BTO Research Report No. 580

Identifying a Range of Options to Prevent or Reduce Avian Collision with Offshore Wind Farms using a UK-Based Case Study

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EXECUTIVE SUMMARY

1. This project aims to review and evaluate potential mitigation options for preventing or reducing avian collisions with offshore wind farms. Offshore wind farms may potentially affect bird populations through the displacement of birds due to the disturbance associated with developments, the barrier they present for migrating birds and birds commuting between breeding sites and feeding areas, habitat change or loss and through collision mortality.

2. The work has four main objectives:
i. To review current avian collision mitigation options, both national and international;
ii. To identify existing and novel mitigation methods that could be used to minimise avian collision;
iii. To identify which bird species, native and migratory (including breeding units and breeding / overwintering populations), are considered most at risk in UK waters, with the view to identifying key species for cumulative assessment;
iv. To model the cumulative risk of avian collision in wind farms and, where sufficient information exists to parameterise the models, model this risk against a range of mitigation options to determine which is most successful, using the Greater Wash as a UK case study.

3. A range of technologies and techniques have been proposed to reduce bird collisions within different sectors. Few have been tested extensively on either onshore or offshore wind farms. In the UK, the majority of measures implemented to reduce collision rates relate to the siting, orientation and spacing of turbines. Ten novel measures were selected for further analysis. These were evaluated in the context of their technical feasibility, implementation and operational costs and effectiveness in reducing the risk of bird collision rates. This evaluation is summarised below.

Mitigation option[1]	Feasibility	Cost	Effectiveness
Temporary shut-down	Medium	High	High
Reducing motion smear – anti–motion–smear patterns	High	Low	Medium
Reducing motion smear – lower rotor speed / larger turbines	Medium	Medium	Medium
Increasing visibility through use of ultraviolet paint / material	High	Low	Low
Increasing visibility through use of lighting, e.g. strobe lights	Medium	Low	Low
Minimal use of lighting	Low	Low	Medium
Laser deterrents	Medium	Medium	Medium
Structural modifications – decoy towers	Medium	Medium	Low
Remote population monitoring - radar, infra-red, pressure / vibration sensors, acoustic detection, etc	Medium	Medium	High
Auditory deterrents	Medium	Low	Low

[1] See section 2.3 for full description of mitigation options.

4. The risk or vulnerability of species to the effects of developments, such as offshore wind farms, reflects the combination of both species' sensitivities and exposure to these effects. In this review, we thus first consider which UK species are likely to be most sensitive to the effect of collision mortality with offshore wind farms in UK waters, before then considering which species might be exposed to this effect as a result of Round 1 and 2 developments,

potential Round 1 and 2 extensions, Round 3 sites, and sites planned for Scottish Territorial Waters.

5. Three previous studies have appraised the sensitivities of bird species to the effects associated with offshore wind farms. Garthe and Hüppop (2004), and King *et al.* (2009) which follows that study, determined a Species Sensitivity Index (SSI) considering aspects relating to all the potential effects posed by offshore wind farms. Langston (2010) used a three-level categorical system to define species' sensitivities to 'Collision risk', 'Displacement', 'Barrier', and 'Habitat/Prey' effects, and a score for species' conservation status, and from these scores derived a species-specific value for 'Overall Risk'.

6. Comparison of the scores related to collision risk from these studies reveals a good level of accord. Given this close correlation, we defined the species that are sensitive to the effect of collision mortality with offshore wind farms in UK waters as those having High or Moderate Collision Risk scores according to Langston (2010). This provided a total of 31 species or species' populations (17 seabird species, 13 wildfowl species or species' populations and one terrestrial species).

7. For the 17 seabird species sensitive to the effect of collision mortality with offshore wind farms in UK waters, we produced maps showing the species' foraging ranges from SPAs and their at-sea-distributions (from European Seabirds at Sea data) showing their exposure to offshore wind farms (Figures 3.3.3 to 3.3.34).

8. Whether due to their foraging ranges from SPAs, or due to their presence in wind farm development zones at times of year that these species are not associated with SPAs, or due to their migration routes, all 31 sensitive species are potentially exposed and thus should be considered vulnerable to the risk of collision with Round 1 and 2 developments, potential Round 1 and 2 extensions, Round 3 sites, or sites planned for Scottish Territorial Waters. However, six species – the Greylag Geese and Corncrake which breed in northwest Scotland, and Pomarine Skua, Long-tailed Skua, Iceland Gull and Glaucous Gull which are only present in UK waters in small numbers – probably face limited exposure to offshore wind farm development zones and should thus be considered to be less vulnerable to collision mortality. Effects on other species, such as the waders and wildfowl considered by King *et al.* (2009) should also not be discounted.

9. Following the results of the review, we investigated how the cumulative risk of avian collision within wind farms might be affected by the shortlisted mitigation options, using the Greater Wash as a case study. Seven options were considered – minimal use of lighting and auditory deterrents not being taken forward due to their respective low feasibility and effectiveness. Remote population monitoring is an approach that would be used in conjunction with other options, such as temporary shutdown, to maximise their effectiveness and thus was not considered directly in this chapter.

10. Mitigation options may operate in a number of different ways, though in the majority of cases by increasing the level of avoidance of wind turbines. As the literature review summarised, relatively little is known as to how effective different measures may be in increasing avoidance and thus it is unlikely to be possible to compare with precision the different short-listed options. Further, there is still a large degree of uncertainty about the level of avoidance of wind turbines that birds demonstrate. The effects of temporary shut-down and changes to turbine design, in contrast, can be more easily quantified. Thus the modelling exercise undertaken here aimed to identify the most promising mitigation measures, along with those that require further work to confirm their value.

11. The model of Band *et al.* (2007) was used to quantify the cumulative collision-related mortality of seabirds resulting from offshore wind farms in the vicinity of the Greater Wash, using data collected during Environmental Impact Assessments of the area. In order to demonstrate the efficacy of any mitigation measures, a range of avoidance rates were considered. Population Viability Analysis (PVA) was also used to model the impact of increased mortality on the populations of seven species of seabird – Northern Gannet, Common Tern, Sandwich Tern, Lesser Black-backed Gull, Black-legged Kittiwake, Common Guillemot and Razorbill – which breed in the area.

12. In terms of overall mortality rates, the greatest cumulative impacts were estimated for Northern Gannet and Lesser Black-backed Gull with an additional 220 and 238 mortalities respectively, assuming a 99% avoidance rate. Results from PVA suggest that, assuming a 99% avoidance rate, populations of Northern Gannet and Common Tern were most likely to be affected by the increased mortality associated with collisions with wind turbines.

13. The potential effect of the short-listed mitigation options on avian mortality rates was then considered in light of these results. Based on the available evidence from the literature, changes to lighting would be among the most effective of mitigation options, though legislation limits what might be achievable. The use of lasers is most likely to be effective at night, whilst ultra-violet paint is most likely to be effective during the day. The use of decoy towers has shown promise, but would only be effective for certain species, such as seaduck, divers and auks which are themselves less prone to collisions. A temporary shut down of turbines is likely to be highly effective, but financial constraints are likely to highly restrict the length of shut down periods. Targeted shut downs for restricted key periods, perhaps further restricted to times of day when key species are most active, represent a possible option given these constraints and would be worth exploring on a site by species basis. No single measure is likely to be effective at reducing collisions for all species at all times, consequently combinations specifically targeted to the species recorded within each wind farm are likely to prove the most effective mitigation strategy.

GLOSSARY

AHAS	Avian Hazard Advisory System
AVOIDANCE RATE	The rate at which birds take action to avoid collisions with wind turbines
BSI	Bird Strike Indicator
BAM	Bird Activity Monitoring
BAND MODEL	Collision risk model developed by Band *et al.* (2007)
BARRIER EFFECT	A wind farm acting as a barrier to birds which would otherwise pass through the area
BTO	British Trust for Ornithology
CAA	Civil Aviation Authority
COLLISION RATE	The rate at which birds collide with wind turbines
COLLISION RISK MODEL	A model to predict the likelihood of birds colliding with wind turbines
COWRIE	Collaborative Offshore Wind Research into the Environment
CUMULATIVE IMPACT	The total number of birds affected across all wind farms
DECC	UK Department for Energy and Climate Change
DECOY TOWERS	Towers placed round the perimeter of a wind farm to deter birds from entering, as outlined by Larsen & Guillemette (2007).
DEFRA	UK Department for Environment, Food and Rural Affairs
DISPLACEMENT	Birds which previously used the area occupied by the wind farm, which no longer do so due to the presence of the turbines
EIA	Environmental Impact Assessment
ESAS	European Seabirds at Sea
EU	European Union
FAA	United States Federal Aviation Authority
FLYSAFE	European Space Agency bird avoidance model
GAO	United States Government Accountability Office
GIS	Geographic Information System

GPS	Global Positioning System
IALA	International Association of Lighthouse Authorities
IBA	Important Bird Area
JNCC	UK Joint Nature Conservation Committee
MET OFFICE	UK Meteorological Office
NGO	Non-Governmental Organisation
PVA	Population Viability Analysis
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SPA	Special Protection Area
SSI	Species Sensitivity Index
TADS	Thermal Animal Detection System, developed by Desholm *et al.* (2006)

1. INTRODUCTION

The Climate Change Act 2008 sets a target of an 80% reduction in greenhouse gas emissions below a 1990 baseline by 2050. The expansion of renewable energy is seen as integral to meeting these targets and consequently there has been considerable expansion and development in offshore wind farms in recent years.

As more wind farms are being built, concerns are increasing about in-combination impacts to bird populations. Offshore wind farms may potentially affect bird populations through the displacement of birds due to the disturbance associated with developments, the barrier they present for migrating birds and birds commuting between breeding sites and feeding areas, habitat change or loss and through collision mortality (Drewitt & Langston 2006). The cumulative or in combination effects across wind farms are of particular concern, as, multiplied, these effects have the potential to lead to significant population reduction (Langston 2010).

The principal available options for mitigating these negative effects aim to reduce the risk of collisions and include the enforcement of a mandatory shut down of some or all wind turbines within a wind farm during certain periods (e.g. migration or breeding seasons). Shut down periods can seriously impact the financial viability of wind farm proposals and can lead to the withdrawal of funding, potentially halting the future expansion of offshore wind farms. Other existing mitigation options include alternative placement of the wind farm and habitat enhancement elsewhere.

Alternative methods, more acceptable to industry and regulators alike, will enable wind farm development to go ahead in a sustainable manner. Identifying novel mitigation methods that enable development to go ahead will also give regulators the opportunity to collect more robust and site specific assessments of the in-combination effects, if any, of these developments on birds as more wind farms come on-line.

The objectives of this work are thus:

1. To review current avian collision mitigation options, both national and international.

2. To identify existing and novel mitigation methods that could be used to minimise avian collision.

3. To identify which bird species, native and migratory (including breeding units and breeding / overwintering populations), are considered most at risk in UK waters, with the view to identifying key species for cumulative assessment.

4. To model the cumulative risk of avian collision in wind farms and, where sufficient information exists to parameterise the models, model this risk against a range of mitigation options to determine which is most successful, using the Greater Wash as a UK case study.

The outputs of the work undertaken to address the objectives identified above will be of use to offshore wind farm developers, their consultants and assist statutory nature conservation bodies and regulators form the basis for the application of conditions during the licensing of offshore wind farms. The outcome of this study is also aimed at providing measures to mitigate the in-combination risk of avian collision associated with both existing and planned offshore wind farms

2. IDENTIFYING A RANGE OF OPTIONS TO PREVENT OR REDUCE AVIAN COLLISION WITH WIND TURBINES

2.1 Objective 1: Review current avian collision mitigation options, both national and international

2.1.1 Literature review

In conjunction with the BTO, AEA undertook a review of the current literature on national and international avian collision mitigation options, with a view to identifying those mitigation options that offer the most promising reductions in avian collision risk. The study differentiates between methods that are in use, those that are undergoing testing and new untested approaches.

- Mitigation options include design, technological and operational solutions to avian collision.
- The options presented apply to offshore wind, onshore wind, other renewable energy, radar, waste management facilities, aviation, architecture, power lines, offshore oil and gas, road traffic and lighthouses.
- We considered mitigation options that are in use, undergoing testing or new/novel and untested.

2.1.2 Search parameters

Our search for information has been limited to material published since 2000, since this should encompass discussion prior to the first large-scale offshore wind farm being commissioned at North Hoyle in December 2003. We have gathered information by:

- Reviewing publications including academic literature and journals, conference proceedings and books via Google Scholar, Scopus and the Web of Science, to identify the wider relevant peer-reviewed and accessible grey literature. The Centre for Evidence-Based Conservation and the Index to Theses (http://www.theses.com), where almost all MSc and PhD theses from Britain and Ireland are indexed, were also checked although the latter source did not produce many extra references. AEA has also made use of paid subscriptions to various institutions, libraries and news services such as ScienceDirect and RenewableUK.
- Reviewing the “grey literature” relating to ongoing work commissioned by policy-makers (DEFRA, DECC, Scottish Government, EU, etc.); by NGOs (e.g. RSPB, Birdlife International); and in industry (COWRIE), etc.

Different ‘key words’ were targeted in these searches; some concentrated on technical terminology and others behavioural science terminology. Once searches in these areas were exhausted, we checked our results to find possible gaps and ascertained whether there were any further key word searches which could be run to fill these gaps. We also studied analogous areas which have experienced avian collision, for example buildings, aeroplanes and power lines to see what mitigation solutions they may have offered. For ScienceDirect for example, the ‘advanced search’ feature was used. The table below shows that some search combinations resulted in large numbers of references being retrieved. Where necessary, these were further filtered to identify the most valuable sources for the purposes of this project.

Table 2.1.2.1 Search parameters used in ScienceDirect searches

Search 1	**Mitigate** OR **reduce** AND **bird impacts** OR **bird collision** OR **avian impact** OR **avian collision** (1,814 articles found)
Search 2	**Mitigate** OR **reduce** AND **bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impact** OR **avian collision** OR **avian mortality** (3,857 articles found)
Search 3	**Mitigate** OR **reduce** AND (bird impacts OR bird collisions OR bird mortality OR avian impacts OR avian collision OR avian mortality) AND wind turbines (54 articles found)
Search 4	**Mitigate** OR **reduce** AND (bird impacts OR bird collisions OR bird mortality OR avian impacts OR avian collision OR avian mortality) AND offshore wind turbines (26 articles found)
Search 5	**Mitigate** OR **reduce** AND (bird impacts OR bird collisions OR bird mortality OR avian impacts OR avian collision OR avian mortality) AND waste OR landfill (682 articles found although a brief look at the results show that most are not relevant)
Search 6	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **aviation** OR **airport** OR **aeroplane** (200 articles found)
Search 7	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **architect** OR **building** OR **window** (1,265 articles found)
Search 8	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND (**electric** OR **power**) AND **line** (968 articles found)
Search 9	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **oil** OR **gas** (1,395 articles found)
Search 10	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **road** OR **traffic** OR **vehicle** (1,331 articles found)
Search 11	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **lighthouse** (20 articles found)
Search 12	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **migration** OR **roost** OR **feed** (2,328 articles found
Search 13	**Mitigate** or **reduce** AND (**bird impacts** OR **bird collisions** OR **bird mortality** OR **avian impacts** OR **avian collision** OR **avian mortality**) AND **radar** (76 articles found)

Table 2.1.2.2 below shows the search phrases used in Web of Science and Google Scholar and the number of useful hits (i.e. papers, reports and conference proceedings relevant to this work) produced. The search was restricted to the years 2000-2010. Individual papers may appear as a "hit" under several search phrases.

Table 2.1.2.2 Search parameters used in Web of Science and Google Scholar searches

Detailed search phrase	**Initial broad search phrase[1]**		**Comment**
	(Wind farm* OR Offshore* OR Collision*) AND (Avian* OR Bird*)		
	Web of Science	**Google Scholar[2]**	
cumulative	5	INCOMPLETE	
mitigation*	15	INCOMPLETE	
casualt* OR injur*	8	INCOMPLETE	
temporary shutdown	0	3	
shutdown	0	6	
reduc* rotor speed	2	31	
timing OR construction OR maintenance	15	36	
sit* OR design OR layout OR corridor*	22	1	
foraging area* OR bait station*	8	3 [2]	
struct* modification*	1	5	
visibility	4	30 [2]	
ultraviolet OR UV	1	5 [2]	
light* OR strobe	7	8	
deflector* OR mirror*	0	1	
auditory deterrent*	0	5	
sound deterrent*	0	2	
visual deterrent*	1	5	
low frequency sound*	0	6	
infraso*	0	1	"infrasound" and "infrasonic" also used
ultraso*	0	1	"ultrasound" and "ultrasonic" also used
noise reduction*	1	7	
turbine noise	2	24	
noise	3	27	
chemical deterrent*	0	9	
behavio* deterrent*	0	12	UK and US spellings covered
radar-activat* deterrent*	0	INCOMPLETE	
deterrent*	0	INCOMPLETE	
turbine design*	2	INCOMPLETE	
turbine number OR configuration	INCOMPLETE	INCOMPLETE	
paint patterns	INCOMPLETE	INCOMPLETE	
flight diverter* OR line marker*	INCOMPLETE	INCOMPLETE	

[1] A * indicates that also other suffixes (i.e. the plural "s" and the genitive "'s") are included.
[2] In Google Scholar further restrictions were commonly used when the initial number of records >500. In these instances (marked with [2]), we excluded papers with the words "bat(s)" and "mammal(s)"

The results of the literature review are included in Appendix 1.

The desk–based literature review has provided us with details of the key features of the mitigation options; the issues encountered in their application; their role in reducing avian collision; and the key success factors.

At this stage we prepared a series of tables illustrating the features of each mitigation option found, including, where information was available, detail on the costs / cost–benefits of avian collision control methodologies or technologies. These are presented (for the short-listed options) in Section 2.4.1 and Appendix 4 (for the non-selected options).

2.1.3 Telephone interviews

A number of key contacts from NGOs, trade associations and commercial organisations were asked to participate in a short telephone interview to allow us to gain a more complete understanding of:

- Current guidance and information sources on avian collision and mitigation options
- Operational experience with mitigation options
- Extent of available data (from research / monitoring projects)
- Novel methods that could be employed by the offshore wind industry

Contacts were selected on the basis of:

- their understanding of mitigation options and of applying measures in practice (for developers, consultants, turbine suppliers and wind farm designers);
- experience of policy and research related to the field (for regulators); or
- scientific research related to the field (researchers).

The interview questions are provided in Appendix 2.

2.2 Objective 2: To identify novel mitigation methods against avian collision

In consultation with DEFRA and with inputs from the project team, AEA built on the work under Objective 1 to draw up a list of up to 10 mitigation options that have not been used in a commercial setting.

In order to assist with future policy decisions, we evaluated each novel mitigation option for its potential using the following criteria:

2.2.1 Feasibility

The list of options generated in Objective 1 arose from a variety of sectors and are at different stages in the development process. The first question to be asked, therefore, is whether the evidence suggests that the measure could be applied in an offshore setting. A mitigation option is considered feasible if no major technological or operational barriers to use have been identified, or if any such barriers have been addressed. As an example, anti-motion-smear paint patterns are scored as ‘high’ for feasibility because this would be a relatively simple option to implement.

2.2.2 Cost of implementation / operation

This criterion takes into account the business interests of the wind sector, by considering the financial impacts of each mitigation measure. Suggested measures that require significant capital expenditure or add substantially to the operating costs will be less attractive to wind industry stakeholders. Low- or no-cost options are therefore of particular interest. Whilst painting turbine blades to increase their visibility is an inexpensive approach (though it is accepted that such measures may be unacceptable to other sea users because of, for example, visual impacts), options such a temporary shut-down are less attractive because of the direct impact on revenue for the operator.

2.2.3 Effectiveness

This applies to the expected reduction in avian collision: the primary interest of this project. Where possible, empirical evidence has been used to define collision avoidance rates. However, such evidence is scarce, and more qualitative descriptions are also used to describe the effectiveness of each measure. It is relatively well-established, for instance, that temporary shut-down is effective in reducing collision risk. The evidence surrounding auditory deterrents meanwhile is less conclusive, because of factors such as potential habituation and background noise at sea.

Each criterion was assigned a score (high / medium / low) to give an amalgamated qualitative value for the potential of each option.

The data-sheets for each shortlisted option, outlining the principles of the technique / technology, beneficial features for reducing avian collision and evaluation data, are presented in Section 2.4.1.

2.3 Results - Objective 1: Review current avian collision mitigation options, both national and international

2.3.1 Literature review

The majority of past research / literature on avian mortality as a result of collision has focused on power lines and communications towers, and more recently on onshore wind. For onshore wind, in the United States, these studies were prompted because of the relatively high number of raptors that were found dead at the Altamont Pass Wind Farm near San Francisco, California, beginning in the 1980s. It has only been in recent years that research organisations, universities, and consultants have begun to conduct studies on avian mortality as a result of offshore wind turbines.

The literature review undertaken as part of this study details avian collision mitigation techniques for onshore and offshore wind turbines, power lines and communications towers, and those related to specific bird species. In some cases, information about bat species is also included, as they are at risk of encountering turbines whilst in flight, much as birds do. However, the main causes of mortality in the two taxa are very different: whilst birds are killed as a result of direct collision with the turbine structure, bats may be killed by the severe change in air pressure around turbines causing internal injuries. Consideration is given through the review to aspects of birds' vision and perception of obstacles (see Martin in press).

2.3.1.1 Temporary shut-down

- In a global case study of the effects of wind farms on birds, Keil (2005) examined the most commonly used mitigation and monitoring techniques, then discussed other considerations including offshore versus onshore wind farms and their differences in impacts and problems. The case studies showed that turbine shut-down during peak migration movement can be instituted at any wind farm and does not necessitate the shutting down of all turbines. Commonly, only the turbines that are directly in the migration path need to be stopped.

However, to utilise this type of mitigation, a detailed understanding of the migration patterns of the bird species in the area is necessary.

- When considering the impacts of onshore wind farms on wildlife, the United States Government Accountability Office (GAO) (2005) found anecdotal evidence suggesting that turning off turbines during nights with low winds during spring and autumn migration (i.e. nights with high numbers of birds migrating and little energy gain due to lack of wind) reduced numbers of avian collisions.
- In their study of the collision effects of offshore and onshore wind turbines and other obstacles (communication towers; buildings and windows; power lines and fences), Drewitt and Langston (2008) stated that, while the effectiveness of temporary turbine shut-down is not yet known, it is reasonable to assume that stationary rotor blades are likely to pose less of a hazard to flying birds than rotating blades. This technique was deemed controversial to developers due to productivity losses.
- In a study on bat fatalities, Baerwald *et al.* (2009) found that, by increasing the rotor start-up wind speed at some turbines, the amount of time these turbines produced electricity was reduced by an average of 42.3%. The study looked at operational parameters of 21 turbines at a site with high bat fatalities in south-western Alberta, Canada, and showed a significant reduction in bat fatalities, due to blades being near motionless in low wind speeds.
- Temporary shut-down (for 2 months during winter migration) of half the turbines at Altamont was proposed in 2005 in response to high bird mortality, particularly of raptors (Lowitz 2009). However, there is little documented evidence of the effectiveness of this approach.
- Research into Marbled Murrelet (*Brachyramphus marmoratus*) in the United States (Nations and Erickson 2009) found that temporary shut-down for 64% of the time reduced collision risk by 50 – 60%.
- When testing the effectiveness of changing the cut-in speed of 12 onshore wind turbines to reduce bat fatalities at wind facilities in Pennsylvania, USA, Arnett *et al.* (2010) found that total fatalities at fully operational turbines were estimated to be 5.4 times greater on average than at curtailed turbines. 82% of all fatalities at curtailment turbines likely occurred when the turbines were fully operational. However, there was no difference between cut-in speed of 5.0 and 6.5 m/s.
- In Bulgaria, temporary shut-down when large groups of birds approach has been used as a mitigation measure at the Saint Nikola wind farm (Foote, 2010) though, again, there is little documented evidence of its effectiveness.
- Overnight shut-down to decrease bat mortality has been estimated to decrease productivity by 1%. The approach has been tested at Garrett, Pennsylvania by Arnett (Curry, 2010).
- Market rates plus compensation paid to wind companies to shut down so as to control inputs to the National Grid (Mendick 2010) could give an indication of the costs to operators of this measure.

