. Deterministic growth rate (r) of Herring Gull and Lesser Black-Backed Gull populations without and with wind farm mortality for different adult mortality figures

	Herring Gull			LBB Gull		
Scenario	Adult annual mortality (>1 year)	r without wind farm mortality	r with wind farm mortality	Adult annual mortality (>1year)	r without wind farm mortality	r with wind farm mortality
-1SD[1]	13.2	0.0639	0.0062	9.3	0.0458	0.0456
Mean[2]	16.6	0.0287	-0.0289	11.5	0.0237	0.0234
+1SD[3]	20	-0.0078	-0.0654	13.7	0.001	0.0008

Discussion

The aim of this study was to determine the vulnerability of two sympatric gull populations, herring gulls and lesser black-backed gulls to Walney Extension Offshore Wind Farm. It was found from the collision risk modelling that the South Walney herring gull population is vulnerable to mortality from collision with Walney Extension turbines and the results of the population viability analysis indicate that this mortality is predicted to cause the population to decline dramatically within the next 50 years. In contrast, the effects upon the South Walney lesser black-backed gull population appear to be minor, and it is predicted that the mortality from the wind farm will cause almost no change in the growth rate of the population in the next 50 years.

The findings from the Band models show that avoidance has a significant impact on the number of collisions of birds with wind farms (Table 6), therefore if avoidance is under or overestimated then this will have a large impact on the predicted number of collisions. There are two types of avoidance displayed by birds: ‘micro-avoidance’ and ‘macro-avoidance’. Micro-avoidance is when birds fly through the wind farm, avoiding individual turbines (Cook *et al*, 2012). Alternatively, macro-avoidance is when birds fly around the whole wind farm by altering their flight path (Desholm and Kahlert, 2005). According to Cook *et al* (2012), data on both micro and macro-avoidance is restricted and unreliable due to inconsistencies in avoidance estimates. This is supported by Chamberlain *et al* (2006), whose study found that slight differences in avoidance rates causes relatively significant differences in the predicted number of collisions of Bewick Swans, Golden Eagles and seabirds. They suggested that calculated avoidance rates can often be largely underestimated because surveys are usually carried out in daylight and good weather conditions, factors which are likely to increase the visibility of wind farms to birds and therefore increase the predicted avoidance rate. Additionally, many models do not account for within-individual variation (Cleasby *et al*, 2014), meaning that current avoidance figures and flight height estimates may be unreliable as they do not account for variation in individual behaviour. Furthermore, gulls are often attracted to offshore wind farms because of their feeding opportunities and because they can be used as perches (Fox *et al*, 2006), which may further increase the collision risk as birds per month may be higher. The sensitivity of collision risk models, such as the Band Model, to avoidance rates and the unreliability of current avoidance rate data suggests that work needs to be done to improve avoidance rate estimates, possibly by applying remote sensing such as those designed in the ORJIP BCA study (Skov *et al*, 2018) which focused on developing a bird monitoring system, monitoring bird behaviour (specifically as Thanet Offshore Wind Farm), quantifying empirical avoidance behaviour and the formulation of recommendations of the use of the data in collision risk assessments in offshore wind planning.

The results of the collision risk modelling show that the number of collisions per annum in relation to population size is estimated to have twice the impact on the herring gull population than on the lesser black-backed gull populations (Table 6). This is because the percentage mortality rate for herring gulls is more than two times higher than for lesser black-backed gulls. Possible explanations for this may be the flight heights used. The percentage at rotor height for herring gulls was 0.4% higher than for lesser black-backed gulls (Johnston *et al*, 2014) which may have caused an increase in the predicted number of collisions. According to Furness *et al* (2013), flight height is the most important factor when assessing the collision risk of seabirds with wind turbines. Furthermore, herring gulls are slightly larger than lesser black-backed gulls in terms of body length and wingspan (Robinson, 2018) and herring gulls fly approximately 1 m/sec slower than lesser black-backed gulls (Pennycuick, 2018), meaning that herring gulls appear to be less agile. Furness *et al* (2013), ranks herring gulls as more vulnerable to collisions than lesser black-backed gulls, partly because they are less agile meaning it is more difficult for them to avoid rotating blades. Additionally, the daytime flying bird densities in Walney Extension used in the collision risk modelling were largely similar for both species of birds (Ellis and Hazelton, 2013), despite the lesser black-backed gull population being much larger. This is supported by GPS tracking papers by Thaxter *et al* (2017) and Thaxter *et al* (2018) which show that the herring gull population makes greater use of Walney Extension than the lesser black-backed gull population. The collision risk modelling found that for both seabird species studied, most collisions are predicted to occur in March (Table 7). The breeding season for herring gulls occurs between March and August (Thaxter *et al*, 2017), and for lesser black-backed gulls from April and July (Ross-Smith *et al*, 2014), meaning that most of the collisions occur at the start / pre-breeding season. This may be due to them being less restricted in where they forage when they are not feeding chicks, for example herring gulls mostly feed in nearby mussel beds during breeding and post-breeding (Thaxter *et al*, 2017) but may be able to travel further for food with no chicks to feed. Daytime bird density data was unavailable for April for both species, as well as May for herring gulls. If this is also high there could be further impacts of the wind farm on the populations. The impact of missing data should be considered when permitting the construction of wind farms. Although the South Walney herring gull population is 3.5 times smaller than the lesser black-backed gull population, the number of collisions occurring in March is higher for this species. This adult mortality at the start of the breeding season is likely to be detrimental to the herring gull population as seabirds are long-lived with a reasonably long breeding lifespan and a low annual reproductive output, making them vulnerable to adult mortality (Erikstad et al, 1998).