2.3.1.2 Reducing motion smear – anti-motion-smear patterns

- Motion smear occurs when an object (such as the rotating blade of a wind turbine) is moving too fast for the brain to process separate images from the retina. The image becomes blurred and, at faster speeds, may appear transparent. Anti-motion-smear paints use painted patterns on the blades to break up the image and allow the retina to detect individual blades more readily. As birds approach a moving turbine blade, the retinal image moves faster, creating motion smear (Hodos, 2003).
- Results of a study by Hodos *et al.* (2000) on comparison of different blade patterns strongly suggests that a thin-stripe, staggered, anti-motion-smear pattern is the most visible of those tested and a single black blade would be a close second in terms of visibility. A further study by Hodos (2003) suggested that a blade coloured in a single solid colour would have poor

visibility against certain backgrounds. However, it goes on to recommend field testing a single-blade, solid-black pattern rather than a thin stripe pattern because of the additional expense required in developing a precision pattern. Trials in the US showed some reduction in fatalities, but a formal study to determine effectiveness was not conducted (W. Hodos pers. comm.).

- When considering the impacts of onshore wind farms on wildlife, the United States Government Accountability Office (2005) encountered mixed results from different studies to reduce motion smear by painting the turbine blades with normal or ultraviolet paint. These ranged from a small effect to having no effect on collision rates.

2.3.1.3 Reducing motion smear –rotor speed / turbine size

See also section 2.3.1.12 on varying the size or number of turbines.

- Reducing the rotor speed can reduce the incidence of motion smear. Reduced rotor speed means that the tip of the blade is travelling less fast and therefore the velocity of the retinal image is reduced. A larger turbine is, in itself, more visible. However, the tip of a larger blade has to travel faster than that of a small blade rotating at the same speed (because it is covering a larger circumference). Therefore the retinal image is correspondingly increased, leading to motion blur (Hodos 2003). As birds approach a large turbine, the problem of motion blur may be further aggravated by the tips of the blades being outside their peripheral vision.

2.3.1.4 Increasing visibility - use of ultraviolet paint / material

- In a review of research into avian collision and mitigation methodologies, Curry and Kerlinger (2000) found that painting turbine blades with high contrast and ultraviolet paint may influence flight behaviour around wind turbines, but suggested that more research was needed.
- Young *et al.* (2003) examined the effects on bird use and mortality of painting wind turbine blades with ultraviolet-reflective paint at the Foote Creek Rim Wind Plant in Carbon County, Wyoming, USA. The study estimated spatial and temporal use and behaviour of birds near turbines with blades coated with ultraviolet-reflective paint versus those coated with non-ultraviolet-reflective paint. It then compared the number of carcasses found near turbines that had blades coated with ultraviolet reflective paint versus those coated with non-ultraviolet-reflective paint. The study did not provide strong evidence that there was a difference in bird use, mortality, or risk between turbine blades painted with an ultraviolet-light reflective paint and those painted with conventional paint.
- One study (Klem, 2009) investigated the efficacy of utilising ultraviolet reflective material to make birds aware of glass being present. It showed that uniformly covering windows with decals or other objects that are separated by 5 to 10 cm was completely or near-completely effective in preventing strikes. Twice the number of window strikes occurred at non-reflective sheet glass compared to conventional clear panes. This is currently still undergoing testing.
- Increasing visibility of turbines may not be effective if birds are searching for food or roosting sites. Martin and Shaw (2010) demonstrated that birds with narrow or small binocular fields may not have good vision in the direction of flight when looking downwards, having significant implications when considering visual clues as mitigation options (see also Martin in press).

2.3.1.5 Increasing visibility - use of lighting

- Current mandatory requirements for offshore structures require low-intensity lighting and identification characters should be visible to observers 3 metres above sea level and at least 150 metres from the turbine (Maritime and Coastguard Agency, 2008a). Synchronised flashing yellow lights, visible from all horizontal directions, are required at the corners of the wind farm (IALA, 2004). All peripheral turbines to be fitted with a steady red light at the top of the structure to comply with aircraft navigational requirements (CAA 2010a), although this may change in future to flashing red lights (CAA 2010b).
- Lighting appears to be the single most critical attractant to wind turbines, and preliminary research indicates that solid and pulsating red lights seem to be more attractive to birds at night during inclement weather conditions than are white strobe lights (Erickson *et al.* 2001).
- Another study (Clarke 2004) noted that strobe lights and laser deterrents were the two methods that had the highest potential for being useful in an autonomous, minimal disturbance bird deterrent system.
- When investigating collision risks and modelling the potential collision rates of specific species at an offshore wind farm, Desholm (2006) concluded that white strobe lights were likely to be less risky than white or red blinking lights.
- A study by Poot *et al.* (2008) explored the finding that many nocturnally migrating birds die or lose a large amount of their energy reserves during migration as a result of encountering artificial light sources. Their study found that the birds were particularly disoriented and attracted by red and white light (containing visible long-wavelength radiation), whereas they were clearly less disoriented by blue and green light (containing less or no visible long-wavelength radiation). The results clearly open possibilities for the development of bird-friendly artificial lighting by manipulating wavelength characteristics.
- Gehring *et al*. (2009) determined the relative avian collision risks posed by different United States Federal Aviation Administration (FAA) communication tower lighting systems. They compared fatalities at towers with different systems: white strobe lights only; red strobe-like lights only; red, flashing, incandescent lights only; and red, strobe-like lights combined with non-flashing, steady-burning, red lights. They found that avian fatalities could be reduced by 50–71% at guyed communication towers by removing non-flashing/steady-burning red lights.
- Manville's (2009) review of work on lighting of communication towers explored the impact of red light on birds' use of magnetoreception for navigation, noting that the impact would be dependent on weather conditions and the extent to which birds were using magnetoreception. The Federal Communications Commission has recommended removal of steady-burning lights on new towers or where retrofits have been implemented.

2.3.1.6 Minimal use of lighting

- Safety guidance on lighting of offshore structures must be taken into account. MGN 371 (Maritime and Coastguard Agency, 2008a) defines what criteria should be considered for marine navigational marking. This includes, for instance, consideration of how the overall site would be marked by day and by night. The guidelines state that low-intensity lighting and identification characters should be visible to observers 3 metres above sea level and at least 150 metres from the turbine. The typical configuration of a wind turbine is illustrated in MGN 372 (Maritime and Coastguard Agency, 2008b). Turbines at the corners of the wind farm have specific requirements for lighting based on the International Association of Lighthouse Authorities (IALA, 2004) Recommendation O-117 on the Marking of Offshore Wind Farms. These require synchronised flashing yellow lights, visible from all horizontal directions. Individual lights must be below the arc of the rotor blades. It should be noted

that alterations to lighting of wind turbines could not contravene these requirements without substantial amendments to marine law and practice.
- Separate regulations must also be followed to comply with aircraft navigation requirements (CAA 2010a). These require all peripheral turbines to be fitted with a steady red light at the top of the structure. The Civil Aviation Authority (CAA) might require additional lighting, as might the Ministry of Defence, under certain circumstances. In a separate Policy Statement (CAA 2010b), it is noted that lighting required for aviation safety is causing difficulties for maritime users. As a result, investigations may result in a change to flashing red lights.

- Gehring *et al.* (2009) found that avian fatalities could be reduced by 50–71% at guyed communication towers by removing non-flashing/steady-burning red lights.
- In a global case study of the effects of wind farms on birds, Keil (2005) found that attaching lighting can be used to alert birds but that it has to be done with extreme caution. Offshore wind turbines, if lit at night, could potentially pose a similar risk to communication towers (Percival 2001). Artificial lights at night have been well documented as being an attractant to migrant birds. Birds migrating at night can be attracted to sources of artificial light, particularly during periods of inclement weather (Percival 2001).

2.3.1.7 Laser deterrents

- In their study, "Use of frightening devices in wildlife damage management", Gilsdorf *et al.* (2002) examined scientific literature on the use of frightening devices to reduce bird and mammal depredation and compiled results to determine the effectiveness of such devices. They found that lasers were effective in dispersing cormorants, reducing numbers at roosts by at least 90% after 1-3 evenings of harassment with a laser. They concluded that when used in an integrated system, frightening devices may be more effective than when used alone. While the total elimination of damage may be impossible, frightening devices and / or combinations of devices were considered useful in reducing wildlife damage.
- In their study "Minimizing bird collisions: What works for the birds and what works for the utility?", Bridges *et al.* (2004) found that lasers were highly effective against some, but not all, species of birds.
- Clarke (2004) noted that strobe lights and laser deterrents were the two methods that had the highest potential for being useful in an autonomous, minimal disturbance bird deterrent system.

2.3.1.8 Increasing visibility – marking of ground wires or power lines

- Alonso *et al.* (1994) conducted a study to evaluate the effectiveness of ground wire marking to reduce bird mortality through collision with a power transmission line between the towns of Valdecaballeros and Guillena, Extremadura, southwest Spain. Flight intensity and collision frequency decreased respectively by 61% and 60% at marked spans compared to the same spans prior to marking. There was no significant change in collision frequency at spans left unmarked.
- When looking at the effects of conductor-marking and static wire marking on the rate of bird collision with power lines in west-central Spain, Janss *et al.* (1998) found that overall reduction in avian mortality for both the spiral and the crossed bands (types of power line markers) was more than 75%.
- In a study of species-specific avian mortality (collision and electrocution) relating to power lines, Janss (2000) found that collision victims tended to be 'poor' fliers, and that electrocution victims were birds of prey, ravens and thermal soarers. In order to reduce power line mortality the study suggested better route planning for power lines, insight into local avifauna (i.e. collision prone, electrocution prone or both) in combination with either better insulation of conductors or making power lines more visible.

- De La Zerda and Rosselli (2002) gathered data on avian collision in a wetland locality crossed by a 2 circuit 500 kV line in northern Colombia. After 2 years of study, mitigation devices (yellow plastic spirals) were installed on one circuit and observations were carried on after the installation in order to evaluate the effectiveness of the spirals. The bird flight diverters proved to reduce mortality of birds as shown by fewer birds reacting close to the line, fewer birds flying at the height of the conductors and lower collision rates with the marked line.
- Rubolini *et al.* (2005) carried out a review of 11 avian mortality censuses and compiled a list of species found among power line victims in Italy, based on over 1,300 reported individual casualties. They found that some groups (e.g. raptors, herons, storks and allies) were highly affected, while others (e.g. passerines and allies) appeared to be poorly represented among species involved in power line accidents. They suggested the use of widely available electrocution-safe structures on distribution medium voltage power lines, and careful siting through a preliminary evaluation of alternative tracks for high voltage transmission lines, particularly in areas known to be hosting high-priority species at elevated collision risk.
- In a review of collision causes and mitigation in a South African context, Jenkins *et al.* (2010) concluded that line marking could reduce bird collision frequencies by 50-60%. However, there was no clarity regarding the most effective marking device and one that works for all species in all conditions (day and night) was yet to be developed.

2.3.1.9 Wind farm siting, design and layout

- In their study “Wind farms and birds: An analysis of the effects of wind farms on birds, and guidance on environmental assessment criteria and site selection issues”, Langston and Pullan (2003) found a strong consensus that location was critically important to avoid deleterious impacts of wind farms on birds. There should be precautionary avoidance of locating wind farms in statutorily designated, qualifying international (e.g. Natura 2000 – SPAs and SACs, ‘Ramsar sites’, Emerald Network and Important Bird Areas (IBAs)) or national sites for nature conservation or other areas with large concentrations of birds (e.g. migration crossing points). Siting should also take into account species identified as being of conservation concern. Adverse impacts on wildlife must be avoided by full evaluation of suitable alternatives, appropriate siting and design.
- When analysing the factors that led birds to fly close to onshore wind turbines and power lines in the Straits of Gibraltar, Barrios and Rodriguez (2004) found that mortality caused by turbines was higher than that caused by power lines. Mortalities were not associated with either structural attributes of wind farms or visibility. The absence of thermals in winter forced vultures to use slopes for lift, the most likely mechanism influencing both their exposure to turbines and mortality. Kestrel deaths occurred during the annual peak of abundance in summer. They concluded that placement of wind turbines was crucial, and wind installations must be preceded by detailed behavioural observation of soaring birds as well as careful mapping of migration routes.
- Hüppop *et al.* (2006) undertook bird migration studies and assessed potential collision risk with offshore wind turbines. They found that almost half of the birds studied flew at ‘dangerous’ altitudes with regard to future wind farms. The number of individuals in reverse migration was found to be considerable, which increased the risk of collision. Under poor visibility, terrestrial birds were attracted by illuminated offshore obstacles and mainly passerines collided in large numbers. They consequently recommended avoiding locating wind farms in zones with dense migration.
- In order to help reduce conflict between sensitive bird species and onshore wind farms in Scotland, Bright *et al.* (2008) created a map of bird sensitivities based on distributions of 16 bird species of conservation priority and statutory Special Protection Areas using data on foraging ranges, collision risk and sensitivity to disturbance. Sixteen species were investigated, 12 of which were listed under Annex I of the Birds Directive. The remaining

four had very localised distributions, were undergoing rapid population decline or were poorly represented by the SPA network. Bright *et al.* (2008) concluded that wind farm developers should prioritise focal vulnerable species and implement geographical avoidance of sensitive species. A similar sensitivity mapping project was subsequently conducted for England (Bright *et al.*, 2009).

- In their study of the avian collision effects of offshore and onshore wind turbines and other obstacles, Drewitt and Langston (2008) stated that suitable siting is the most important factor in minimising collision impacts.
- The following elements in site selection and turbine layout and in developing infrastructure for the facility should be considered (Edkins, 2008):
    - Minimise fragmentation and habitat disturbance.
    - Establish buffer zones to minimize collision hazards (for example, avoiding placement of turbines within 100 meters of a riparian area).
    - Reduce impacts with appropriate turbine design and layout.
    - Reduce artificial habitat for prey at turbine base area.
    - Avoid lighting that attracts birds and bats.
    - Minimize power line impacts by placing lines underground whenever possible.
    - Avoid using structures with guy wires.
    - Decommission non-operational turbines.

Several of Edkins' proposed options are considered in further detail in other sections of the report.

- In a report for the RSPB entitled "Positive planning for onshore wind: Expanding onshore wind energy capacity while conserving nature", Bowyer *et al.* (2009) concluded that most avian collision threats can be minimised by avoiding placing wind turbines in sites with sensitive habitats.
- When ranking bird species with regard to their relative sensitivity to wind turbine collisions, and applying it to a data set comprising 38 avian migrant species at the Nysted offshore wind farm in Denmark, Desholm (2009) concluded that avoiding siting offshore wind turbines in those areas with particularly sensitive species would significantly contribute to reducing impacts of avian collision at a population level.
- Langston (2010) identified species that were most likely to be vulnerable to collision with Round 3 zones, extensions to Round 1 and Round 2 sites and developments in Scottish territorial waters. The selection of species was based on proximity to breeding colonies, foraging ranges and non-breeding distributions. The author noted that any proposed wind farm development would need to take into account bird species that contribute to the qualifying interest of relevant SPAs, based on likely foraging ranges (King *et al.*, 2009). These two studies were used to identify species most vulnerable to collision mortality from offshore wind farms and are discussed further in section 3.

2.3.1.10 Structural modifications – decoy towers

- Decoy towers have been tested at Altamont in an attempt to reduce the elevated collision risk often associated with ends of turbine strings. The logic is that adding a rotorless decoy at the end of a row will reduce collision compared with an operational turbine. The structure does not necessarily need to be a turbine. It should be noted that the most current operational offshore wind turbine structures incorporate transitional pieces (between the driven monopiles and towers) that might be attractive as perches. Offshore sub-stations might serve the same purpose as decoy towers, depending on their location in relation to the wind-farm.
- In a review of research into avian collision and mitigation methodologies, Curry and Kerlinger (2000) stated that the use of decoy towers without functioning blades is one idea under consideration as a potential risk-reduction treatment in the Altamont Pass Wind Resource Area, California. However, their effectiveness was not known, and while provision

of these alternative perches would help keep birds off the turbines, it might also attract birds to the general area of the turbines, or encourage them to remain longer.
- Field research by Smallwood *et al.* (2009) at Altamont indicated that 22% of perching time was on towers of turbines that were not operational (compared with 1% on working towers).

Using decoys to attract birds away from wind farms is not discussed in this report, because little literature was found on the subject. However, work has been carried out by Guillemette *et al.* (1998) using decoys to find out how close to a wind farm Eiders will fly or land. This found that they will not preferentially land within 100m of a wind-farm.

2.3.1.11 Structural modifications – lattice or tubular construction / stringing mesh around lattice towers

- The literature relating to lattice versus tubular towers is inconclusive.
- When studying bird mortality associated with onshore wind turbines at the Buffalo Ridge wind resource area, Minnesota, Osborn *et al.* (2000) found that the design of a new wind turbine with a closed tubular design and no horizontal cross-beams was not attractive for perching and nesting raptors. In California the turbines are of lattice type with cross-beams that attracts perching and nesting raptors. It is possible that offshore turbines in Round 3 developments may have similar open lattice foundations.
- Research from Altamont Pass, however, suggested that birds' use of lattice towers as perches may not significantly increase collision risk (Percival, 2001).
- When considering the behavioural and environmental correlates of soaring-bird mortality at onshore wind turbines, Barrios and Rodríguez (2004) found that updating older model turbines towers from a lattice framework to a tubular construction had proven to be very effective in reducing collisions.
- It was suggested by Marsh (2009) that reduced collision risk attributed to tubular construction may in fact have been because of wider spacing between the turbine towers.

2.3.1.12 Structural modifications – size / number of turbines

See also section 2.3.1.3 on reducing motion smear through the use of different rotor speeds or turbine sizes.

- In designing a new wind farm, there is a trade-off between turbine size and number. To obtain a given power output both turbine size and number can vary. Fewer larger turbines are broadly equivalent to a greater number of smaller turbines. The relative mortality arising from different turbine sizes (i.e. different rotor swept areas) is correlated with the turbine number and sizes for any given power output. The hub height of the turbine is another consideration as this defines the upper and lower heights above sea level utilised by a rotor. Variation in hub height has the potential to significantly alter predicted collision risk and is related to the distribution of flight heights for a species. The current data on flight height may not be able to inform the predicted effect of this variation greatly, as bands are assigned to broadly define rotor collision risk area (i.e. >20m). However, as a mitigation option, raising rotors (thereby potentially decreasing the number of birds in the risk area) may be as effective as using larger or slower turbines. The predicted effect and feasibility of this option would benefit from further investigation (S. Allen pers. comm.).
- Larsen and Clausen (2002) studied the morning and evening flights of Whooper Swans (*Cygnus cygnus*) wintering near Overgaard, Eastern Jutland, Denmark. They assessed the potential risk of collisions with medium sized or with large turbines, the medium sized turbines also having a lower hub height and therefore a lower sweep. The study found that

the birds could be particularly prone to collisions during evening flights, as these took place in rather poor light conditions. Recorded heights of swan flights indicated that a park consisting of medium sized wind turbines would be more critical in terms of collision risk than one with large turbines, with 38% of observed individuals flying within height range of the rotors in the former, only 13% in the latter.

- Barclay *et al.* (2007) assessed the influence of turbine size on bird and bat fatalities, using data from North American wind energy facilities. They found that the diameter of the turbine rotor did not influence the rate of bird or bat fatality, and the height of the turbine tower had no effect on bird fatalities per turbine, but bat fatalities increased exponentially with tower height. This suggested that migrating bats fly at lower altitudes than nocturnally migrating birds and that newer, larger turbines were reaching that airspace. Minimising tower height may help reduce bat fatalities. In addition, while replacing older, smaller turbines with fewer larger ones may reduce bird fatalities per MW, it may result in increased numbers of bat fatalities.
- When comparing past and current displacement effects of two onshore wind farms and a line of land-based turbines on spring-staging Pink-footed Geese (*Anser brachyrhynchus*) to see if there was evidence of habituation, Madsen and Boertmann (2008) found that geese were still displaced at sites with larger turbines. This was likely because larger turbines create more disturbance; either due to the larger rotor swept area and longer rotor blades, or the possible effects of blade-tip and blade wake turbulence.
- According to Kikuchi's (2008) model of collision probability, the rotor speed does not make a significant difference in collision probability. The hub was considered to be the most dangerous part of the turbine and large birds (e.g. raptors) were at greatest risk.
- Krijgsveld *et al.* (2009) found a threefold reduction in collision risk with smaller turbines at three wind-farms in the Netherlands.
- Research into collision risk of the Marbled Murrelet (*Brachyramphus marmoratus*) in the United States (Nations and Erickson 2009) suggested that collision risk is similar for small (77m) and medium-sized (90m) rotors, although this result is due in some part to differing numbers of turbines in the arrays under investigation. The hub height was taken to be the same for all rotors, so that larger turbines would have a lower sweep than smaller ones. The collision risk was found to be 25% greater for large (101m) rotors. Higher winter mortality was explained in terms of increased rotor speed arising from increased average wind velocities. However, the authors found higher mortality in the breeding season because of increased passage rates.
- There is a trend towards larger turbines and blades up to 150m diameter for 10 MW generators (Dvorak, 2010).

2.3.1.13 Awareness, research and monitoring

- One study noted that new wind installations must be preceded by detailed behavioural observation of soaring birds as well as careful mapping of migration routes (Barrios and Rodriguez 2004).
- One study (Langston and Pullan, 2003) noted that a map of potential and high sensitivity locations for wind energy development on the basis of nature conservation concerns, for example avoidance of focal points for migration crossings, would be beneficial. That study led to subsequent sensitivity mapping projects for Scotland (Bright *et al.*, 2008) and England (Bright *et al.*, 2009). High sensitivity locations encompass those requiring the strictest tests of compatibility with sustainable development. Similar mapping approaches have been or are being developed in other countries across Europe and further afield, e.g. South Africa. Data gaps are an important constraint on such maps, but they are a useful tool for site selection and scoping (R. Langston, pers. comm.).

- Langston and Pullan (2003) also noted that there is a need for best practice guidance on standard study methods, to inform the EIA process.

2.3.1.14 Remote sensing and monitoring

- Thermal Animal Detection System (TADS):
    - The development of an infra-red based technology (TADS) to record birds flying in close proximity to wind turbines as a means of gathering highly specific information about actual collision rates, and also for parameterising predictive collision models was discussed by Desholm (2003). The report concluded that the thermal camera and TADS were capable of recording migrating birds approaching the rotating blades of a turbine, even under conditions with poor visibility. Desholm *et al.* (2005) subsequently recommended TADS for identifying species and measuring flock sizes in poor visibility (including darkness). If TADS were to be used in a vertical viewing scenario it would comply with the requirements for a setup used for estimating the avian collision frequency at offshore wind turbines. This is described as the best technique for monitoring very close to wind turbines (Desholm *et al.*, 2005). However, the work at Nysted wind farm in Denmark has shown that there is, under normal circumstances, a very low probability of an individual camera recording a collision event. A further review by Walls *et al.* (2009) reinforced the suitability of thermal cameras for species-specific identification, use in conditions of poor visibility and to observe avoidance behaviour. The review, however, felt that detection might be limited by species size and the technique would be expensive to deploy.
    - Image intensification. Night vision scopes or binoculars use infra-red to detect birds in the vicinity of wind turbines. They are cheaper to deploy than thermal imaging cameras, but require some ambient light and may provide poorer quality images than those obtained from TADS (Walls *et al.*, 2009).
- Population modelling and tracking:
    - When assessing the impacts of wind farms on birds, Drewitt and Langston (2006) found that, as well as improving remote technology for observing behavioural reactions of birds including collisions and displacement, the development of demographic and spatial models was also important to predict, and subsequently test, predictions of population-level impacts attributable to a wind farm, as distinct from other factors. Spatial models were especially valuable for studies of displacement of birds in the offshore environment, where the data on abundance and distribution were usually based on particularly small samples and were themselves subject to wide confidence limits. As well as predicting the impacts of a single wind farm, spatial modelling could be essential for predicting the possible cumulative displacement of bird populations on a wider scale resulting from the combined impacts of several wind farms.
    - Field observation may be used to record the movements of target species. An example of this approach has been conducted with Galapagos Petrel *Pterodroma phaeopygia* by Cruz-Delgado *et al*. (2010).
    - A variety of tagging and tracking technologies are available to follow the movements of individual birds, so as to draw conclusions about populations (Walls *et al.*, 2009). These include radio-tracking, satellite tracking, GPS tracking, satellite linked to GPS and global location sensing. All of these techniques allow movements to be monitored over long distances, often without direct observer effort. Several (but not all) can be used without birds being re-captured, and data can be downloaded for future modelling. The costs involved vary, depending on the prices for tags, receiving equipment and software. Whilst satellite tracking allows data to be downloaded

from satellite, radio-tracking requires observers to track individual birds. Techniques involving loggers might require the bird to be re-captures to enable retrieval of the logger. The techniques may also be unsuitable for some species, particularly if the mass of the tracker / logger is too high relative to that of the bird or if diving energetics are negatively affected. Finally, any kind of tagging or tracking requires specialist handling of birds by licensed personnel.

  - Use of satellite tracking has been used on Whooper Swans (*Cygnus cygnus*) to analyse their migration routes in relation to offshore wind farms (Griffin *et al.* 2010). This approach can be used to inform the siting of wind farms and / or shut-down periods, but it is expensive, time consuming. The study also pointed out that hourly data would not accurately pinpoint the time when a bird on migration was passing through a wind-farm area.

- Other remote sensing techniques:
  - Desholm *et al.* (2005) and Desholm *et al.* (2006) assessed the potential of other (some as yet undeveloped) techniques for collecting information on bird flight and behaviour, both pre- and post-construction of the offshore wind farms. These included the use of ordinary video surveillance equipment, microphone systems, laser range finder, ceilometers and pressure sensors. Several methods were further reviewed by Walls *et al.* (2009), although it was noted that they were largely unproven for ornithological monitoring for offshore environments and in particular at wind farms.
  - Laser rangefinders can be used to measure the altitudes of birds flying through an area. However, they cannot be used effectively for large numbers of birds, and have a limited range (Walls *et al.*, 2009).
  - Stereo filming uses parallax shifts between images to determine 3-dimensional positions of birds relative to wind turbines. However, Walls *et al.* (2009) concluded that, whilst detailed information that could be gained from this technique, a large amount of input was needed to analyse the data, the equipment was cumbersome and the approach was not proven in an offshore context.
  - Acoustic monitoring can be used to identify species from their flight calls and also to record collisions from vibrations. The approach may be hampered offshore by high levels of background noise, and the presence of boats may affect the 'normal' behaviour of birds. Specialist analysis would be necessary to interpret the data (Walls *et al.*, 2009).
  - Preliminary work on pressure / vibration sensors has not developed into a commercially viable system. Any such system would have to overcome inherent vibration at sea and could form only part of a system for collision detection to identify the source of a particular event, rather than triggering shut-down or other mitigation measures (R. Langston, pers. comm.).
  - In their 2001 study, "New solutions for bird collision and electrocution outage problems", Harness and Carlton (2001) referred to research to develop a Bird Strike Indicator (BSI) and Bird Activity Monitoring (BAM) to remotely detect and record avian collisions and electrocutions from power lines. These tools would allow scientists and engineers to better understand where problems were occurring and to determine whether existing mitigation measures were working.

2.3.1.15 Radar

- When assessing the impacts of wind farms on birds, Drewitt and Langston (2006) found that the most important advantage of radar over visual observations was that it allowed continuous and simultaneous sampling of bird movements over a large area. This was regardless of time of day and visibility conditions (although limited in high moisture, radar extends the range of observations considerably beyond that possible for visual observations). Clearly, continuous sampling would be desirable for monitoring bird movements, especially at sea, as such movements are often complex and fluctuate greatly. A combination of horizontal and vertical radar can provide information on flight direction and flight heights. In the UK there was, until recently, little deployment of radar to assist wind farm environmental assessments, partly because of the lack of available equipment and expertise. This situation should be remedied with the recent development of radar specifically for bird monitoring. This equipment detects bird movements in both the horizontal and vertical planes and analyses and summarises radar data using GIS tools and statistical techniques.

- With an objective of mitigating strike risk of birds and bats at operational offshore wind farms, DeTect Inc has adapted MERLIN radar technology to form a Supervisory Control and Data Acquisition (SCADA) system, integrating avian radar technology with the wind farm operating system. Kelly and Fiedler (2008) evaluated the usefulness of MERLIN SCADA, which functions as a continuous monitoring and control system, with the added capability of activating mitigation measures (generally idling blades) during conditions of high bird or bat mortality risk. Potential mitigation measures generally involve idling turbines via the SCADA when pre-set conditions indicative of high strike risk have been met.
- MERLIN technology has mainly been used pre-construction to inform siting of wind turbines. However, MERLIN SCADA has been installed at the operational Gulf Wind I and Penascal wind farms in Texas USA, where it is used to automatically idle selected turbines if warranted by high bird mortality risk (DeTect, Inc., 2010).
- Iberdrola Renewables, operating a coastal wind farm in Texas, has also used radar to detect large numbers of approaching birds and automatically shut down turbines. The technology is developed by DeTect Inc., based on its airport bird-strike avoidance radar (American Bird Conservancy, 2010). If the pilot is successful, a similar approach is proposed for use in New Jersey (State of New Jersey, n.d.).
- In the 2010 report "Mitigating avian collision with wind turbines using information from weather radars", Norman (2010) (included in Appendix 3) discussed the UK Met Office's us

information, although it was found that the weather radars were useful for providing 3D information (instead of 2D information from the military radars used).
  - AHAS: In the United States, weather radar, weather forecasts and known bird distribution data are inputs to a model which forecasts bird activity over a 24 hour period. A small subset of species, deemed to be most hazardous to aircraft, is modelled.
- Ronconi *et al.* (2004) described a radar system (BirdAvert: Peregrine Systems) used to detect birds on contaminated inland ponds. The system used standard marine radar connected to a computer to allow real-time detection of groups of birds. They proposed extension of the application to deter birds from offshore oil-spills, the main challenges being availability of suitably trained personnel, detection of swimming birds and effects of weather.

A full report from the Met Office 'Mitigating avian collision with wind turbines using information from weather radars' is provided in Appendix 3.

2.3.1.16 Auditory deterrents

- Gilsdorf *et al.* (2002) examined scientific literature on the use of frightening devices to reduce bird and mammal depredation and compiled results to determine the effectiveness of such devices. They found that reception of high frequencies (>10,000 Hz, i.e. ultrasound) was very poor in birds. Pigeons can detect frequencies as low as 0.05 Hz (i.e. infrasound), but it was unclear how the birds use this capability. Otherwise very little evidence existed that ultrasound deterred birds. Alarm and distress calls were only effective for a few days (maximum a few weeks). When used in an integrated system, frightening devices might be more effective than when used alone. Gilsdorf *et al.* (2002) concluded that the total elimination of damage may be impossible, but frightening devices and / or combinations of devices are useful in reducing wildlife damage. Ultrasonic frightening devices are ineffective in repelling birds and mammals whereas other devices offer some protection.
- Dooling (2002) considered what is known about basic hearing capabilities in birds in relation to the characteristics of noise generated by wind turbines. He concluded that in the case of birds, acoustic deterrents did not work for two reasons. First, even though loud noises, explosions, alarm calls, and other complex sounds had been promoted over the years as acoustic deterrents, birds habituate to such stimuli. It cannot be stated too strongly that none of these acoustic strategies had proven effective over the long term. The all too common observation of birds foraging and nesting near busy airport runways was given as an example of such a failure. The second reason that acoustic deterrents were typically seen as an attractive solution was the possibility of using sounds outside the range of human hearing. In the case of birds, this was simply impossible because the range of bird hearing was narrower than the range of human hearing. Any sound audible to birds would also be audible to humans. Thus, as attractive as the notion of an acoustic deterrent outside the range of human hearing was, it would not be possible in the case of birds because birds cannot hear outside the range of human hearing.
- In their review of international research literature regarding the effectiveness of auditory bird scaring techniques and potential alternatives, Bishop *et al.* (2003) collated and reviewed the published and unpublished information on bird deterrents. They critically evaluated studies which attempted to scientifically assess the relative cost effectiveness of the different techniques and identified areas for further work in order to fill gaps in knowledge. They found that auditory deterrents were considered the most effective in terms of cost effectiveness.
- In their study "Minimizing bird collisions: What works for the birds and what works for the utility?", Bridges *et al.* (2004) found that the use of distress signals as a sound only deterrent was of limited to no utility. Without the visual signal of a predator holding a captured prey to corroborate the sound, distress calls had been shown to have no effect. When coupled with

a predator species holding a victim of the sort emitting the distress call, a brief investigation was followed by evacuation. However this response could be subject to habituation given regular exposure.

- Whilst no literature was found to support this view, it is possible that habituation is not such a problem for migratory species that only encounter wind farms infrequently and irregularly.
- The impacts of auditory deterrents on marine mammals and fish were not researched in this study. However, we consider it unlikely that the impacts would be significant. Bird deterrents would be likely to be deployed at considerable height above sea level. Operational noise from offshore turbines is low (Nedwell *et al.*, 2007) and the cumulative impacts are therefore not considered to be a significant barrier to deployment.

2.3.1.17 Timing of construction and maintenance

- When assessing the impacts of wind farms on birds, Drewitt and Langston (2006) stated that mitigation measures fall into two broad categories: best-practice measures which could be followed by any wind farm development and should be adopted as an industry standard, and additional measures which are aimed at reducing an impact specific to a particular development. Examples of best practice measures related to offshore wind turbines included timing construction to avoid sensitive avian breeding or migration periods as well as careful timing of routine maintenance.
- It should be noted that Round 1 licence conditions have dictated when construction (and maintenance) happens as a matter of course. Timing of construction and maintenance is implemented as a mandatory measure.

2.3.1.18 Other mitigation measures

Other mitigation measures that have limited or no information in literature include:

- Radar-activation of deterrents
- Vertical axis wind turbines
- Installing perch guards on turbines to stop raptors using them as perches
- Alternative feeding areas / bait stations
- Use of decoys to divert birds away from danger areas
- Chemical bird deterrents
- Behavioural bird deterrents
- Turbine noise adjustment
- Underground transmission cables
- Intense rodent control programs that reduce prey availability

This literature review has made it possible to identify the existing and novel methods for mitigating avian collision, what the shortcomings in knowledge and understanding are, as well as where the evidence is lacking, inconclusive, contradictory and what views require further investigation.

All references (including some that are not cited within this text) are listed as the results of the literature review in Appendix 1.

2.3.2 Telephone interviews

As part of the process to identify the range of options to prevent avian collision with offshore wind turbines, a number of telephone interviews were carried out. Representatives from a range of organisations were invited to participate in the interviews.

- Government bodies
- NGOs (with an interest in wind energy and / or avian impacts)
- Trade associations
- Research institutions
- Wind farm owners, operators and developers
- Turbine suppliers
- Wind farm designers
- Consultants

One initial finding from the process was that many of the invitees responded to the interview request saying that they felt unable to response due to their lack of knowledge about available mitigation options and that the subject was outside of their field of expertise. Because of this, the number of invitees interviewed was lower than the anticipated sample size of approximately 20, but with a spread across organisation types. One representative from each of the following groups was interviewed in order to determine their views on potential mitigation methods, techniques and technologies.

1. **Interview 1**: A marine research institute.
2. **Interview 2**: A statutory advisor on national and international nature conservation.
3. **Interview 3**: A Government body.
4. **Interview 4**: A renewable energy developer and operator.
5. **Interview 5**: A professional ornithologist.

Interview 1. A marine research institute

The interviewee from the marine research institute noted that they had very limited knowledge in the area of avian collision, as their expertise deals with underwater species. However, there could be some similarities between methods of predicting underwater collisions with avian collisions offshore. One difficulty that is common to both is the difficulty in observing the number of hits and the inability to see the number of bodies (as you can with onshore turbines). Therefore it is difficult to calibrate models that predict collision.

The approach that the marine institute takes is to look at the encounter rate – i.e. the number of possible encounters that a species would have with the collision object. The encounter model can be used to predict different encounter rates for different species, using information on depths that species spend most time at, typical routes, etc. This can indicate particular species that are more likely to encounter the collision object and therefore might require mitigation measures or additional information to be collected (further research). However, there is still difficulty in predicting actual collision risk. With certain fish species it is slightly easier to predict, particularly where there is a lot of information on how the species reacts when something is looming – i.e. have knowledge on their reactions, in which directions they will swim, etc. Other species are not as well researched, so this information is not available and their collision risk will be less well understood. It is expected that bird collision models will have similar issues and therefore further research may be required on certain 'at risk' species.

Overall the conclusion was that one could apply the encounter model to offshore wind. Local densities of certain species would be required, as well on information on the times these species spend at different altitudes. This would allow encounter rates for different species to be predicted, enabling species most at risk to be established. One could build in probability of evasion into the model from knowledge of species behaviour and turbine velocity.

The interviewee also mentioned that blade velocity may have an impact on collision risk. There is likely to be a higher chance of evasion with a slower moving blade. It was also mentioned that some of the experience from onshore wind turbines is likely to be applicable to offshore wind turbines.

Interview 2. A statutory advisor on national and international nature conservation
The interviewee from the statutory advisor on national and international nature conservation first noted some concerns on duplication of research projects in the area of avian collision and that better use could be made of research resources in this area.

According to this interviewee, the siting of a wind farm is the most crucial mitigation option. It was noted that in order to be effective, there needs to be a very fine scale of knowledge about bird species in the area, behaviours, etc. One issue with this key mitigation option is that environmental impact assessments (EIA), risk mitigation, etc, can be seen as very expensive by developers and it was noted that marine planning has not been very strong on these in the past.

Other mitigation options that can be effective are the micro siting of turbines (within the site) and size of turbine. The interviewee commented that smaller turbines reduce collision risk, as there is less area of blade (rotor swept area) per turbine, but this is countered by requiring more turbines to produce the same energy output.

Overall, mitigating avian collision should really be about minimising mortality. Therefore, developers should be looking at avoiding certain areas completely.

The interviewee stated the following two key points that one needs to understand when considering mitigation options.

- Need to know whether birds will avoid a wind farm area – will they deviate from routes they would usually take and are therefore not putting themselves at risk. Species which will behave in this way will not require mitigation options.
- For species that don't avoid the wind farm area, but fly through it, the risk of them actually hitting a blade needs to be understood. An understanding of points such as the height they fly at, what their flight purpose is (so awareness of predators / objects ahead), etc, is necessary in order to predict this. There is a need to model this risk and the modelling must be species specific and informed by use of area by bird species.

Other mitigation options mentioned by the interviewee were shut-down of turbines at key times (such as breeding season and migration times) and approaches that are being used for terrestrial turbines (such as radar to detect bird approach and then shut-down – but the interviewee noted that it is unclear as to whether this would work for the species of concern in marine wind).

During the final part of the interview, monitoring of collision was discussed. The interviewee noted that currently there is not the technology to adequately monitor collisions with offshore turbines – particularly nocturnally (it can be done during day). This was mentioned as a key concern. One of the issues is that, unlike with onshore wind turbines, one cannot collect corpses, etc. From observation current modelling may use precautionary avoidance rates, that may overestimate the collision risk and ultimately lead to developmental inhibition.

There is a need to gather this data from constructed wind farms, as well as to develop better remote detection technologies – both for monitoring of hits <u>AND</u> near misses.

Interview 3. A Government body
The Government body interviewee stated that there is a need to better understand the collision risks so that one can plan and design a wind farm project in an improved way. This requires better tools to carry out modelling at the planning stage of a wind farm and to evaluate the collision risks. Overall, this was seen by the interviewee as a better and more useful option than mitigation measures you can retrofit to turbines. These types of measures can be integrated when carrying out site selection or site design and can make a huge different to the impact of the site.

One problem with getting such issues considered early in the planning of projects is getting buy-in from key consultees. These are the ones that advise decision makers. There is a need to get everyone bought in from the start. The interviewee had seen such issues in the past with wanting to try new survey techniques. It was not possible to convince the key consultees that the project would deliver, which resulted in delays to the project.

One mitigation option mentioned by the interviewee was temporary shut-down of turbines, linked to some form of detection, such as radar. However, it was suggested that this option does not really work, compromises project feasibility and could result in very large losses in profits. One would need to have a very good understanding of risk and modelling so turbines can be shut down for the least amount of time possible.

One further option mentioned was lighting, but it is unclear as to how effective this is, particularly in fog. The interviewee was not familiar with the science behind lighting mitigation options.

During the final part of the interview, monitoring of collision was discussed. The interviewee noted that there is a lot of sophistication in pre- and post-construction monitoring – linked to experimental design. But it was again mentioned that issues with key consultee buy-in can mean that such new methods are not used. Monitoring techniques mentioned included video surveillance, night vision systems for monitoring birds at night and high definition video and stills (can look at displacement effect, etc, in more detail).

A final comment was that there is a need to be able to tie monitoring to hypotheses, so that one knows what the observations mean.

Interview 4. A renewable energy developer and operator
The renewable energy developer and operator noted that the only offshore mitigation tool they had ever used was the positioning of the turbine. They considered that this is the only way of actually reducing collision risk. They noted that it would be good to further understand collision risk. The risk model that they currently are aware of is very complicated and they are uncertain about how accurate it is.

In terms of further research, it would be good to understand what is really applicable in the current model, as well as where information on particular species is lacking and additional investigation is required. For example, is the data on flight altitudes, risk of collision in different weather conditions, etc, accurate? It would also be useful to see whether the model can be tested with onshore wind turbines to look at aspects such as actual impacts in comparison to what the model had predicted.

The interviewee noted that there is definitely some cost-benefit analysis to be done on mitigation options. What actually works is an important question to consider.

It was also mentioned that it is likely to be better to do measures at the beginning in the planning phases and onshore, rather than potentially more expensive measures offshore.

One needs to be wary of very expensive measures, such as turbine shut-down, as licence conditions such as this on the planning consent can make getting initial funding very difficult.

Lighting was noted as a difficult mitigation option, as there is the question on whether the birds are being attracted or not by the lighting. Therefore, it is not clear on whether it is beneficial or not. The interviewee went back to the earlier point and noted that it is also important to consider cost and benefits of other impacts of having or not having lighting – e.g. would there be more boat collisions if lighting was not present, etc.

Interview 5. A professional ornithologist
The professional ornithologist noted that there is too much emphasis on ornithology survey work for baselines within fixed project timescales. These don't necessarily lend themselves well to picking up on birds passing through at particular times of day or season. This is particularly an issue for birds of conservation concern (e.g. Schedule 1 species) such as Red-throated Diver and Scoter. On the River Thames, habitat displacement might be more of an issue than collision risk. Furthermore, habituation to offshore wind farms might be an issue e.g. for terns and divers.

In terms of techniques and technologies to reduce bird collisions, the interviewee mentioned that temporary shut-down has been considered for onshore turbines, but it is not considered favourable because of the economic implications. Siting and design of turbines seems to be the only frequently used approach to reducing risk of avian collision.

2.4 Results - Objective 2: identify existing and novel mitigation methods that could be used to minimise avian collision

2.4.1 Shortlist of mitigation options

In the original proposal for this project, it was agreed that AEA would draw up a list of up to 10 mitigation options, in consultation with DEFRA and with inputs from the project team.

The following table summarises the mitigation options that have been identified as a result of the research in Objective 1. Each is assessed in terms of the 'novelty' of the approach in order to reduce the list to ten options.

Table 2.4.1.1 Mitigation options to be considered

Mitigation option	Shortlist?	Comments
Temporary shut-down	Yes	Not yet routinely implemented, so worth further investigation.
Reducing motion smear – anti-motion-smear patterns	Yes	Largely theoretical model that has not been tested in the field.
Reducing motion smear – rotor speed / turbine size	Yes	Worth further investigation.
Increasing visibility - use of ultraviolet paint / material	Yes	Only limited trials so far, so this is a novel technique.
Increasing visibility - use of lighting *	Yes	Might increase risk of collision, but largely untested.
Minimal use of lighting*	Yes	No evidence of widespread testing on offshore wind farms.
Laser deterrents	Yes	Further research needed.
Increasing visibility – marking of ground wires or power lines	No	Only applied to ground wires and power lines to date. Probably not transferrable to offshore wind turbines.
Wind farm siting, design and layout	No	This is the most commonly used approach cited in planning applications. But not novel. This is the baseline against which the effectiveness of other measures needs to be assessed.
Structural modifications – decoy towers	Yes	Effectiveness not known.
Structural modifications – lattice or tubular construction / stringing mesh around lattice towers	No	Literature is inconclusive regarding reduction in collisions. These are likely to be retrofit options so not relevant to this project.
Structural modifications – size / number of turbines	No	Shown to reduce collisions. But these are retrofit options so not relevant to this project.
Awareness, research and monitoring	No	More of an action than a mitigation option.
Remote sensing and monitoring Includes Thermal Animal Detection Systems (TADS), population modelling and tracking, other remote sensing techniques and radar	Yes	Radar in use (for mitigating bird strike with aircraft). These past studies have used radar networks that are already in use, in combination with mobile radar and observational data. Radar techniques could also be used to activate deterrents / preventative actions (shut-down etc). Radar used to track flight direction and heights of birds, so has potential as monitoring tool and / or in developing Environmental Statements.
Auditory deterrents	Yes	Further testing / research needed. These may not be a practical option for seabirds offshore, though perhaps they could be used as a deterrent during the autumn for nocturnal migrants.
Timing of construction and maintenance	No	Not strictly a mitigation measure and more related to disturbance than to collision risk. Could be considered in good practice guidelines.

* use of lighting (e.g. strobe lights) and minimal lighting are both listed as possible options, and may have applications under different circumstances.

2.4.2 Assessment of shortlisted mitigation options

Each criterion (feasibility, cost of implementation / operation, effectiveness) has been assigned a score (high / medium / low). Each score is accompanied by some explanatory text summarising the reasoning behind the assessment.

As many of the measures assessed in this section are novel or have only been applied in a different context, there is some uncertainty in the criteria, particularly relating to effectiveness. Most of the mitigation measures discussed require experimental testing, possibly initially on land.

Table 2.4.2.1a Temporary shut-down

	Temporary shut-down
Description	A mitigation measure where turbines are temporarily shut down during certain times, such as during migratory events or in the breeding season, in order to prevent avian collision.
Benefits / impacts	May be successful in reducing mass collisions during migration.
Drawbacks / risks	This is a controversial measure, due to wind farm productivity losses. Costs of shut-down will depend on frequency, prevailing wind/weather conditions, predictability of timing and duration advocated for effective implementation, as well as the associated costs of the trigger mechanism.
Effectiveness / status	This measure is yet to be routinely implemented. Therefore its effectiveness is not well known. However, it is reasonable to assume that stationary rotor blades are likely to pose less of a hazard to flying birds than rotating blades.
Application	Only the turbines that are directly in the flight path need to be stopped. Therefore a detailed understanding of the movements of the bird species in the area is necessary.
Other comments	-

Table 2.4.2.1b Temporary shut-down

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	High	High
There is no technical barrier to turning off wind turbines. This is a routine requirement for safety and maintenance operations. However, it has not been routinely implemented as a mitigation measure against avian collision. Implementation requires thresholds to be set, monitoring and shut-down / start-up protocols. This would be an unpopular measure with developers and operators, who might argue that such a severe condition would only be warranted if the proposal would otherwise adversely affect the integrity of a European site (SPA / Ramsar) without shutting down.	Turbine shut-down is a controversial choice for a turbine operator as for every hour that the turbines are not producing electricity, this represents a financial loss. There is a trade-off between their bottom line and reducing avian collision.	Believed to be successful in reducing mass collisions during migration.