The results of the population viability analysis, seen in Table 8, shows that the mortality from the wind farm is predicted to have almost no effect on the deterministic growth rate of the South Walney lesser black-backed gull population, displaying steady growth (Figure 3). However, the collisions are predicted to have a negative impact upon the growth rate of the South Walney herring gull population, displaying a dramatic decline in the population (Figure 2). The impacts are worse for herring gulls as there is predicted to be relatively more collisions in relation to population size for this species (Table 6). Although this study has focused on the impact of Walney Extension Offshore Wind Farm, any impacts are additional to those of Walney 1 & 2, which are also located in the Irish Sea, approximately 15km from Walney Island (Ørsted, 2017), making the gulls vulnerable to cumulative risks. This is important when considering that the herring gull breeding population in South Walney decreased from approximately 10,000 in 1998 (Mitchell *et* al, 2004) to 5593 by 2009 (Sellers and Shackleton, 2011). Furthermore, according to Hosey and Goodridge (1980), due to them being so closely related, there is competition between herring gulls and lesser black-backed gulls for breeding territories. Their study found that lesser black-backed gulls are partially migratory, and return to Walney Island after herring gulls have already established their nests. Therefore, this predicted decline in the herring gull population may cause the lesser black-backed gull population to increase as it may be easier for them to breed in the safest territories in terms of avoiding predation.

One of the assumptions of the study was that there is constant mortality, avoidance and collision rates as a proportion of population size. However, this may be inaccurate as GPS studies indicate that not all of the birds enter the wind farm, and those that do are not entering the wind farm all of the time (Thaxter *et al*, 2017; Thaxter *et al*, 2018). Therefore, if an ORED user dies, it may not be replaced by another ORED user and mortality will not be constant. Another assumption of the study is that all of the herring gulls and lesser black-backed gulls making use of Walney extension are from the South Walney population. Therefore, in reality, the impact upon the growth rate of the South Walney populations in the next 50 years may be less than calculated in this study. A limitation of the demographic data used for both bird populations is that the UK national average survival rates were used to find out the mortality rates for the population viability analysis, as well as the national average productivity, due to a lack of site specific data for bird survival (Horswill and Robinson, 2015). The actual site specific data might be significantly higher or lower than the national average data used and Tables 9, 10 and 11 highlight that altering the productivity and mortality used in the study by just 1 standard deviation causes an increase or decrease in the calculated deterministic growth rates. This indicates that more research needs to be done to ensure that accurate site specific data for productivity and survival is available for assessing the population level impact of wind farms on seabird species. This may be difficult for survival rates in particular as obtaining survival data takes time and it would need to fit in with current EIA timescales. The maximum lifespan used for herring gulls may also be inaccurate as there was no site specific data or UK data available, therefore the lifespan of populations in the Netherlands was used (Fransson *et al*, 2010). Additionally, the study used a theoretical maximum proportion of time operational (Cumbria.gov.uk, 2018) for the wind farm, which did not include downtime and maintenance, again due to a lack of data. Therefore, the mortality rate may be much lower in reality.

This study used data collected from boat-based surveys in the collision risk modelling, however future work should incorporate GPS data to more accurately assess the number of birds using the wind farm and to which populations they belong. The results of the study indicate that although the impacts of offshore wind farms seem small, there could be long-term impacts. This highlights that more research need to be carried out to ensure population size of bird species will not be affected in the future when designing and permitting offshore wind farm projects to go ahead. Specifically, more research needs to be carried out to ensure per colony data on avoidance and tracking, productivity and survival is accurate, and ensuring that there are no gaps in survey data.

Conclusion

It can be gathered from this study that herring gulls appear to be more vulnerable to mortality from offshore wind farm developments than lesser black-backed gulls. Flight height and daytime bird density appear to be the main factors that make herring gulls more vulnerable. Avoidance has a large impact on the estimated number of birds colliding with the wind farm and this needs to be taken into account when assessing the vulnerability of populations to proposed wind farm developments. Furthermore, using unreliable national average productivity and mortality/survival data can have a large impact on the calculated impact on population growth, therefore there is a need for more research into site specific figures for future studies. The number of collisions appears to be small for herring gulls, however the study found that it could cause the population to decline dramatically within the next 50 years. This is likely to be due to the vulnerability of seabird populations to adult mortality. Therefore, there needs to be more consideration to population level impacts when developing offshore wind farms. This is relevant now more than ever as energy from offshore renewable sources is becoming more popular.

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SKILLS	**How used/enhanced during dissertation**
1. Subject-specific Knowledge	Developed an understanding of the behaviour, ecology and population vulnerability of two sympatric gull species to offshore windfarm developments.
2. Subject-specific Skills	Used industry-standard quantitative approaches in order to analyse data. (Collision Risk Model and Population Model)
3. General Skills and Attributes	
a) **Self-management**	Developed self and time-management skills by creating and sticking to a timetable in order to ensure that the project was completed in time.
b) **Positive attitude**	Dealt with any setbacks or challenges when faced with them by maintaining a positive outlook e.g. a lack of data and failing models.
c) **Problem solving**	Analysed data in order to come up with possible explanations and conclusions about the vulnerability of the two species to windfarm developments. Fixed any broken/failing models.
d) **Teamworking**	Worked with my dissertation supervisor in order to design a relevant and achievable research project.
e) **Communication and literacy**	Presented my research clearly, precisely and succinctly, in the format of a short paper (5000-6000 words), in order to communicate with the appropriate audience.
f) **Application of numeracy**	Carried out the relevant calculations for a Collision Risk Model and Population Model in order to analyse data.
g) **Application of information technology**	Used a range of software to carry out my analysis such as VORTEX, EXCEL .etc.
h) **Business and customer awareness**	N/A
i) **entrepreneurship/ enterprise**	N/A