Table 2.4.2.2a Reducing motion smear - anti-motion-smear patterns

	Reducing motion smear - anti-motion-smear patterns
Description	Motion smear is the degradation of the visibility of rapidly moving objects. It results from the inability of the brain to process the high temporal frequencies of stimulation that result from high velocities of retinal-image motion. In the case of wind turbines, motion smear occurs primarily at the tips of the blades, making them deceptively transparent at high retinal-image velocities. Anti-motion-smear patterns are designed to reduce motion smear by not repeating a pattern in one location on a turbine blade at the same location on any other blade. In a three-blade turbine, the temporal frequency of stimulation is thereby reduced by a factor of three.
Benefits / impacts	Results of a study (Hodos *et al.* 2000) on comparison of different blade patterns, strongly suggests that a thin-stripe, staggered, anti-motion-smear pattern is the most visible of any that was tested and a single black blade would be a close second in terms of visibility.
Drawbacks / risks	Data from the blade patterns study only applies to conditions of bright illumination. No idea presented as to what extent these blade pattern stimuli retain their improved visibility under sub-optimal viewing conditions, such as mist, rain, etc. Nor will they (or any other visual pattern, for that matter) retain their visibility once the animal gets close enough for the retinal image velocity to exceed 200dva/sec, at which point the bird's retina has passed the limit of its ability to process temporally changing stimuli.
Effectiveness / status	Such patterns are worth testing in the field to determine whether the visibility advantages they offer will reduce avian mortality.
Application	The proposed approach is to use different patterns on each blade. The patterns are designed so that a pattern on any given blade region is not repeated on the equivalent region of the other two blades. Thus stimulations per second of any given retinal region are reduced by a factor of three and the time between stimulations is virtually tripled. The finding that a single, solid-black blade, paired with two blank blades is a highly visible stimulus could have useful economic consequences (compared with precise application of stripes) for wind power operators with an interest in testing this type of deterrent, as there would be no requirement for the precision application of stripes in specific positions on each of three blades.
Other comments	-

Table 2.4.2.2b Reducing motion smear - anti-motion-smear patterns

Feasibility	**Cost of implementation / operation**	**Effectiveness**
High	Low	Medium
The concept of avian collision mitigation via the marking of rotor blades is attractive since it is one of the few options based upon a possible assessment of an actual visual problem. There are no obvious barriers to marking the blades.	For a wind farm operator, pairing a single, solid-black blade, with two blank blades would be relatively inexpensive to implement as there would be no requirement for the precision application of stripes in specific positions on each of three blades.	This technique does not appear to have been evaluated to date. While it was recommended a number of years ago, it has not been trialled in the United States. Such a trial could be undertaken in the UK. Such patterns are worth testing in the field to determine whether the visibility advantages they offer will reduce avian mortality.

Table2.4.2.3a Reducing motion smear –rotor speed / turbine size

	Reducing motion smear - rotor speed / turbine size
Description	Reducing rotor speed is a measure that adjusts the rotational speed of the turbine and / or the size of the rotor blades, leading to a reduction in motion smear. A larger blade is more visible, but the tip has to travel faster, increasing motion smear.
Benefits / impacts	
Drawbacks / risks	Larger turbine blades are more visible, but the tips of the blades have to move faster to cover the same distance, therefore increasing motion smear. Very large turbine blades may also be outside the peripheral vision of the bird as it approaches.
Effectiveness / status	
Application	
Other comments	-

Table2.4.2.3b Reducing motion smear –rotor speed / turbine size

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	Medium	Medium
Larger blades would be complex to retro-fit. There is a trend towards larger turbines and blades up to 150m diameter for 10 MW generators (Dvorak, 2010).	Because of gearing mechanisms within the generators, changing rotor speed would not affect productivity. Increasing turbine size would incur a cost, but this would be outweighed by the benefits of greater productivity.	Studies in the United States and Canada have shown that reducing rotor speed significantly reduced numbers of bat fatalities. This may be transferrable to bird collisions with offshore wind turbines in the Greater Wash, although the reasons for mortality in bats are different from those in birds. Lower rotor speed can be expected to reduce motion smear and therefore collision risk. The tips of the blades of larger turbines will have to travel faster, increasing the effects of motion smear. The problem may be exacerbated by the tips of the blades being outside a bird's peripheral vision.

Table2.4.2.4a Increasing visibility - use of ultraviolet paint / material

	Increasing visibility - use of ultraviolet paint / material
Description	This measure involves increasing the visibility of wind turbine blades through application of ultraviolet paint or other ultraviolet material.
Benefits / impacts	This measure is suggested as potentially helpful in alerting birds to the presence of the rotors. Initial indications from one study (Curry and Kerlinger, 2000) suggested that flight behaviour around the turbines may be influenced by the provision of visual cues. However it noted that more research is needed.
Drawbacks / risks	It may be that because birds can see light in the ultraviolet range, objects reflecting or emitting ultraviolet light are simply viewed as a different colour to the avian eye.
Effectiveness / status	Overall it is noted that there have been limited trials and more research is needed. One study (Klem, 2009) investigated the efficacy of utilising ultraviolet reflective material to make birds aware of glass being present. It showed that uniformly covering windows with decals or other objects that are separated by 5 to 10 cm was completely or near-completely effective in preventing strikes. Twice the number of window strikes occurred at non-reflective sheet glass compared to conventional clear panes. This is currently still undergoing testing. Another (older) study (Young *et al.* 2003) did not provide strong evidence that there is a difference in bird use, mortality, or risk between turbine blades painted with a ultraviolet - light reflective paint and those painted with conventional paint.
Application	Due to limited research few recommendations can be made at this point regarding wind plant design features to minimise avian impacts.
Other comments	-

Table2.4.2.4b Increasing visibility - use of ultraviolet paint / material

Feasibility	Cost of implementation / operation	Effectiveness
High	Low	Low
There have only been limited trials so far, so this is a novel technique. Ultraviolet paint is easily available and its application is straightforward.	As compared to other mitigation techniques, painting blades is relatively inexpensive for wind turbine operators.	There is little evidence that this technique is effective. It is possible that painting rotor blades to make them more conspicuous will have different levels of effectiveness depending on environmental conditions. For example, painted rotor blades might contrast highly with the sky during the day, but have very low contrast under low light conditions. As such, any trial involving the painting of rotors and pylons would have to monitor carefully when mortality occurs as well as overall mortality. It could well be that one mitigation will reduce mortality under one set of conditions, but not under another. Birds that see in the ultraviolet also see well in the visible so it is unclear whether making something visible in the ultraviolet will give it extra salience for birds. Ultraviolet reflectance by selected paints is no different from increasing reflectance in other parts of the spectrum by using paints, i.e. it is no different from recommending yellow, green or red paint; all they do is restrict reflectance to one part of the spectrum. This is the same as would be achieved by using ultraviolet reflecting paint, in fact a selective ultraviolet reflecting surface would look black (to humans) since it would absorb at all other wavelengths apart from the ultraviolet. There has been some speculation that white or grey turbines may attract insects and therefore bats and birds (Long *et al.* 2010). It is unlikely that insectivorous birds are attracted to offshore foraging.

Table 2.4.2.5a Increasing visibility - use of lighting

	Increasing visibility through use of lighting, e.g. strobe lights
Description	This mitigation option involves attaching lighting (e.g. strobe lights) to turbines to increase visibility and alert birds.
Benefits / impacts	A study on minimising bird collisions (Bates and Timberlake 2010) noted that night lighting in high rise buildings can significantly increase the likelihood of night time migratory fatalities.
Drawbacks / risks	This measure must be used with extreme caution. Offshore wind turbines, if lit at night, could potentially pose similar risks to communication towers. Artificial lights at night have been well documented as being an attractant to migrant birds. Birds migrating at night can be attracted to sources of artificial light, particularly during periods of inclement weather (Percival 2001). Lighting appears to be the single most critical attractant, and preliminary research indicates that solid and pulsating red lights seem to be more attractive to birds at night during inclement weather conditions than are white strobe lights (Erickson *et al,.* 2001). Another study (Clarke 2004) noted that strobe lights and laser deterrents were the two methods that had the highest potential for being useful in an autonomous, minimal disturbance bird deterrent system. One study (Poot *et al.* 2008) noted that nocturnally migrating birds were disoriented and attracted by red and white light (containing visible long-wavelength radiation), whereas they were clearly less disoriented by blue and green light (containing less or no visible long-wavelength radiation). This was especially the case on overcast nights. Strict international guidelines on lighting and marking of offshore structures, including wind farms, might be contravened if lighting was changed.
Effectiveness / status	Red strobe or strobe-like lights do not appear to influence bat and songbird fatalities (Avery *et al.* 1976). Using different light patterns to increase the visibility of the rotating blades is of unknown effectiveness. One study tested the effectiveness of 250w white landing lights pulsed at 45 cycles/min in influencing behaviour of captive birds in response to an oncoming ground-based vehicle. The avoidance response was inconsistent across experiments with Cowbirds, and little or no avoidance behaviour was observed in experiments with other species (Blackwell and Bernhardt 2004).
Application	-
Other comments	-

Table 2.4.2.5b Increasing visibility - use of lighting

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	Low	Low
The main barrier to changing lighting is ensuring sufficient visibility to shipping and aviation. There are mandatory requirements which cannot be neglected.	Lighting would likely represent a low cost implementation and operation option for a wind turbine operator.	A significant barrier to implementation exists, in that research suggests that lights can actually attract birds towards the turbines. This would increase rates of avian collision. A study (Clarke 2004) noted that strobe lights and laser deterrents were the two methods that had the highest potential for being useful in an autonomous, minimal disturbance bird deterrent system. However, lighting at night, whether steady or strobe, is a very controversial mitigation option since experience with light from housing and large buildings suggests that lit objects can actually become a trap for birds under conditions of mist and fog.

Table 2.4.2.6a Minimal use of lighting

	Minimal use of lighting
Description	Minimal use of lighting with the intention of reducing collision risk by reducing the attraction of potential prey and the likelihood of disorientation of birds. Under poor visibility terrestrial birds are attracted by illuminated offshore obstacles and mainly passerines collide in large numbers (Hüppop *et al.* 2006).
Benefits / impacts	This is a fairly low cost option.
Drawbacks / risks	Strict international guidelines on lighting and marking of offshore structures, including wind farms, might be contravened if lighting was reduced.
Effectiveness / status	The results of one study (Gehring *et al.* 2009) stated that avian fatalities could be reduced, perhaps by 50–71%, at guyed communication towers by removing non-flashing / steady-burning red lights.
Application	Shield all outside lights (except navigation lights) towards the sky and systematically record any incidence of birds at the platform before and after shielding. Turn off all unnecessary outside lights.
Other comments	-

Table 2.4.2.6b Minimal use of lighting

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Low	Low	Medium
There is no widespread application at offshore wind farms. The main barrier to minimal lighting is ensuring sufficient visibility to shipping and aviation. There are mandatory requirements which cannot be neglected.	Lighting would likely represent a low / medium cost implementation and operation option for a wind turbine operator.	With use of lighting having been proven to attract birds towards offshore wind farms, minimising use of lighting should reduce avian collision risk. One study indicated that avian fatalities could be reduced by 50-71%, at guyed communication towers by removing non-flashing/steady-burning red lights. This could easily be applied to offshore wind farms.

Table 2.4.2.7a Laser deterrents

	Laser deterrents
Description	The basic operation is the training of a laser emitter on a target bird, resulting in the species leaving the site.
Benefits / impacts	A study (Bridges *et al.*, 2004) showed that lasers are highly effective against most, but not all, species of birds. Some species are highly responsive to the application of lasers, while others have little or no response.
Drawbacks / risks	The variation in species sensitivity requires that species targeted and receptivity to laser light wavelengths to be known. The use of lasers also requires an operation to regularly disperse the birds, adding significantly to the cost.
Effectiveness / status	Currently there is no indication that species habituate to lasers, indicating that they could be a suitable technology for areas where bird presence is particularly problematic.
Application	Research to determine species type and severity of problem necessary, particularly in order to justify the cost of an operator.
Other comments	-

Table 2.4.2.7b Laser deterrents

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	Medium	Medium
Laser technology is available and has been used in other sectors to deter birds. There may be barriers to the installation and remote operation of laser equipment in an offshore environment.	Use of lasers would likely represent a considerable cost for a wind turbine operator both in terms of implementation and operation.	Further research in this area is needed as some bird species are highly responsive to the application of lasers, while others have little or no response. It is unclear whether lasers would be effective at increasing the visibility of offshore wind farms since they operate at visible wavelengths and in fact within very narrow spectral bands. It does not necessarily follow that laser light should be any more effective in deterring birds from wind farms than light from other sources.

Table 2.4.2.8a Structural modifications – decoy towers

	Structural modifications – decoy towers
Description	This mitigation option involves carrying out structural modifications within the wind farm to minimise avian collision. For example, decoy towers without functioning blades, which could be considered as a potential risk-reduction measure. The approach has been trialled at Altamont in an attempt to reduce collisions at the end of turbine strings.
Benefits / impacts	The idea behind decoy towers is that the provision of alternative perches would help keep birds away from turbines (Curry and Kerlinger 2000).
Drawbacks / risks	Decoy towers may attract birds to the general area of the turbines, or encourage them to remain longer.
Effectiveness / status	The effectiveness of decoy towers is not known.
Application	-
Other comments	Offshore sub-stations might serve the same purpose as decoy towers, depending on their location in relation to the wind-farm.

Table 2.4.2.8b Structural modifications – decoy towers

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	Medium	Low
The use of decoy towers is not yet known, and warrants further investigation. It may be easier to test the principle initially on land than at sea. Constructing a decoy tower is likely to be no more difficult than constructing a turbine tower. However, this approach would increase the 'footprint' of the wind-farm, potentially impacting on other sea users and navigational safety. There is potential for increased indirect habitat loss and barrier effects.	The installation of decoy towers would likely represent a relatively significant cost for a wind turbine operator in terms of implementation and operation.	The use of decoy towers without functioning blades is one idea under consideration as a potential risk-reduction treatment in the Altamont Pass Wind Resource Area, California. However, the effectiveness is not known, and while provision of these alternative perches would help keep birds off the turbines, it might also attract birds to the general area of the turbines, or encourage them to remain longer. This would increase avian collision rates.

Table 2.4.2.9a Remote sensing and monitoring.
Includes Thermal Animal Detection Systems (TADS), population modelling and tracking, other remote sensing techniques and radar.

	Remote sensing and monitoring
Description	Thermal Animal Detection Systems (TADS) TADS (Desholm *et al.* 2006) uses an infra-red video camera in an attempt to record birds flying in close proximity to wind turbines. TADS seems to be the only remotely controlled type of hardware arrangement that has been used for monitoring the collision frequency in offshore areas. Population modelling and tracking Development of demographic and distributional (or spatial) models to predict, and subsequently test predictions, of population-level impacts attributable to the wind farm, as distinct from other factors. Other remote sensing techniques Other remote techniques include the use of pressure / vibration sensors within turbine blades to detect bird strikes and acoustic detection to monitor bird movements from their calls. One study (Carlton and Harness, 2001) discussed two types of automated system – one to monitor and document bird collisions with wires and guys (Bird Strike Indicator), and the other to videograph bird activities on and around structures (Bird Activity Monitor). Used separately and together, these automated observation systems will enable determination of the frequency of avian interactions (e.g. strikes) as well as examination of bird behaviours that can lead to injuries and fatalities. Radar A combination of horizontal and vertical radar can provide information on flight direction and flight heights.
Benefits / impacts	Thermal Animal Detection Systems (TADS) TADS can provide valuable information on flight behaviour, avoidance and collisions, especially in offshore areas where visual observations and the collection of corpses is not feasible, thus providing essential data to populate collision avoidance models. TADS can also function in conditions of poor visibility and at night. Population modelling and tracking Spatial population models are especially valuable for studies of displacement of birds in the offshore environment, where the data on abundance and distribution are usually based on particularly small samples and are themselves subject to wide confidence limits. Population modelling is also essential for predicting the possible cumulative displacement of bird populations on a wider scale resulting from the combined impacts of several wind farms. Further research and monitoring can also identify 'pinch points', where migratory corridors are relatively narrow and where birds are most likely to cross wind farm footprints in greatest numbers. Radar An important advantage of radar over visual observations is that it allows continuous and simultaneous sampling of bird movements over a large area, regardless of time of day and visibility conditions. Continuous sampling is desirable for monitoring bird movements, especially at sea, as such movements are often complex and fluctuate greatly.

	Remote sensing and monitoring
Drawbacks / risks	Radar Weather and air-surveillance radar have limited range, so can only be used a certain distance offshore (dependent on coverage at any given location). Coverage can be improved by installation of additional radars. Scan strategy (scanning at multiple elevations, or one elevation) will be determined by the operational set-up of radars and how they are used for their primary purpose (it is not a limitation of the hardware itself).
Effectiveness / status	Thermal Animal Detection Systems (TADS) Undergoing testing. Population modelling and tracking In use. Other remote techniques Undergoing testing. Radar The real time use of weather radar in the mitigation of bird strike to aircraft is proven and now in use. In the UK, until recently, there has been little deployment of radar to assist wind farm environmental assessments, partly because of the lack of available equipment and expertise.
Application	-
Other comments	The Collaborative Offshore Wind Research into the Environment (COWRIE) Steering Group has commissioned a project to develop best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore wind farms.

Table 2.4.2.9a continued

Table 2.4.2.9b Remote sensing and monitoring (radar only)

Feasibility	Cost of implementation / operation	Effectiveness
Medium	Medium	High
In the case of weather radars in the UK, some development work would be required to build software to detect the birds in radar data. It would be of considerable interest to apply this technique to monitor birds' movements about and through a wind farm using radar. However, there will be problems of setting a threshold of bird density for triggering a warning and subsequent action.	Past studies have used radar networks that are already in use (no installation cost) in combination with smaller, cheaper mobile radars, purpose built for bird detection. As well as installation / hardware costs, a lot of expertise is required to design the best set-up for any given detection system.	These approaches do not directly reduce collision risk but can be associated with measures such as temporary shut-down. Real time observations of birds from radar can be used to mitigate the risk to birds at wind farm sites. Military radars cannot detect individual species, but are used in conjunction with specialist bird detection software (e.g. FlySafe and ROBIN). Weather radars can scan at several elevation angles (the military radars in FlySafe only scan at one elevation), so data can be collected from a larger volume, as well as the additional altitudinal information.

Table 2.4.2.10a Auditory deterrents

	Auditory deterrents
Description	Use of scaring devices, such as recorded birds' alarm calls, whistles or low frequency sound to reduce avian collisions.
Benefits / impacts	
Drawbacks / risks	Can be unacceptably intrusive if close to human use - any sound audible to birds will also be audible to humans, as the range of bird hearing is narrower than the range of human hearing. There may be a less pressing need to make deterrents inaudible to humans in an offshore environment, although the needs of shipping and other offshore installations would still have to be taken into account. Effective scaring techniques may make the wind farm area unsuitable for birds and so equate to habitat loss.
Effectiveness / status	No acoustic strategies have proven effective over the long term because of habituation. It is possible that habituation is not such a problem for migratory species that only encounter wind farms infrequently and irregularly, although no evidence was found to support this view. One study (Drewitt and Langston, 2008) stated that scaring devices, such as recorded birds' alarm calls, are likely to be of limited and only short-term effectiveness and in some cases have been shown to have no effect. Another study (Bishop *et al.* 2003) indicated a belief that auditory deterrents were the most effective (evidence unclear). Ultrasonic and infrasonic devices have been shown to lack effectiveness (Bates and Timberlake, 2010). A number of studies suggest that further experiments and research are needed.
Application	-
Other comments	-

Table 2.4.2.10b Auditory deterrents

Feasibility	**Cost of implementation / operation**	**Effectiveness**
Medium	Low	Low
Auditory deterrents can be unacceptably intrusive if close to human use - any sound audible to birds will also be audible to humans, as the range of bird hearing is narrower than the range of human hearing. This is not directly applicable to offshore wind turbines. Background noise from the sea is a potential barrier. Further testing / research is needed into the use of auditory deterrents. Impacts on marine mammals and / or fish are unlikely to be significant. Auditory bird deterrents would be deployed at height. Operational noise underwater is relatively low (Nedwell *et al*, 2007).	The installation and operational costs of auditory deterrents are unlikely to be high. They could be used as a deterrent during the autumn for nocturnal migrants i.e. targeted use, thus further reducing the cost.	Studies of auditory deterrents have tended to demonstrate that effectiveness declines over time as a result of habituation. It is unclear whether habituation is an issue for migratory birds that encounter the deterrent only infrequently and irregularly.

2.5. Discussion and Conclusions

As a result of the literature review and telephone interviews we have identified a number of avian collision mitigation techniques at the national and international level. These apply across a variety of sectors, including onshore wind, aviation, architecture, power supply and communications. Information about options has been identified from sources throughout the world, including the UK, Europe, the United States and South Africa.

Despite the prevalence of information about mitigation options, few techniques have been extensively tested, especially in the offshore wind sector. Even fewer have been implemented. In the UK, for example, the only mitigation in regular use relates to siting, orientation and spacing of turbines. This is borne out by evidence from telephone interviews with key contacts with experience of the offshore wind sector.

As many of the measures assessed in this section are novel or have only been applied in a different context, there is some uncertainty in the criteria, particularly relating to effectiveness. Most of the mitigation measures discussed require experimental testing, possibly initially on land.

2.5.1 Evaluating the shortlisted options

Of the 16 mitigation options identified, each was assessed in terms of the 'novelty' of the approach in order to reduce the list to ten options. These shortlisted options were further assessed using three evaluation criteria (feasibility, cost of implementation / operation and effectiveness) in order to determine which are the likely to be the most feasible and effective, at the least cost. The results of that evaluation are summarised in Table 2.5.1.1.

Table 2.5.1.1 Comparison of shortlisted mitigation options

Mitigation option	Feasibility	Cost	Effectiveness
Temporary shut-down	Medium	High	High
Reducing motion smear – anti-motion-smear patterns	High	Low	Medium
Reducing motion smear – lower rotor speed / larger turbines	Medium	Medium	Medium
Increasing visibility - use of ultraviolet paint / material	High	Low	Low
Increasing visibility - use of lighting	Medium	Low	Low
Minimal use of lighting	Low	Low	Medium
Laser deterrents	Medium	Medium	Medium
Structural modifications – decoy towers	Medium	Medium	Low
Remote sensing and monitoring Includes Thermal Animal Detection Systems (TADS), population modelling and tracking, other remote sensing techniques and radar	Medium	Medium	High
Auditory deterrents	Medium	Low	Low

2.5.2 Feasibility

None of the options were considered to be impossible to implement. The most feasible options are those that are straightforward to put in place and can be applied to both new and existing wind farms. For example, applying anti-motion-smear patterns or painting with ultraviolet paint are easily applied. Temporary shut-down is carried out routinely for safety and maintenance operations, but has not been applied to avian collision mitigation. In order to be implemented, it requires appropriate thresholds to be set, monitoring to trigger those thresholds and protocols for shut-down and start-up. Reducing motion smear through lower rotor speeds similarly depends upon appropriate monitoring and equipment to adjust the speed as necessary. Use of larger turbines is most likely to be applicable at the design stage of new turbines or wind farms but would be complex to retro-fit. Another structural modification is the use of decoy towers. Using lasers as a deterrent or remote sensing techniques such as radar require specialist equipment and careful design and installation if they are to be effective. Auditory deterrents also require specialist equipment and may be affected by background noise from the sea.

2.5.3 Cost of implementation / operation

The costs of implementation or operational impacts are essential components in considering any mitigation option. If the costs are too high, then operators are unlikely to take them up.

The most costly option is considered to be temporary shut-down, which has a direct impact on revenue. The use of lower rotor speed and / or larger turbines is considered to be of medium cost, because of the cost of alternative design or retro-fitting existing installations. Low cost options equate closely to several of the easily feasible measures described above – application of anti-smear-patterns and use of ultraviolet paint. Minimal lighting is not simply a case of turning out the lights because of the need to maintain visibility for shipping and aviation. However, this remains a relatively low cost measure.

2.5.4 Effectiveness

The research carried out during this project has suggested that some of the options shortlisted may not be sufficiently effective in reducing the risk of avian collision. Lighting is known to attract birds at sea and it is therefore likely that strobe lights will not be an effective option. Decoy towers may also attract birds, instead of deterring them. Habituation to noise renders most auditory deterrents ineffective over time, although the extent of habituation in migrating birds is unclear. Temporary shut-down is perhaps the most potentially effective method, with lower rotor speeds and larger turbines also proving successful. In considering visual deterrents, it is important to understand what birds see. It is noted, for example, that ultraviolet paint is unlikely to be any more effective than any other paint because birds see just as well in the visible range. Visual deterrents may also vary in effectiveness in different light conditions, an important factor to bear in mind when considering nocturnal migrants.

The shortlisted options give an indication of a variety of possible methods for reducing the risk of avian collision. Few have been developed beyond a theoretical stage, and there is a considerable need for further research to establish a stronger evidence base for selecting options.

Two of the shortlisted options – minimal use of lighting and auditory deterrents – were not taken forward for subsequent consideration in this report due to their respective low feasibility and effectiveness.

3. IDENTIFICATION OF SPECIES MOST VULNERABLE TO COLLISION MORTALITY FROM OFFSHORE WIND FARMS

3.1 Introduction

The third objective of this work aims to identify which bird species are considered most at risk, i.e. vulnerable, to collision mortality with offshore wind farms in UK waters, and thus inform the remaining objectives of the work.

The risk or vulnerability of species to the effects of developments, such as offshore wind farms, reflects the combination of both species' sensitivities and exposure to these effects. In this review, we thus first consider which UK species are likely to be most sensitive to the effect of collision mortality with offshore wind farms in UK waters, before then considering which species might be exposed to this effect as a result of Round 1 and 2 developments, potential Round 1 and 2 extensions, Round 3 sites, and sites planned for Scottish Territorial Waters. We consequently summarise which species are likely to be most vulnerable to this effect.

3.2 Methods

3.2.1 Species sensitivity

Species' sensitivity to the effect of collision mortality with offshore wind farms will reflect a number of factors relating to i. their flight behaviour and ii. their population status and life-history traits.

Factors that are associated with flight behaviour, and may affect species' sensitivity to collisions with wind farm turbines, include the following variables:

- <u>Flight manoeuvrability</u>: the lower the species' manoeuvrability, the higher the risk of colliding;
- <u>Flight altitude</u>: the greater the time spent at the height at which rotor blades operate, the greater the risk;
- <u>Percentage time flying</u>: the greater the time spent flying, the higher risk of colliding;
- <u>Nocturnal flight activity</u>: more nocturnal flight activity is expected to lead to higher collision risk.

Factors associated with population status, i.e. population size and trends and life-history traits, that may affect the sensitivity of species' populations to withstand the mortality associated with collisions with wind farm turbines include:

- <u>Biogeographical population size</u>: the smaller population size, the larger the risk that effects associated with wind farm developments may impact on the population;
- <u>Adult survival rate</u>: species with high annual adult survival rates (which also normally have low reproductive rates) may be less able to withstand any increase in mortality brought about by collisions with wind farm developments;
- <u>Reproductive rate</u>: species with low reproductive rates may be less able to compensate for any increase in mortality brought about by collisions with wind farm developments;
- <u>Current population trend:</u> the impact of any increase in mortality brought about by collisions with wind farm developments will be greater for those species declining in numbers than those with stable or increasing population trends.

Using such information, three previous studies (Garthe & Hüppop 2004, King *et al*. 2009, Langston 2010) have appraised the sensitivities of bird species to the effects associated with offshore wind farms. These studies considered aspects relating to all the effects that offshore wind farms might have, i.e. in addition to collision mortality, displacement due to disturbance and barrier effects.

Garthe and Hüppop (2004), and King *et al.* (2009) which follows that study, included all the factors mentioned above, apart from reproductive rate, and as a proxy of current population trend they used the information given by Tucker & Heath (1994) that reflects both threat and conservation status. Their Species Sensitivity Index (SSI) was calculated by the formula:

$$SSI = \frac{(a+b+c+d)}{4} \times \frac{(e+f)}{2} \times \frac{(g+h+i)}{3}$$

using scores for *a* = Flight manoeuvrability, *b* = Flight altitude, *c* = Percentage time flying, *d* = Nocturnal flight activity, *e* = Disturbance by ship and helicopter traffic, *f* = Flexibility in habitat use, *g* = Biogeographical population size, *h* = Adult survival rate and *i* = European threat and conservation status. For full explanation of the formula, see Garthe and Hüppop (2004).

Recently, Langston (2010) used a three-level categorical system for defining species' sensitivities to 'Collision risk', 'Displacement', 'Barrier', and 'Habitat/Prey' effects based on Garthe and Hüppop (2004) and experience from operational wind farms, and a score for conservation status based on the minimum % of the relevant biogeographical population breeding in Great Britain. A species-specific value for 'Overall Risk' was derived by taking the highest value from each of these scores.

In this review, we present and compare the scores presented in Garthe and Hüppop (2004), King *et al.* (2009) and Langston (2010), highlighting the specific sensitivities of species to collision mortality.

Using published sources (i.e. Baker *et al.* 2006, JNCC 2010a, 2010b, O'Brien *et al.* 2008, Stroud *et al*. 2001) we also present information on the UK population sizes of those species considered in this review, as well as the numbers included as breeding or wintering features of UK Special Protected Areas (SPAs) in the UK.

3.2.2 Species exposure

A species' sensitivity to the adverse effects of wind farms is of no consequence if that species is not exposed to wind turbines. This scenario would arise if no wind farms fell within a species' biogeographical range. With this in mind, we set out to identify which species are likely to encounter both existing and proposed offshore wind farm zones around the United Kingdom, encompassing existing Round 1 and 2 developments, potential Round 1 and 2 extensions, Round 3 sites, and sites planned for Scottish Territorial Waters.

The exposure of birds to offshore wind turbines is difficult to assess, because of substantial variation in the location of individuals of a species. This is due to several factors, including temporal cycles (for example, migration and chick provisioning during the breeding season), and environmental constraints, such as food availability and weather conditions. Such difficulty is compounded by a relative paucity of data available on the behaviour of species at sea. Existing datasets, for example the JNCC's European Seabirds at Sea (ESAS) database (http://www.jncc.gov.uk/page-1547; http://seamap.env.duke.edu/datasets), have gaps in their coverage (Pollock & Barton 2006) but do give estimates of the relative distributions of species. However, technological advances, such as the use of GPS loggers that pinpoint individuals during their offshore flights, are improving our understanding of this topic (Burger & Shaffer 2008).

For the purposes of this review, we examined offshore wind farm exposure for those species considered at High or Moderate Risk of colliding with wind turbines (after Langston 2010) – see section 3.3.1. For those seabird species listed, we produced two sets of maps to indicate whether these species were likely to traverse wind farm zones.

The first series of maps was designed to evaluate the exposure to offshore wind farms of populations of these species from those UK SPAs for which they are interest features (following Stroud *et al*. 2001). Representative foraging range values were taken the review of peer-reviewed published and grey literature undertaken by Thaxter *et al.* (in review). Here, we used the mean maximum ranges presented by that study. Using these values, the potential foraging areas of seabirds around the SPAs for which they are features were projected onto maps as a radius from each SPA. The locations of the offshore wind farms development zones were also mapped, to show which species could potentially encounter wind farms during their foraging activities from the SPAs.

Using these maps, we tabulated which SPA species' populations might potentially be exposed to the effect of collision mortality with offshore wind farms. It should be noted that the estimates of foraging ranges used in this appraisal were selected to be representative, in an attempt to give a typical view of the likelihood of exposure. Therefore, the figures used might be conservative and hence underestimate the number of SPAs affected for each species, especially given the limited knowledge of species' behaviour at sea. Thus, SPAs for which species' foraging ranges narrowly miss a wind farm zone are also listed. It should also be borne in mind that these maps show a theoretical foraging range around each SPA and do not represent species' actual foraging ranges, and that actual foraging ranges will not cover a fixed area throughout the time that each species resides in a particular SPA.

The second series of maps was created in order to address these issues, as well as taking into account species or populations that are not features of SPAs, while also providing some indication of individuals' locations during seasons when they might not be based at an SPA (e.g. outside the breeding season, or during migration). These maps used data on the average numbers of birds per km^2 recorded per survey visit across the year from the ESAS database to evaluate the overlap in the at-sea distributions of each species of High or Moderate Collision Risk and offshore wind farm development zones. It should be noted that the data obtained from the ESAS database provide an overview of the average distribution of seabirds at sea across the year, and do not show differences in survey effort across the year between areas.

3.3 Results

3.3.1 Species sensitivity

The three major studies quantifying different bird species' sensitivities to offshore wind farms (i.e. Garthe & Hüppop 2004, King *et al.* 2009, Langston 2010) together provided sensitivity scores for 81 species or subspecies / biogeographic populations (Table 1). Garthe and Hüppop (2004) and King *et al.* (2009) together estimated Species Sensitivity Indices for 70 species, whereas Langston (2010) estimated an 'Overall Risk' for 57 species. All in all, 47 species were evaluated by both studies.

Red-throated Diver *Gavia stellata* and Black-throated Diver *Gavia arctica* were classified as being of highest overall sensitivity to offshore wind farm developments by Garthe and Hüppop (2004), while Langston (2010) also placed them in the highest Overall Risk category (Table 3.3.1).

The results of the two approaches are not always in agreement, however. For example, Bewick's Swan *Cygnus columbianus*, Dark-bellied Brent Goose *Branta bernicla bernicla*, Velvet Scoter *Melanitta fusca*, Great Cormorant *Phalacrocorax carbo*, European Shag *Phalacrocorax aristotelis*, Slavonian Grebe *Podiceps auritus*, Little Tern *Sternula albifrons*, Sandwich Tern *Sterna sandvicensis* and Black Guillemot *Cepphus grylle* were all classified as being of high overall sensitivity to offshore wind farm developments by Garthe and Hüppop (2004) and King *et al.* (2009) – having Species Sensitivity Indices of at least 21.7 – whereas they were classified as species being of intermediate risk by Langston (2010) (Fig. 3.3.1 and Table 3.3.1). Similarly, Pink-footed Goose *Anser brachyrhynchus*, Greylag Goose *Anser anser* (Icelandic race), European White-fronted Goose *Anser albifrons albifrons*, Manx Shearwater *Puffinus puffinus*, Northern Gannet *Morus bassanus*, Great Skua *Stercorarius skua*, Lesser Black-backed Gull *Larus fuscus* were all classified as being of relatively low overall sensitivity to offshore wind farm developments by Garthe and Hüppop (2004) and King *et al.* (2009) – having Species Sensitivity Indices of 8.7-16.5, whereas Langston (2010) classified them as species with high Overall Risk (Fig. 3.3.1 and Table 3.3.1).

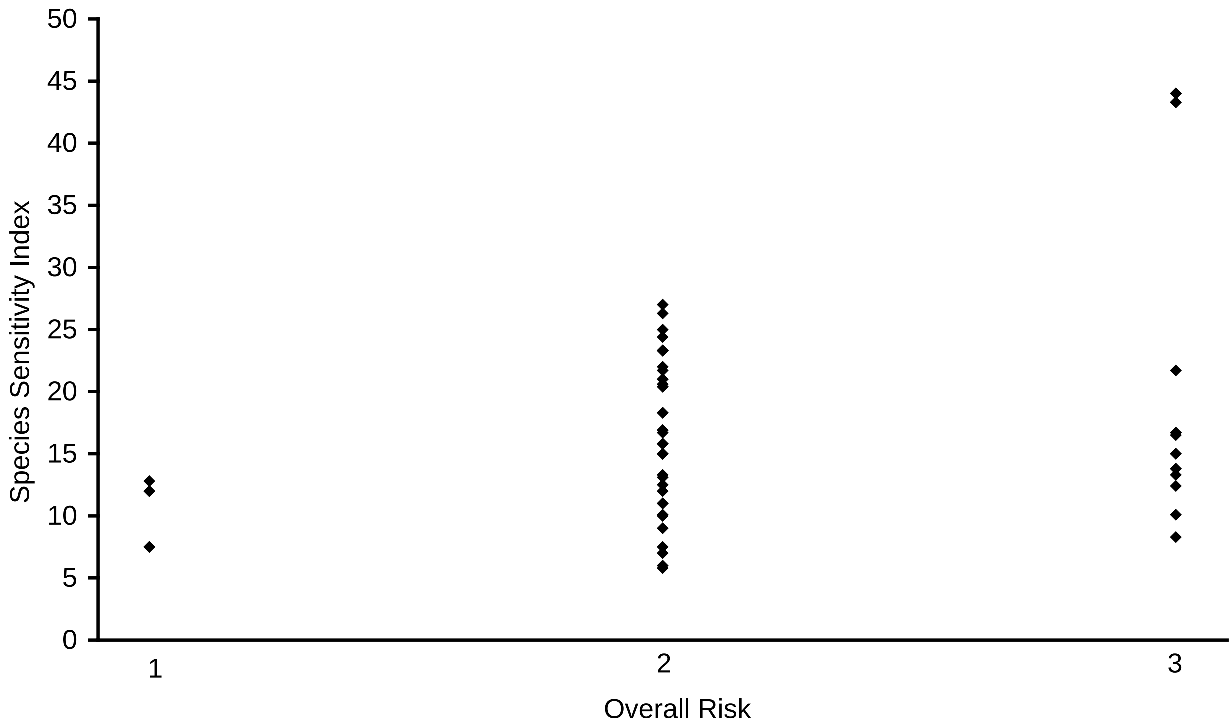

Figure 3.3.1 Relationship between the Species Sensitivity Index presented by Garthe and Hüppop (2004) and followed by King *et al.* (2009) and the Overall Risk score presented by Langston (2010). Only species that had been evaluated by both studies (n = 47) are included in the graph.

The two different ways of estimating a species' sensitivity to wind farm developments (i.e. Garthe & Hüppop 2004, King *et al.* 2009 vs. Langston 2010) both have their strengths and weaknesses. However, the approach described in Garthe and Hüppop (2004) is clear and offers other researchers a method that can be extended to other species, as was done by King *et al*. (2009). The approach taken by Langston (2010) is perhaps less more subjective in that it is not clear how much influence the 'experience from operation wind farms' had in the classification.

Nevertheless, the approach provided by Langston (2010) does provide a simple assessment of species' potential sensitivities to each of the main effects pose by offshore wind farms, including collision risk. Comparison of the 'Collision Risk' scores from Langston (2010) with the combined scores from Garthe and Hüppop (2004) and King *et al*. (2009) for factors relating to flight behaviour and population status and life-history traits that are associated with species' sensitivities to the effect of collision mortality reveals a good level of accord (Fig. 3.3.2).

Given this close correlation, from henceforth, we define the species that are sensitive to the effect of collision mortality with offshore wind farms as those having High or Moderate Collision Risk scores in Langston (2010). Species not considered by Langston (2010) that were considered by the other studies, though primarily by King *et al.* (2009), were mostly waders and wildfowl, which would only be at risk during migration periods.

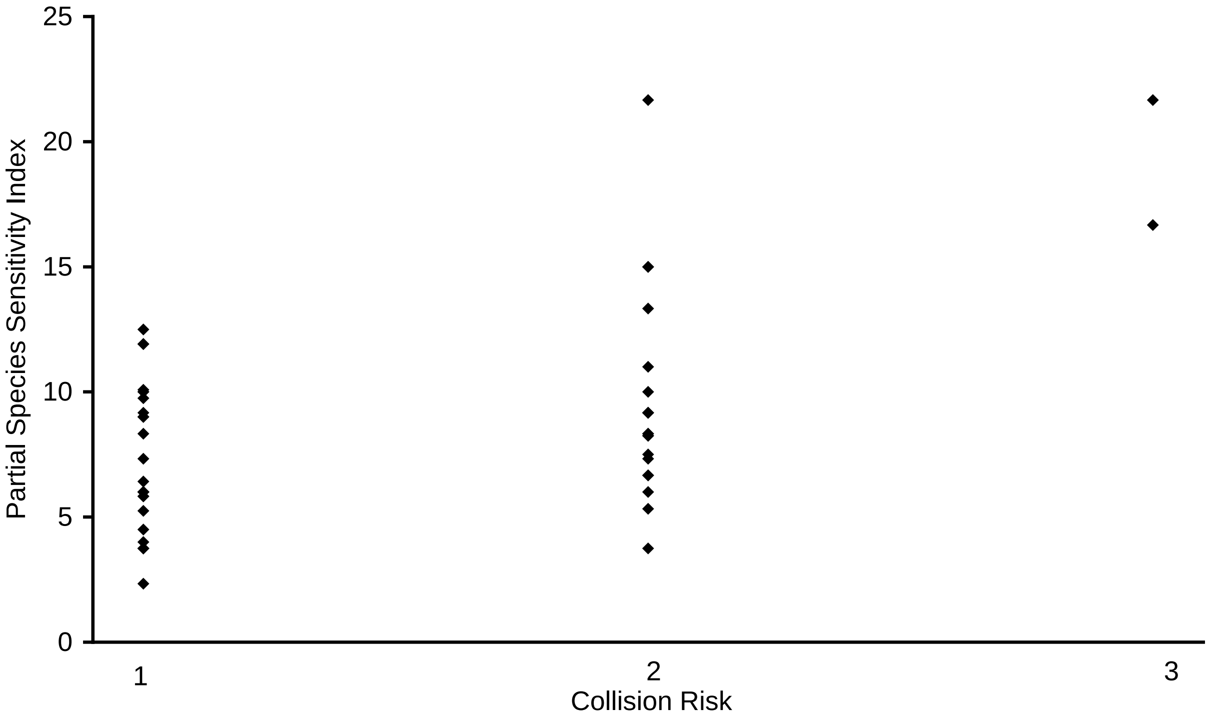

Figure 3.3.2 Relationship between the Partial Species Sensitivity Index derived from Garthe and Hüppop (2004) and King *et al.* (2009) for factors relating to flight behaviour and population status and life-history traits that are associated with species' sensitivities to the effect of collision mortality* and the 'Collision Risk' scores presented by Langston (2010). Only species that had been evaluated by both studies (n = 47) are included in the graph.

* - Partial *SSI* calculated as $\frac{(a + b + c + d)}{4} \times \frac{(g + h + i)}{3}$

with scores for *a* = Flight manoeuvrability, *b* =Flight altitude, *c* = Percentage time flying, *d* = Nocturnal flight activity, *g* = Biogeographical population size, *h* = Adult survival rate and *i* = European threat and conservation status.

3.3.2 Species exposure

In total, 31 species or species' populations were classified as having High or Moderate Collision Risk scores by Langston (2010). For the 17 seabird species, we produced maps showing the species' foraging ranges from SPAs and their at-sea-distributions (from ESAS data) in relation to offshore wind farms (Figures 3.3.3 to 3.3.34).

Tables 3.3.2 and 3.3.3 provide summaries of the information on species' foraging ranges and the source studies, and for each species, which SPA populations might potentially be exposed to the effect of collision mortality with offshore wind farms.

It should be re-iterated that the foraging areas shown in the figures in this report are based on representative foraging ranges for the species (following Thaxter *et al.* in review) and thus do not necessarily represent the actual foraging areas used by birds from each colony.

For all but two of these species (Arctic Skua *Stercorarius parasiticus* and Great Skua), the estimated foraging ranges for individuals from SPAs were found to overlap with the zones of existing or potential wind farms. (Table 3.3.2). Round 3 sites fell within the SPA foraging ranges of five species (Great Cormorant, Northern Gannet, Black-legged Kittiwake *Rissa tridactyla*, Mediterranean Gull and Arctic Tern *Sterna paradisaea*), and were just outside the foraging range of one other species, the Lesser Black-backed Gull (Table 3.3.3). Pomarine Skua *Stercorarius pomarinus*, Long-tailed Skua *Stercorarius longicaudus*, Iceland Gull *Larus glaucoides* and Glaucous Gull *Larus hyperboreus* are only present in UK waters in small numbers and thus face limited exposure to the offshore wind farm development zones.

Examination of ESAS data (Figs. 3.3.3 to 3.3.34) revealed that individuals of every species examined, except for the Roseate Tern *Sterna dougallii*, have also been sighted in the zones of proposed Round 3 developments, as well as other in wind farm zones closer to shore.

A further 14 migrant species or species' populations, primarily wildfowl, were also classified as having High or Moderate Collision Risk scores by Langston (2010). These were: Bewick's Swan, Whooper Swan *Cygnus cygnus*, Bean Goose *Anser fabalis* (Tundra), Pink-footed Goose, Greenland White-fronted Goose *Anser albifrons flavirostris*, European White-fronted Goose, Greylag Goose (Iceland), Greylag Goose (NW Scotland), Barnacle Goose *Branta leucopsis* (Nearctic), Barnacle Goose (Svalbard), Dark-bellied Brent Goose, Light-bellied Brent Goose *Branta bernicla hrota* (Svalbard), Light-bellied Brent Goose (Canada) and Corncrake *Crex crex*. The migration routes of all these species potentially take them through offshore wind farm development zones, though the Greylag Geese and Corncrake which breed in northwest Scotland probably face limited exposure. The remaining species all migrate to winter in the UK and northwest Europe either from the northwest, from Iceland, Greenland or High Arctic Canada or from the northeast, from the Siberian Arctic, and thus may cross several of the wind farm development zones.

Appendices 5-7 provide a summary of those species considered as being potentially vulnerable to collisions in the Round 3, Round 1 and 2 extension and Scottish Territorial Waters offshore wind farm development zones by Langston (2010) and thus needing to be included in any risk assessment.

3.4 Species vulnerability

A total of 31 species or species' populations were classified as having High or Moderate Collision Risk scores by Langston (2010) and are thus considered in this study as sensitive to the effect of collision mortality with offshore wind farms. Whether due to their foraging ranges from SPAs, or due to their presence in wind farm development zones at times of year that these species are not associated with SPAs, or due to their migration routes, all these species are potentially exposed and thus should be considered vulnerable to the risk of collision with Round 1 and 2 developments, potential Round 1 and 2 extensions, Round 3 sites, or sites planned for Scottish Territorial Waters. These species are: Great Cormorant, Northern Gannet, Bewick's Swan, Whooper Swan, Bean Goose (Taiga), Pink-footed Goose, Greenland White-fronted Goose, European White-fronted Goose, Greylag Goose (Iceland), Greylag Goose (NW Scotland), Barnacle Goose (Nearctic), Barnacle Goose (Svalbard), Dark-bellied Brent Goose, Light-bellied Brent Goose (Svalbard), Light-bellied Brent Goose (Canada), Pomarine Skua, Arctic Skua, Long-tailed Skua, Great Skua, Black-legged Kittiwake, Mediterranean Gull, Lesser Black-backed Gull, Herring Gull, Great Black-backed Gull, Sandwich Tern, Common Tern, Roseate Tern, Arctic Tern and Corncrake.

Greylag Goose and Corncrake which breed in northwest Scotland, and Pomarine Skua, Long-tailed Skua, Iceland Gull and Glaucous Gull, which are only present in UK waters in small numbers, probably face limited exposure to offshore wind farm development zones and should thus be considered to be less vulnerable to the effect of collision mortality. Effects on other species, such as the waders and wildfowl considered by King *et al.* (2009) should also not be discounted.

Table 3.3.1. Scores of species' sensitivity to the development of offshore wind farms taken from Garthe and Hüppop (2004) and Langston (2010). Scores relating to collision risk are highlighted.

Species	Population	Garthe and Hüppop (2004) / King *et al.* (2009)[1]										Langston (2010)							
		Flight manoeuvrability	Flight altitude	% time flying	Nocturnal flight activity	Disturbance by ship and helicopter traffic	Flexibility in habitat use	Biogeographical population size	Adult survival rate	European threat and conservation status	Sensitivity Score	Collision score	Displacement	Barrier	Habitat/Prey	GB/UK min %	Over-all Risk	UK population[2]	Number of SPAs (assemblage component only)[3]
Red-throated Diver	Breeding	5	2			4	4	4	3	5	43.3	*	***	**	**	**	***	1,218 P	9
Red-throated Diver	Wintering	5	2	2	1	4	4	4	3	5	43.3	*	***	**	**	**	***	17,116	2 (1)
Black-throated Diver	Breeding	5	2	3	1	4	4	5	3	5	44.0	*	***	**	**	*	***	172 P	11
Black-throated Diver	Wintering	5	2	3	1	4	4	5	3	5	44.0	*	***	**	**	*	***	700	
Great Northern Diver	Wintering											*	***	**	**	**	***	*2750*	
Slavonian Grebe	Breeding	3	2	1	1	3	5	5	1	4	23.3	*	**	**	**	*	**	41 P	6
Slavonian Grebe	Wintering	3	2	1	1	3	5	5	1	4	23.3	*	**	**	**	*	**	775	2
Great Crested Grebe	Breeding	4	2	3	2	3	4	4	1	1	19.3							9,400 A	1 (1)
Great Crested Grebe	Wintering	4	2	3	2	3	4	4	1	1	19.3							19,140	6
Red-necked Grebe	Breeding	4	2	1	1	3	5	5	1	1	18.7							1 P	
Red-necked Grebe	Wintering	4	2	1	1	3	5	5	1	1	18.7							200	
Northern Fulmar	Breeding	3	1	2	4	1	1	5	5	1	5.8	*	*	*	**	*	**	504,756 P	12
Cory's Shearwater	Migratory											*	*	?	?	?	?		
Great Shearwater	Migratory	3	1	3	4	1	1	4	5	4	11.9	*	*	?	?	?	?		
Sooty Shearwater	Migratory	2	1	3	4	1	1	1	5	4	8.3	*	*	?	?	?	?		
Manx Shearwater	Breeding	2	1	3	5	1	1	3	5	3	10.1	*	*	?	**	***	***	299,712 P	5
Balearic Shearwater	Migratory	2	1	3	4	1	1	5	5	5	12.5	*	*	?	**	?	**?		
European Storm-petrel	Breeding	1	1	5	5	1	1	3	2	1	6.0	*	*	?	**	*	**	25,650 P	10
Leach's Storm-petrel	Breeding	1	1	5	5	1	1	4	2	3	9.0	*	*	?	**	*	**	48,047 P	6
Northern Gannet	Breeding	3	3	3	2	2	1	4	5	3	16.5	**	*	*	*	***	***	218,546 N	9
Great Cormorant	Breeding	4	1	4	1	4	3	4	3	1	23.3	**	*	**	**	**	**	9,018 P	6 (1)
Great Cormorant	Wintering	4	1	4	1	4	3	4	3	1	23.3	**	*	**	**	**	**	24,200	8 (3)
European Shag	Breeding	4	1	3	1	4	3	4	4	4	26.3	*	**	**	**	**	**	274,77 P	11 (3)
Bewick's Swan	Wintering	5	5	5	5	2	0	5	3	5	21.7	***	*	*	-	**	***	8,240	16
Whooper Swan	Breeding	5	5	5	5	2	0	5	3	2	16.7	***	*	*	-	*	***	5 P	
Whooper Swan	Wintering	5	5	5	5	2	0	5	3	2	16.7	***	*	*	-	*	***	6,920	18
Bean Goose (Taiga)	Wintering	5	5	5	5	2	0	5	2	1	13.3	**	**	*	-	*	**	400	1
Pink-footed Goose	Wintering	5	5	5	5	2	0	4	3	2	15.0	**	**	*	-	***	***	241,000	22
Greenland White-	Wintering											**	**	*	-	***	***	21,000	13

Species	Population	Garthe and Hüppop (2004) / King *et al.* (2009)[1]										Langston (2010)							
		Flight manoeuvrability	Flight altitude	% time flying	Nocturnal flight activity	Disturbance by ship and helicopter traffic	Flexibility in habitat use	Biogeographical population size	Adult survival rate	European threat and conservation status	Sensitivity Score	Collision score	Displacement	Barrier	Habitat/Prey	GB/UK min %	Over-all Risk	UK population[2]	Number of SPAs (assemblage component only)[3]
fronted Goose																			
European White-fronted Goose	Wintering	5	5	5	5	2	0	3	1	1	8.3	**	**	?	-	*	**	5,790	3 (1)
Greylag Goose (Iceland)	Wintering	5	5	5	5	2	0	5	3	1	15.0	**	**	*	-	***	***	81,900	19
Greylag Goose (NW Scotland)	Breeding											**	**	*	-	***	***	3,200 P	1
Greylag Goose (NW Scotland)	Wintering											**	**	*	-	***	***	9,620	
Barnacle Goose (Nearctic)	Wintering											**	**	*	-	***	***	45,000	11
Barnacle Goose (Svalbard)	Wintering											**	**	*	-	***	***	22,000	1
Dark-bellied Brent Goose	Wintering	5	5	5	5	2	0	4	4	5	21.7	**	**	*	-	**	**	98,100	20 (1)
Light-bellied Brent Goose (Svalbard)	Wintering											**	**	*	-	**	**	2,900	1
Light-bellied Brent Goose (Canada)	Wintering											**	**	*	-	***	***	20,000	7
Common Shelduck	Breeding	4	4	5	5	1	0	4	2	1	5.3							10,900 P	2 (2)
Common Shelduck	Wintering	4	4	5	5	1	0	4	2	1	5.3							81,300	18 (1)
Eurasian Wigeon	Breeding	3	4	4	5	1	0	2	1	1	2.7							400 P	1
Eurasian Wigeon	Wintering	3	4	4	5	1	0	2	1	1	2.7							426,000	20 (2)
Common Teal	Breeding	2	3	5	5	1	0	4	1	1	3.8							2,200 P	1
Common Teal	Wintering	2	3	5	5	1	0	4	1	1	3.8							197,000	19 (3)
Northern Pintail	Breeding	4	3	3	5	1	0	5	1	4	6.3							22 P	0
Northern Pintail	Wintering	4	3	3	5	1	0	5	1	4	6.3							28,180	14
Northern Shoveler	Breeding	3	3	5	5	1	0	5	1	4	6.7							1,250 P	4
Northern Shoveler	Wintering	3	3	5	5	1	0	5	1	4	6.7							15,200	17
Greater Scaup	Wintering	3	2	2	3	3	0	4	3	5	15.0	*	**	**	**	?	?	9,200	5 (1)
Common Eider	Breeding	4	1	2	3	3	4	2	4	1	20.4	*	*	**	**	*	**	31,650 P	0
Common Eider	Wintering	4	1	2	3	3	4	2	4	1	20.4	*	*	**	**	*	**	80,000	3 (1)
Long-tailed Duck	Wintering	3	1	2	3	3	4	1	3	1	13.1	*	**	**	**	*	**	16,250	3 (1)
Common Scoter	Breeding	3	1	2	3	5	4	2	2	1	16.9	*	**	**	**	*	**	95 P	1
Common Scoter	Wintering	3	1	2	3	5	4	2	2	1	16.9	*	**	**	**	*	**	50,000	6 (1)

Species	Population	Garthe and Hüppop (2004) / King *et al.* (2009)[1]										Langston (2010)							
		Flight manoeuvrability	**Flight altitude**	**% time flying**	**Nocturnal flight activity**	**Disturbance by ship and helicopter traffic**	**Flexibility in habitat use**	**Biogeographical population size**	**Adult survival rate**	**European threat and conservation status**	**Sensitivity Score**	**Collision score**	**Displacement**	**Barrier**	**Habitat/Prey**	**GB/UK min %**	**Over-all Risk**	**UK population**[2]	**Number of SPAs (assemblage component only)**[3]
Velvet Scoter	Wintering	3	1	2	3	5	4	3	2	3	27.0	*	**	**	**	*	**	3,000	2 (1)
Common Goldeneye	Breeding	3	1	2	3	3	4	2	3	1	15.8	*	*	**	**	*	**	200 P	1
Common Goldeneye	Wintering	3	1	2	3	3	4	2	3	1	15.8	*	*	**	**	*	**	35,000	12 (3)
Red-breasted Merganser	Breeding	3	1	2	3	3	4	4	3	1	21.0	*	*	**	**	*	**	2,370 P	
Red-breasted Merganser	Wintering	3	1	2	3	3	4	4	3	1	21.0	*	*	**	**	*	**	10,500	5
Corncrake	Breeding											***	-	***	-	**	***	*589 M*	10
Oystercatcher	Breeding	2	5	5	5	1	0	2	4	1	5.0							113,000 P	4 (3)
Oystercatcher	Wintering	2	5	5	5	1	0	2	4	1	5.0							338,700	15 (3)
Common Ringed Plover	Breeding	1	5	5	5	1	0	5	2	1	5.3							8,540 P	6
Common Ringed Plover	Wintering	1	5	5	5	1	0	5	2	1	5.3							34,510	14 (2)
European Golden Plover	Breeding	1	5	5	5	1	0	4	1	1	4.0							22,600 P	8
European Golden Plover	Wintering	1	5	5	5	1	0	4	1	1	4.0							310,000	12
Grey Plover	Wintering	1	5	5	5	1	0	4	2	1	4.7							53,300	23 (4)
Northern Lapwing	Breeding	1	5	5	5	1	0	1	2	5	5.3							156,000 P	6 (6)
Northern Lapwing	Wintering	1	5	5	5	1	0	1	2	5	5.3							1,600,000	8 (2)
Red Knot	Wintering	1	5	5	5	1	0	4	3	4	7.3							295,000	18
Sanderling	Wintering	1	5	5	5	1	0	4	3	1	5.3							20,700	11 (2)
Dunlin	Breeding	1	5	5	5	1	0	2	1	2	3.3							9,525 P	8 (2)
Dunlin	Wintering	1	5	5	5	1	0	2	1	2	3.3							577,100	20 (1)
Black-tailed Godwit	Breeding	2	5	5	5	5	1	0	5	4	9.9							48 P	2
Black-tailed Godwit	Wintering	2	5	5	5	5	1	0	5	4	9.9							15,860	15 (1)
Bar-tailed Godwit	Wintering	2	5	5	5	1	0	4	3	1	5.7							65,430	16
Eurasian Curlew	Breeding	2	5	5	5	1	0	3	1	4	5.7							107,000 P	2 (1)
Eurasian Curlew	Wintering	2	5	5	5	1	0	3	1	4	5.7							164,700	13 (2)
Common Redshank	Breeding	1	5	5	5	1	0	4	2	4	6.7							38,800 P	8 (7)
Common Redshank	Wintering	1	5	5	5	1	0	4	2	4	6.7							125,800	28
Grey Phalarope	Migratory	1	2	2	2	2	2	3	2	1	7.0							?	
Pomarine Skua	Migratory	1	3	5	1	1	1	3	5	3	10.1	**	*	*	*	?	**?	?	

Species	Population	Garthe and Hüppop (2004) / King *et al.* (2009)[1]										Langston (2010)							
		Flight manoeuvrability	Flight altitude	% time flying	Nocturnal flight activity	Disturbance by ship and helicopter traffic	Flexibility in habitat use	Biogeographical population size	Adult survival rate	European threat and conservation status	Sensitivity Score	Collision score	Displacement	Barrier	Habitat/Prey	GB/UK min %	Over-all Risk	UK population[2]	Number of SPAs (assemblage component only)[3]
Arctic Skua	Breeding	1	3	5	1	1	2	4	3	1	10.0	**	*	*	*	*	**	2,136 P	5 (4)
Long-tailed Skua	Migratory											**	*	*	*	?	**?	?	
Great Skua	Breeding	1	3	4	1	1	2	5	4	2	12.4	**	*	*	*	***	***	9,634 P	9 (8)
Mediterranean Gull	Breeding											**	*	*	*	*	*	220	3
Little Gull	Wintering	1	1	3	2	1	3	5	2	4	12.8	*	*	*	*	?	?		
Black-headed Gull	Breeding	1	5	1	2	2	2	1	3	1	7.5	*	*	*	*	*	*	138,014 P	1
Black-headed Gull	Wintering	1	5	1	2	2	2	1	3	1	7.5	*	*	*	*	*	*	1,697,797	
Common Gull (Mew Gull)	Breeding	1	3	2	3	2	2	2	2	4	12.0	*	*	*	*	*	*	48,720 P	2 (1)
Common Gull (Mew Gull)	Wintering	1	3	2	3	2	2	2	2	4	12.0	*	*	*	*	*	*	430,927	
Lesser Black-backed Gull	Breeding	1	4	2	3	2	1	4	5	2	13.8	**	*	*	*	***	***	112,074 P	7
Lesser Black-backed Gull	Wintering	1	4	2	3	2	1	4	5	2	13.8	**	*	*	*	***	***	60,830	
Herring Gull	Breeding	2	4	2	3	2	1	2	5	1	11.0	**	*	*	*	*	**	139,309 P	3 (2)
Herring Gull	Wintering	2	4	2	3	2	1	2	5	1	11.0	**	*	*	*	*	**	378,748	
Iceland Gull	Wintering	1	3	2	3	2	2	4	5	1	15.0	**	*	*	*	?	**	?	
Glaucous Gull	Wintering	2	3	2	3	2	2	4	5	1	16.7	**	*	*	*	?	**	?	
Great Black-backed Gull	Breeding	2	3	2	3	2	2	4	5	2	18.3	**	*	*	*	**	**	17,160 P	4 (1)
Great Black-backed Gull	Wintering	2	3	2	3	2	2	4	5	2	18.3	**	*	*	*	**	**	43,156	
Black-legged Kittiwake	Breeding	1	2	3	3	2	2	1	3	1	7.5	**	*	*	*	*	**	379,892 P	20 (2)
Sandwich Tern	Breeding	1	3	5	1	2	3	4	4	4	25.0	**	*	*	**	**	**	12,490 P	17
Roseate Tern	Breeding	1	2	5	1	2	3	5	3	3	20.6	**	*	*	**	*	**	56 P	7
Common Tern	Breeding	1	2	5	1	2	3	3	4	1	15.0	**	*	*	**	*	**	11,838 P	26
Arctic Tern	Breeding	1	1	5	1	2	3	3	4	1	13.3	**	*	*	**	*	**	53,388 P	16
Little Tern	Breeding	1	2	5	1	2	3	5	4	4	24.4	*	*	*	**	*	**	1,947 P	25
Black Tern	Migratory	1	1	4	1	2	3	4	4	4	17.5							?	
Common Guillemot	Breeding	4	1	1	2	3	3	1	4	1	12.0	*	**	**	**	**	**	1,420,900	22
Razorbill	Breeding	4	1	1	1	3	3	2	5	2	15.8	*	**	**	**	*	**	188,576	17 (1)
Black Guillemot	Breeding	4	1	1	2	3	3	4	4	3	22.0	*	**	**	**	*	**	39,316	4 (1)
Little Auk	Wintering	3	1	2	1	3	3	1	2	1	7.0	*	**	**	**	?	**?	?	

Species	Population	Garthe and Hüppop (2004) / King *et al.* (2009)[1]										Langston (2010)							
		Flight manoeuvrability	Flight altitude	% time flying	Nocturnal flight activity	Disturbance by ship and helicopter traffic	Flexibility in habitat use	Biogeographical population size	Adult survival rate	European threat and conservation status	Sensitivity Score	Collision score	Displacement	Barrier	Habitat/Prey	GB/UK min %	Over-all Risk	UK population[2]	Number of SPAs (assemblage component only)[3]
Atlantic Puffin	Breeding	3	1	1	1	2	3	2	5	5	15.0	*	**	**	**	*	**	580,799 P	13 (2)

Garthe and Hüppop (2004) / King *et al.* (2009): Flight manoeuvrability: Species scored subjectively from high manoeuvrability (=1) to low manoeuvrability (=5). **Flight altitude**: 1 = median height 0-5m; 2 = median height 5-10m; 3 = median height 10-20m and the 90% percentile at <50m; 4 = median height 10-20m and the 90% percentile at <100m; 5 = median height 10-20m and the 90% percentile at >100m. **% time flying:** 1 = 0-20% of time flying at sea to 5 = 81-100% of time flying at sea. **Nocturnal flight activity:** Species scored subjectively from 1 (hardly any flight at night) to 5 (much flight activity at night). **Disturbance by ship and helicopter traffic:** Species scored subjectively between 1 (hardly any avoidance behaviour and/or short fleeing distance) and 5 (strong avoidance and/or large fleeing distance). **Flexibility in habitat use:** Species scored subjectively from 1 (very flexible in habitat use) to 5 (reliant on specific habitat characteristics); 0= not dependent on offshore habitats. **Biogeographical population size:** 1 >3 million individuals; 2 >1 million up to 3 million individuals; 3 >500,000 up to 1 million individuals; 4 >100,000 up to 500,000 individuals; 5 <100,000 individuals. **Adult (annual) survival rate:** 1 <0.75, 2 = 0.75-0.80, 3 = 0.80-0.85, 4 = 0.85-0.90, 5 >0.90. **European threat and conservation status:** 1 = 'secure' and no species of European concern (SPEC) status given (following Tucker & Heath 1994), 2 = 'secure' and SPEC status of 4, 3 = 'localised', 4 = 'declining', 5 = 'vulnerable'. **Sensitivity Score** calculated according to Garthe and Hüppop (2004; see also text).

Langston (2010): Collision score, Displacement, Barrier and **Habitat/Prey** * = Low risk, ** = Moderate risk, *** = High risk. **GB/UK min%** = for breeding seabirds, the minimum % of the relevant biogeographical population breeding in Britain, taken from Mitchell *et al.* (2004); for other species which are primarily of concern for their non-breeding populations, UK population estimates are taken from Baker *et al.* (2006) and expressed as %s of European populations taken from BirdLife International (2004): * <25%; ** 25-50%; *** >50%. **Overall Risk** = Highest score across the variables Collision score, Displacement, Barrier, Habitat/Prey and GB/UK min%.

[1] Scores for italicised species taken from King *et al*. (2009);

[2] Taken from Baker *et al.* (2006) and O'Brien *et al.* (2008): A = adults, M = males, N = nests, P = pairs, otherwise individuals;

[3] Taken from Stroud *et al.* (2001) and JNCC (2010a, 2010b).

Table 3.3.2. Coincidence of wind farms with foraging ranges from SPAs for species of moderate and high risk of collision with wind turbines (from Langston 2010).

Species	Potentially affected SPAs	Representative foraging range (km) and source*
Great Cormorant *Phalacrocorax carbo*	Abberton Reservoir (b, nb); Blackwater Estuary (nb); Breydon Water (nb); Broadland (nb); Colne Estuary (nb); Dengie (nb); East Caithness Cliffs (b); Firth of Forth Islands (b); *Firth of Tay and Eden Estuary (nb);* Humber Estuary (nb); Medway Estuary and Marshes (nb); Mersey Estuary (nb); Morecambe Bay (nb); North Norfolk Coast (nb); Poole Harbour (nb); Ribble and Alt Estuaries (nb); Solent and Southampton Water (nb); Stour and Orwell Estuaries (nb); Teesmouth and Cleveland Coast (nb); The Dee Estuary (nb); The Swale (nb); The Wash (nb); Upper Solway Flats and Marshes (nb); Ynys Seiriol (b)	25±10 (Thaxter *et al.* in review)
Northern Gannet *Morus bassanus*	Ailsa Craig (b); Fair Isle (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Grassholm (b); *Hermaness, Saxa Vord and Valla Field (b)*; North Rona and Sule Sgeir (b); Noss (b); St Kilda (b); Sule Skerry and Sule Stack (b)	282.1±178.8 (Thaxter *et al.* in review)
Arctic Skua *Stercorarius parasiticus*	Hoy (b)	62.5±17.7 (Thaxter *et al.* in review)
Great Skua *Stercorarius skua*	Hoy (b)	58±43 (Thaxter *et al.* in review)
Black-legged Kittiwake *Rissa tridactyla*	Ailsa Craig (b); Canna and Sanday (b); East Caithness Cliffs (b); *Copinsay (b)*; Farne Islands (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Fowlsheugh (b); Hoy (b); Mingulay and Bernerlay (b); North Caithness Cliffs (b); North Colonsay and Western Cliffs (b); Rathlin Island (b); Rum (b); Skomer and Skokholm (b); St Abb's Head to Fast Castle (b); Troup, Pennan and Lion's Heads (b)	61.6±30.8 (Thaxter *et al.* in review)
Mediterranean Gull *Larus melanocephalus*	North Norfolk Coast (b); Poole Harbour (b); Solent and Southampton Water (b); The Swale (b)	20 (Thaxter *et al.* in review)
Lesser Black-backed Gull	Ailsa Craig (b); Alde-Ore Estuary (b); Bowland Fells (b); Firth of Forth	132.1±68.4 (Thaxter *et al.* in review)

Species	Potentially affected SPAs	Representative foraging range (km) and source*
Larus fuscus	Islands (b); Isles of Scilly (b); Lough Neagh and Lough Beg (b); Morecambe Bay (b); Rathlin Island (b); Ribble and Alt Estuaries (b); Skomer and Skokholm (b)	
Herring Gull *Larus argentatus*	Ailsa Craig (b); Alde-Ore Estuary (b); *Buchan Ness to Collieston Coast (b)*; Canna and Sanday (b); East Caithness Cliffs (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Fowlsheugh (b); Morecambe Bay (b); Rathlin Island (b); St Abb's Head to Fast Castle (b); Troup, Pennan and Lion's Heads (b)	61.1±44 (Thaxter *et al.* in review)
Great Black-backed Gull *Larus marinus*	*East Caithness Cliffs (b)*	10 km (Furness & Tasker 2000)
Sandwich Tern *Sterna sandvicensis*	Alde-Ore Estuary (b); *Chichester and Langstone Harbours (b);* Coquet Island (b); Duddon Estuary (b); *Farne Islands (b)*; Firth of Forth (p); Firth of Forth Islands (b); Foulness (b); Morecambe Bay (b); North Norfolk Coast (b); Solent and Southampton Water (b); Teesmouth and Cleveland Coast (p); The Dee Estuary (p); Ynys Feurig, Cemlyn Bay and the Skerries (b)	31.7±21.3 (Thaxter *et al.* in review)
Common Tern *Sterna hirundo*	Breydon Water (b); *Farne Islands (b)*; Firth of Forth Islands (b); Foulness (b); North Norfolk Coast (b); Poole Harbour (b); Ribble and Alt Estuaries (b); Solent and Southampton Water (b); The Dee Estuary (b); The Wash (b); Ynys Feurig, Cemlyn Bay and the Skerries (b)	24.9±5 (Thaxter *et al.* in review)
Roseate Tern *Sterna dougallii*	*Coquet Island (b)*; Firth of Forth Islands (b); North Norfolk Coast (b); *Solent and Southampton Water (b);* Ynys Feurig, Cemlyn Bay and the Skerries (b)	16.6±11.6 (Thaxter *et al.* in review)
Arctic Tern *Sterna paradisaea*	Coquet Island (b) *Farne Islands (b)*; Firth of Forth Islands (b); Ynys Feurig, Cemlyn Bay and the Skerries (b)	25.3±6.6 (Thaxter *et al.* in review)

* Unless otherwise stated, the representative range given is the mean maximum (Thaxter *et al.* in review).
b = breeding colony SPA; nb = non-breeding site SPA; p = passage site SPA; italics indicate those sites which fell just outside the mapped foraging range of the species in question.

Table 3.3.3. Coincidence of Round 1 and 2, Round 3 and Scottish offshore wind farms with foraging ranges from SPAs for species of moderate and high risk of collision with wind turbines (from Langston 2010).

Species	Potentially affected SPAs (Rounds 1 & 2)	Potentially affected SPAs (Round 3)	Potentially affected SPAs (Scottish Territorial Waters)
Great Cormorant *Phalacrocorax carbo*	Abberton Reservoir (b, nb); Blackwater Estuary (nb); Broadland (nb); Breydon Water (nb); Colne Estuary (nb); Dengie (nb); Humber Estuary (nb); Medway Estuary and Marshes (nb); Morecambe Bay (nb); North Norfolk Coast (nb); Ribble and Alt Estuaries (nb); Stour and Orwell Estuaries (nb); Teesmouth and Cleveland Coast (nb); The Dee Estuary (nb); The Swale (nb); The Wash (nb); Upper Solway Flats and Marshes (nb); Ynys Seiriol (b)	Broadland (nb); East Caithness Cliffs (b); *Firth of Forth Islands (b)*; *Firth of Tay and Eden Estuary (nb);* Poole Harbour (nb); Solent and Southampton Water (nb);	East Caithness Cliffs (b); Firth of Forth Islands (b); *Firth of Tay and Eden Estuary (nb);* Upper Solway Flats and Marshes (nb);
Northern Gannet *Morus bassanus*	Ailsa Craig (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Grassholm (b)	Ailsa Craig (b); Fair Isle (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Grassholm (b); *Hermaness, Saxa Vord and Valla Field (b)*; North Rona and Sula Sgeir (b); Noss (b); Sule Skerry and Sule Stack (b);	Ailsa Craig (b); Fair Isle (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); *Hermaness, Saxa Vord and Valla Field (b)*; North Rona and Sula Sgeir (b); Noss (b); St Kilda (b); Sule Skerry and Sule Stack (b)
Arctic Skua *Stercorarius parasiticus*	NA	Hoy (b)	Hoy (b)
Great Skua *Stercorarius skua*	NA	*Hoy (b)*	Hoy (b)
Black-legged Kittiwake *Rissa tridactyla*	Farne Islands (b); Flamborough Head and Bempton Cliffs (b)	*Copinsay (b)*; East Caithness Cliffs (b); Farne Islands (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Fowlsheugh (b); Hoy (b); North Caithness Cliffs (b); Skomer and	Ailsa Craig (b); Canna and Sanday (b); *Copinsay (b)*; East Caithness Cliffs (b); Farne Islands (b); Firth of Forth Islands (b); Fowlsheugh (b); Hoy (b); Mingulay and Berneray (b); North Caithness Cliffs

Species	Potentially affected SPAs (Rounds 1 & 2)	Potentially affected SPAs (Round 3)	Potentially affected SPAs (Scottish Territorial Waters)
		Skokholm (b); St Abb's Head to Fast Castle (b); Troup, Pennan and Lion's Heads (b)	(b); Northern Colonsay and Western Cliffs (b); Rathlin Island (b); Rum (b); St Abb's Head to Fast Castle (b); *Troup, Pennan and Lion's Heads (b)*
Mediterranean Gull *Larus melanocephalus*	North Norfolk Coast (b); The Swale	Poole Harbour (b); Solent and Southampton Water (b)	NA
Lesser Black-backed Gull *Larus fuscus*	Ailsa Craig (b); Alde-Ore Estuary (b); Bowland Fells (b); Firth of Forth Islands (b); Lough Neagh and Lough Beg (b); Morecambe Bay (b); Rathlin Island (b); Ribble and Alt Estuaries (b)	Ailsa Craig (b); Alde-Ore Estuary (b); Bowland Fells (b); Firth of Forth Islands (b); Isles of Scilly (b); Morecambe Bay (b); Lough Neagh and Lough Beg (b); Ribble and Alt Estuaries (b); Skomer and Skokholm (b)	Ailsa Craig (b); Bowland Fells (b); Firth of Forth Islands (b); Lough Neagh and Lough Beg (b); Morecambe Bay (b); Rathlin Island (b); Ribble and Alt Estuaries (b)
Herring Gull *Larus argentatus*	Alde-Ore Estuary (b); Flamborough Head and Bempton Cliffs (b); Morecambe Bay (b)	Alde-Ore Estuary (b); *Buchan Ness to Collieston Coast (b)*; East Caithness Cliffs (b); Firth of Forth Islands (b); Flamborough Head and Bempton Cliffs (b); Fowlsheugh (b); Morecambe Bay (b); St Abb's Head to Fast Castle (b); Troup, Pennan and Lion's Heads (b)	Ailsa Craig (b); Canna and Sanday (b); East Caithness Cliffs (b); Firth of Forth Islands (b); Fowlsheugh (b); *Morecambe Bay (b)*; Rathlin Island (b); St Abb's Head to Fast Castle (b); *Troup, Pennan and Lion's Heads (b)*
Great Black-backed Gull *Larus marinus*	NA	NA	*East Caithness Cliffs (b)*
Sandwich Tern *Sterna sandvicensis*	Alde-Ore Estuary (b); Coquet Island (b); Duddon Estuary (b); Foulness (b); Morecambe Bay (b); North Norfolk Coast (b); Teesmouth and Cleveland Coast (p); The Dee Estuary (p)	Alde-Ore Estuary (b); *Chichester and Langstone Harbours (b); Duddon Estuary (b);* Firth of Forth (p); Firth of Forth Islands (b); Solent and Southampton Water (b); Ynys Feurig, Cemlyn Bay and the Skerries (b)	*Farne Islands (b)*; Firth of Forth (p); Firth of Forth Islands (b)
Common Tern	Breydon Water (b); Foulness (b); North	*Breydon Water (b)*; Firth of Forth Islands	*Farne Islands (b)*; Firth of Forth Islands

Species	Potentially affected SPAs (Rounds 1 & 2)	Potentially affected SPAs (Round 3)	Potentially affected SPAs (Scottish Territorial Waters)
Sterna hirundo	Norfolk Coast (b); Ribble and Alt Estuaries (b); The Dee Estuary (b); The Wash (b)	(b); Poole Harbour (b); Solent and Southampton Water (b); Ynys Feurig, Cemlyn Bay and the Skerries (b)	(b);
Roseate Tern *Sterna dougallii*	*Coquet Island (b)*; North Norfolk Coast (b)	*Firth of Forth Islands (b)*; *Solent and Southampton Water (b);* Ynys Feurig, Cemlyn Bay and the Skerries (b)	Firth of Forth Islands (b);
Arctic Tern *Sterna paradisaea*	Coquet Island (b)	Firth of Forth Islands (b); Ynys Feurig, Cemlyn Bay and the Skerries (b)	*Farne Islands (b)*; Firth of Forth Islands (b);

b = breeding colony SPA; nb = non-breeding site SPA; p = passage site SPA; italics indicate those sites which fell just outside the mapped foraging range of the species in question.

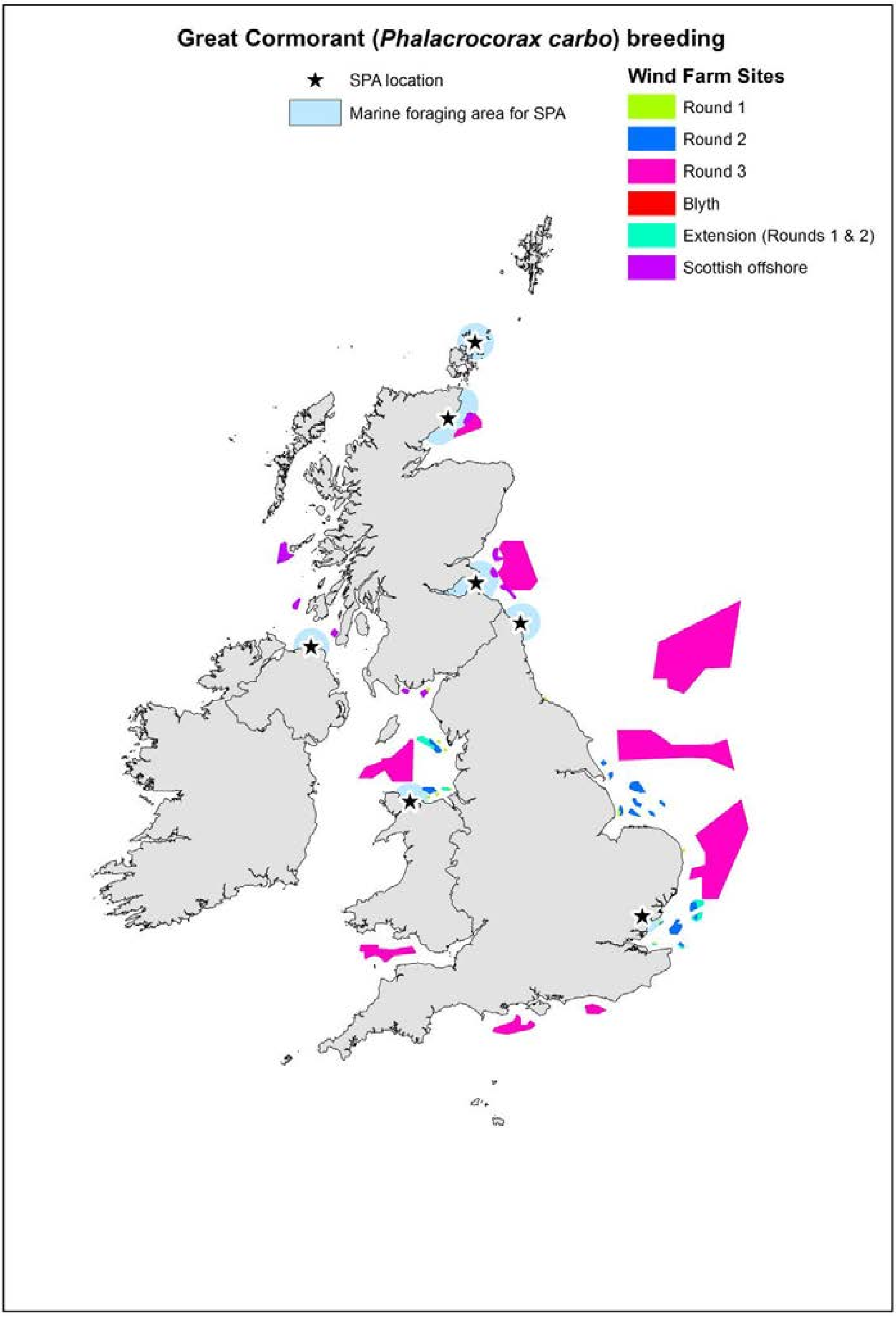

Figure 3.3.3 Potential foraging range[1] of Great Cormorant *Phalacrocorax carbo* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

[1] Note foraging areas shown in this and subsequent figures (except for Great Black-backed Gull) are based on representative mean maximum foraging ranges for the species (following Thaxter *et al.* in review) and thus do not necessarily represent the actual foraging areas used by birds from each colony (see text for more details). The foraging range used for Great Black-backed Gull follows the value given in Cook and Burton (2010).

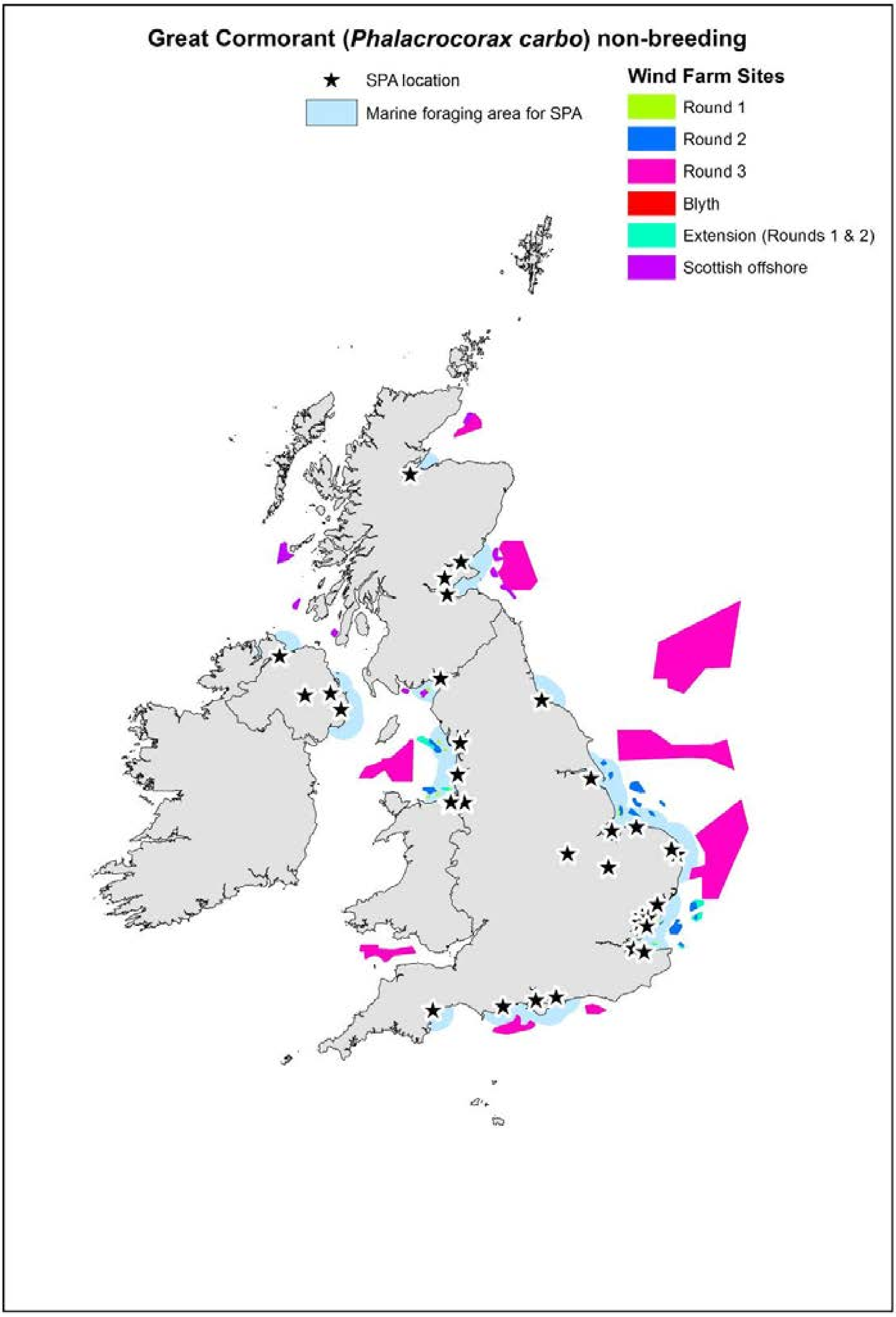

Figure 3.3.4 Potential foraging range of Great Cormorant *Phalacrocorax carbo* from non-breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

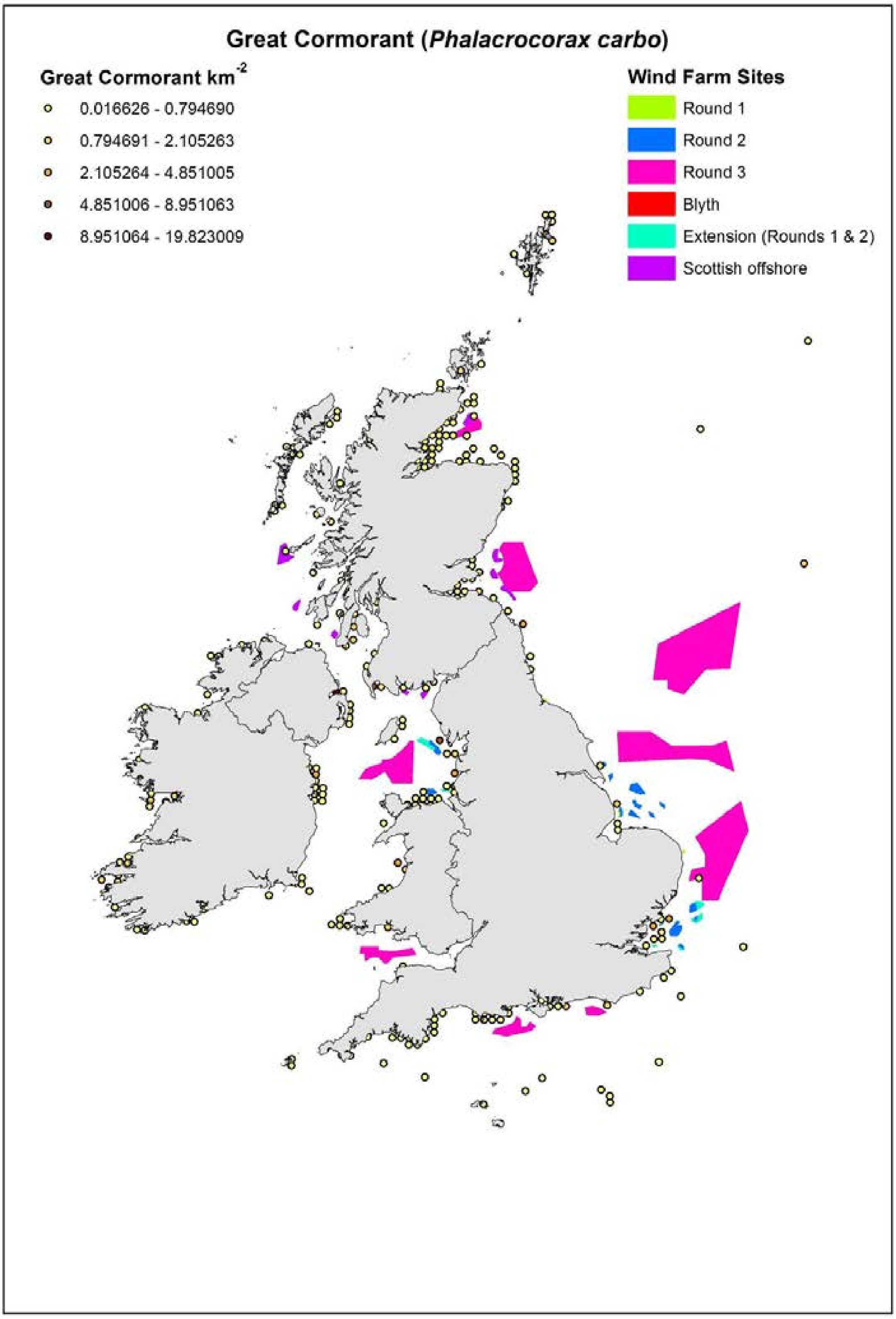

Figure 3.3.5 At-sea distribution of Great Cormorant *Phalacrocorax carbo* in relation to (constructed, consented and proposed) offshore wind farms.

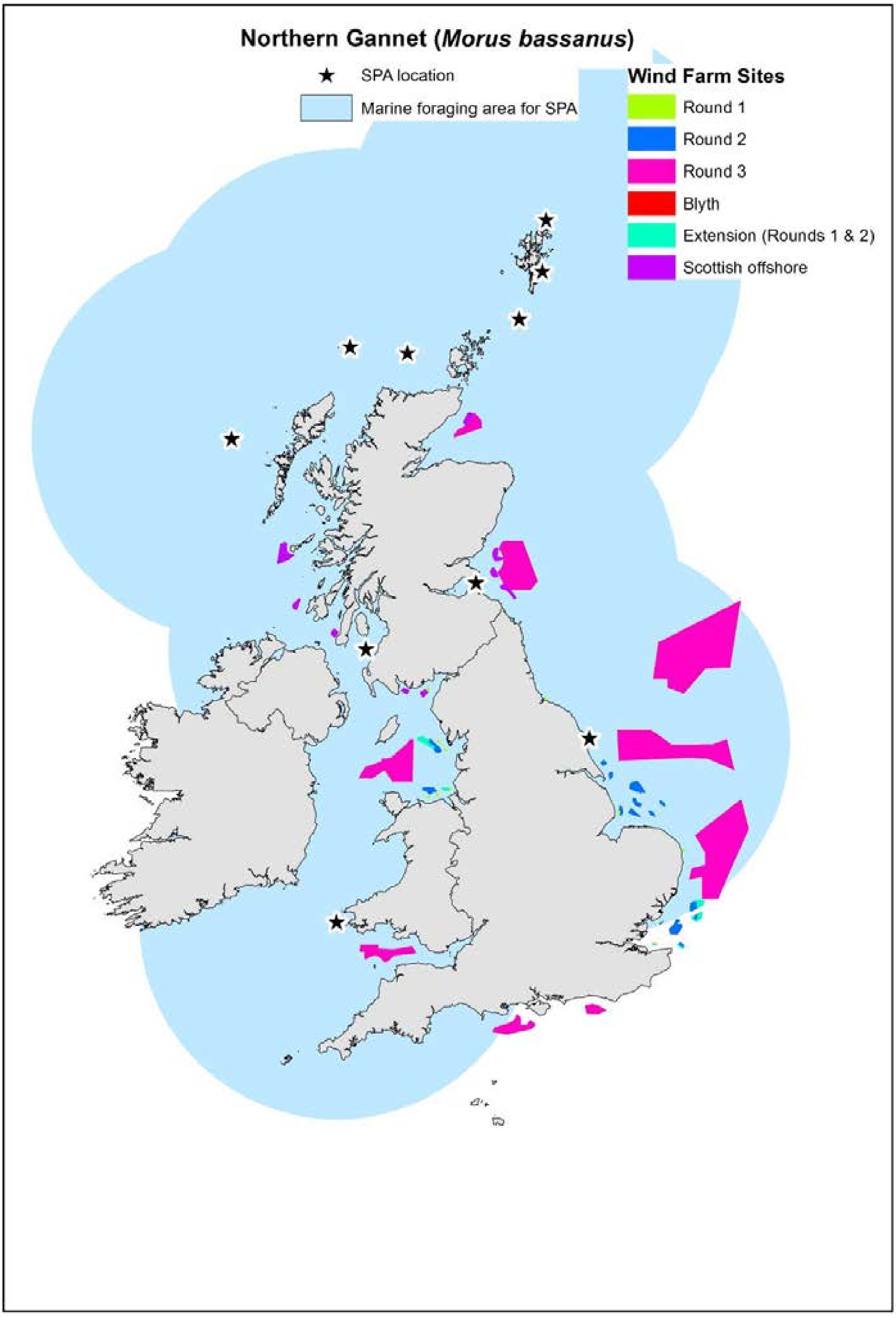

Figure 3.3.6 Potential foraging range of Northern Gannet *Morus bassanus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

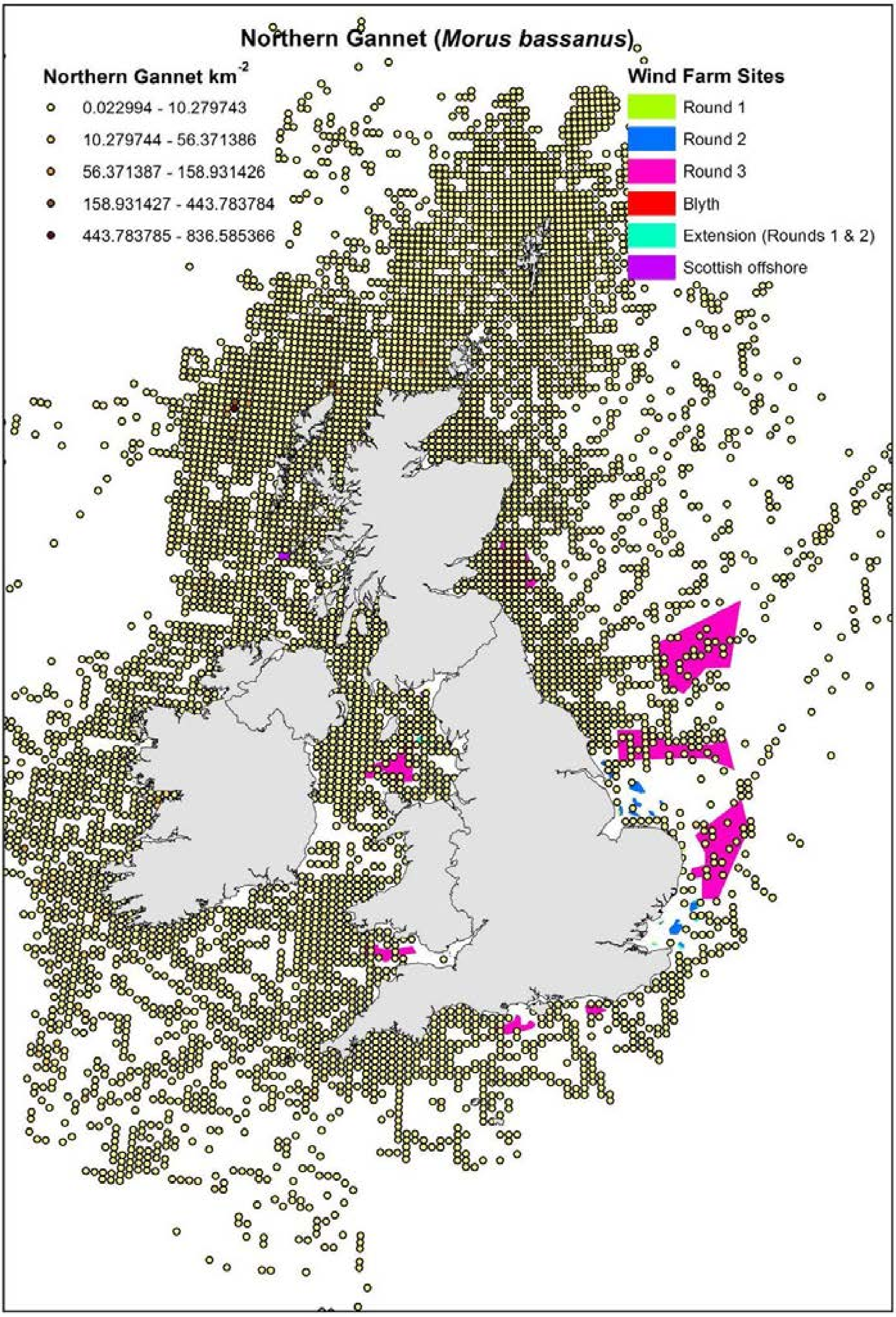

Figure 3.3.7 At-sea distribution of Northern Gannet *Morus bassanus* in relation to (constructed, consented and proposed) offshore wind farms.

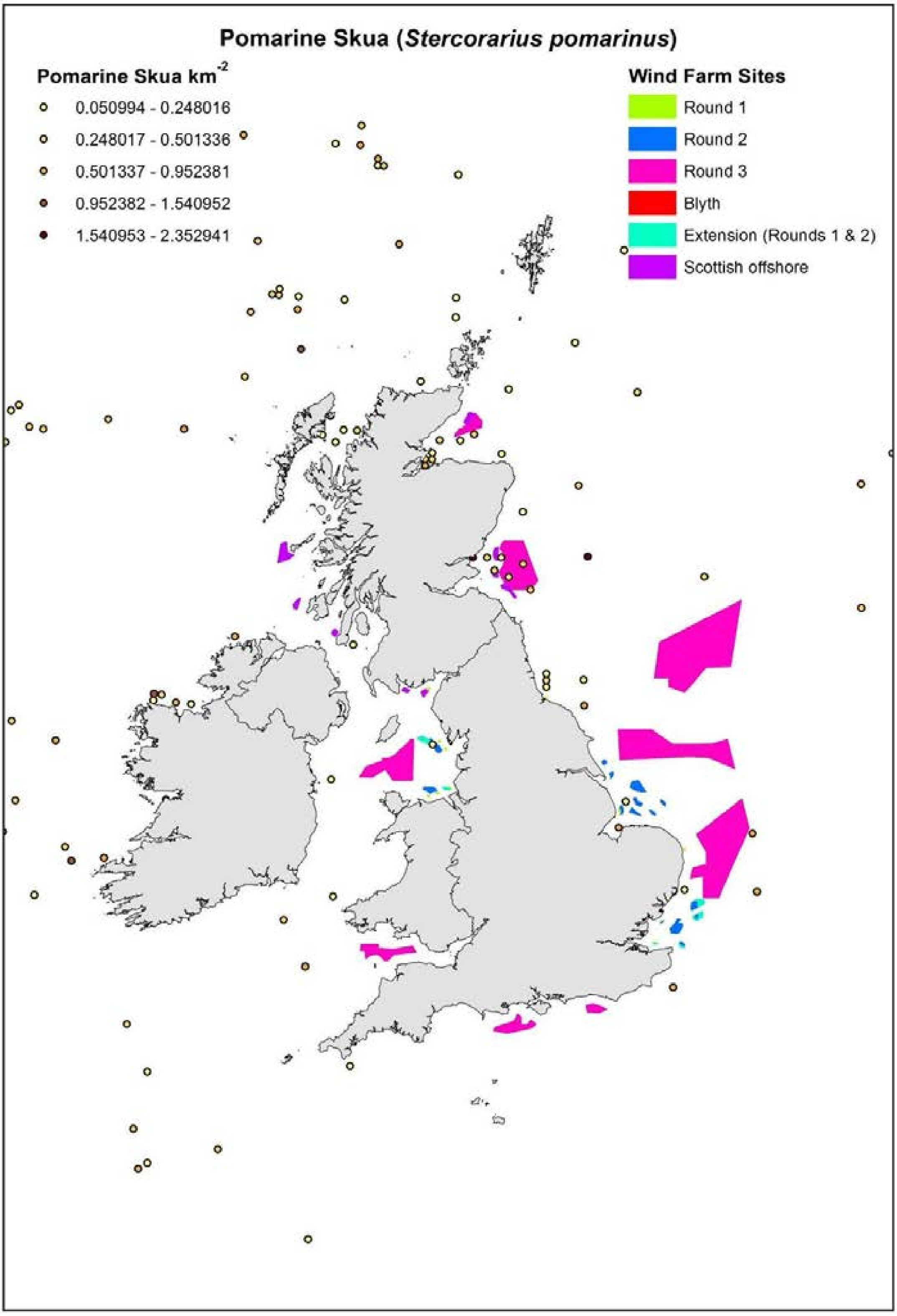

Figure 3.3.8 At-sea distribution of Pomarine Skua *Stercorarius pomarinus* in relation to (constructed, consented and proposed) offshore wind farms.

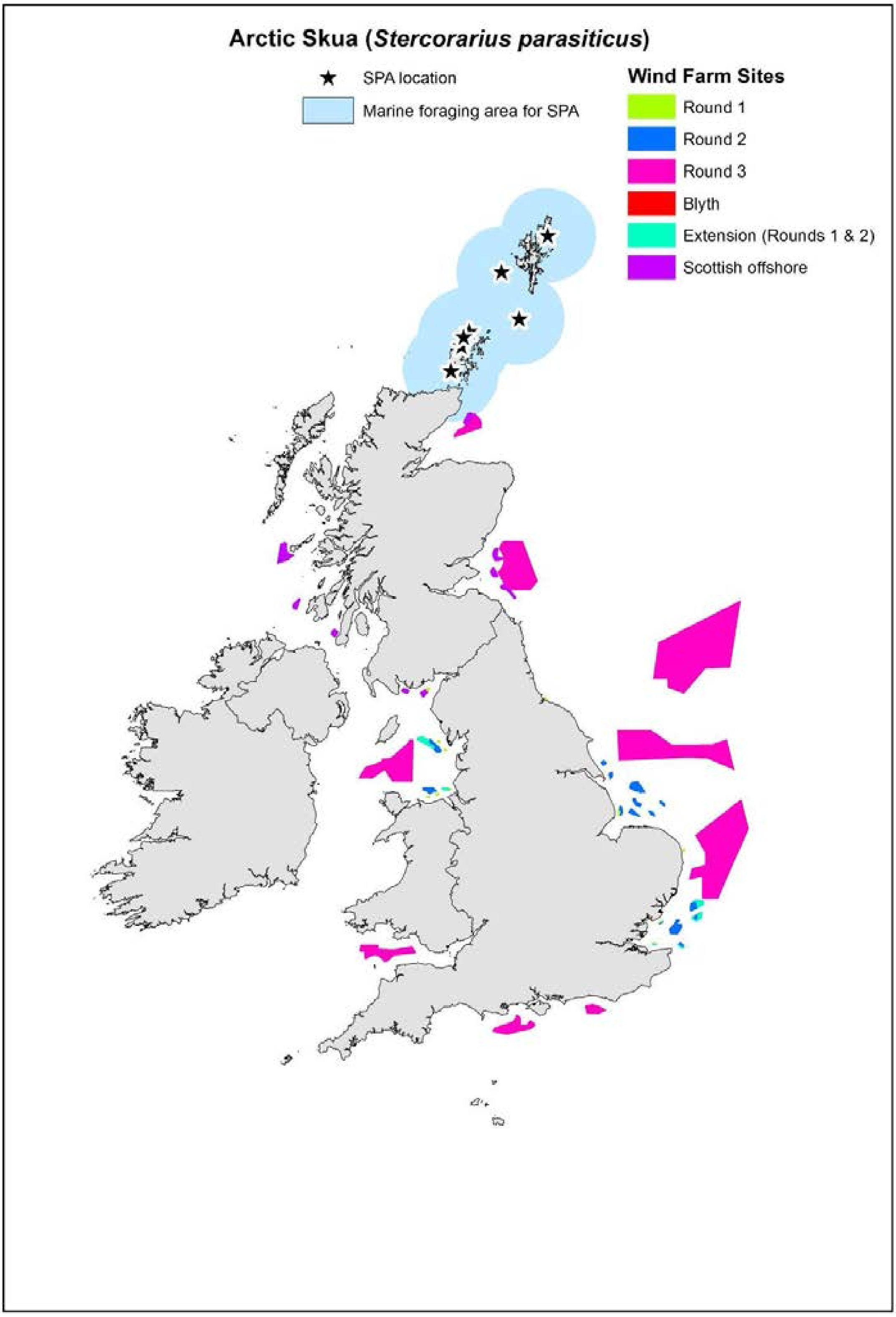

Figure 3.3.9 Potential foraging range of Arctic Skua *Stercorarius parasiticus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

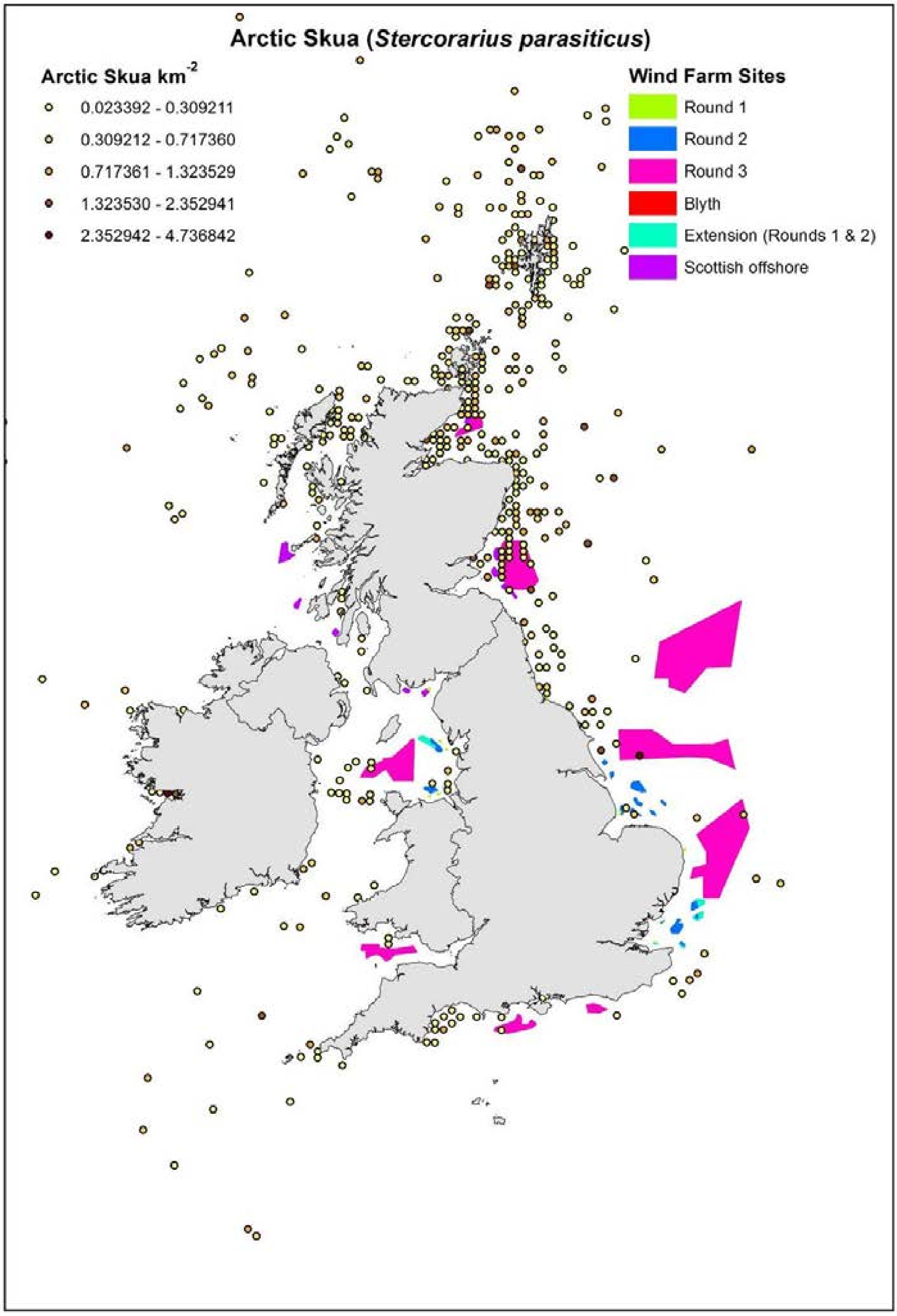

Figure 3.3.10 At-sea distribution of Arctic Skua *Stercorarius parasiticus* in relation to (constructed, consented and proposed) offshore wind farms.

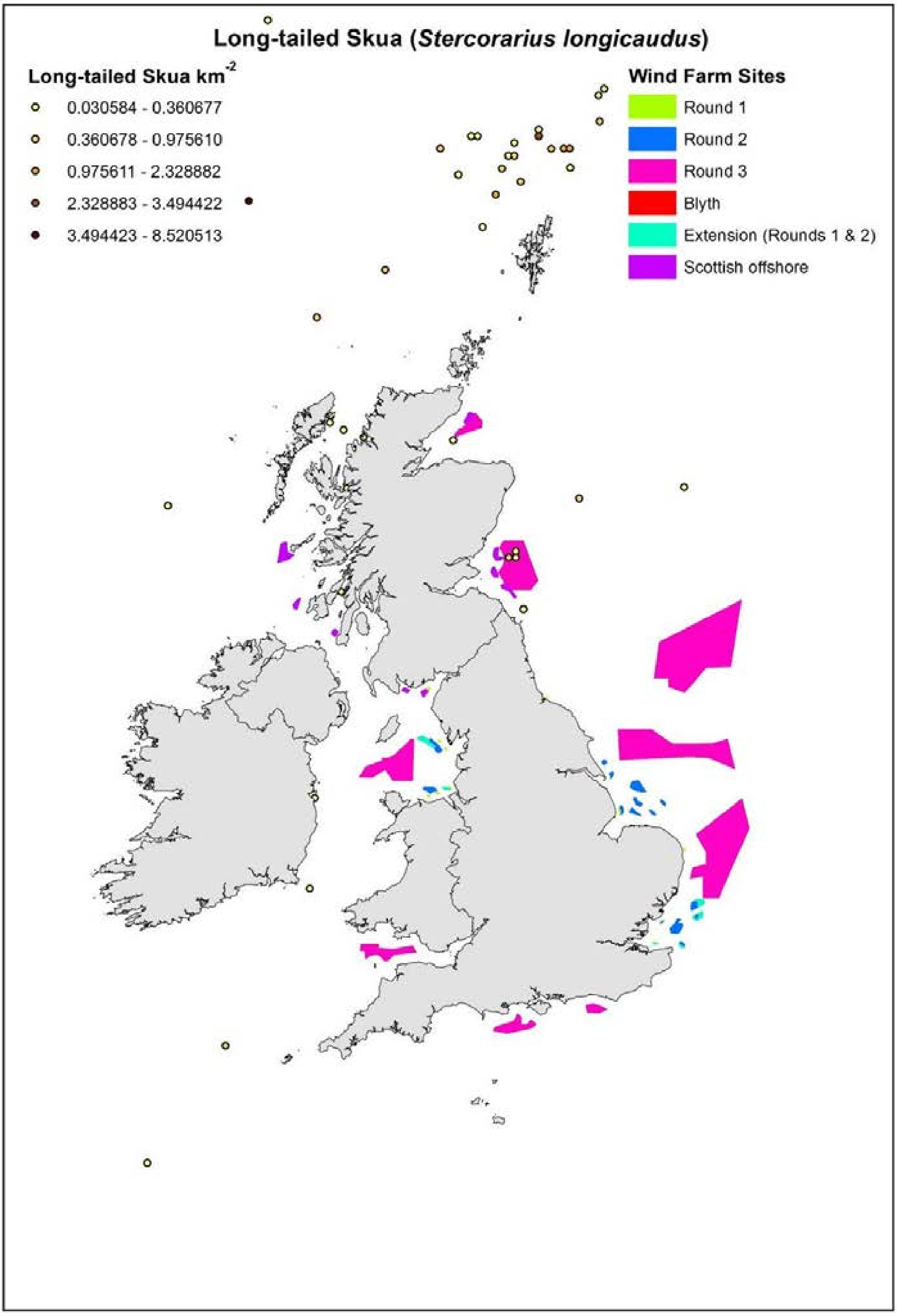

Figure 3.3.11 At-sea distribution of Long-tailed Skua *Stercorarius longicaudus* in relation to (constructed, consented and proposed) offshore wind farms.

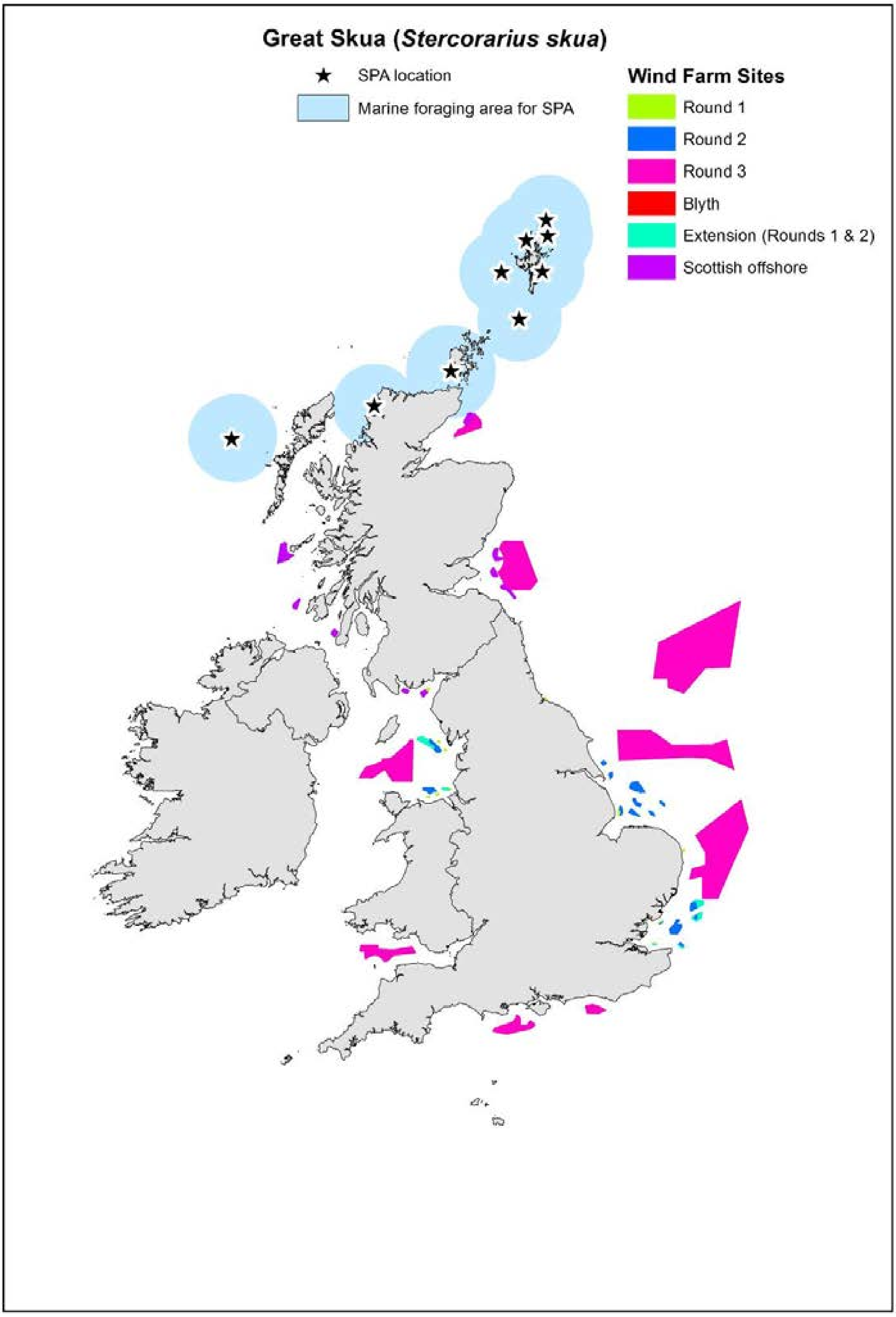

Figure 3.3.12 Potential foraging range of Great Skua *Stercorarius skua* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

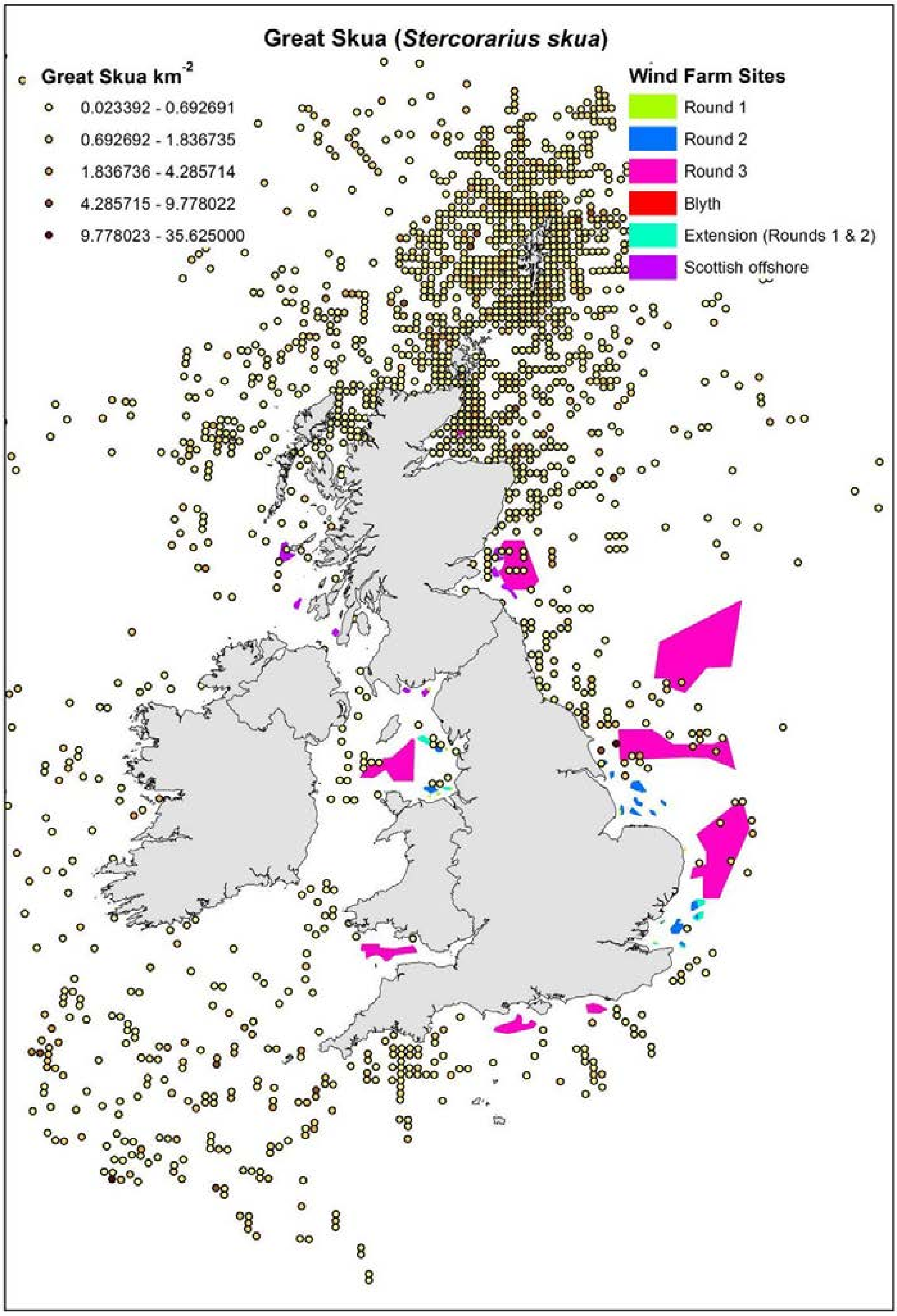

Figure 3.3.13 At-sea distribution of Great Skua *Stercorarius skua* in relation to (constructed, consented and proposed) offshore wind farms.

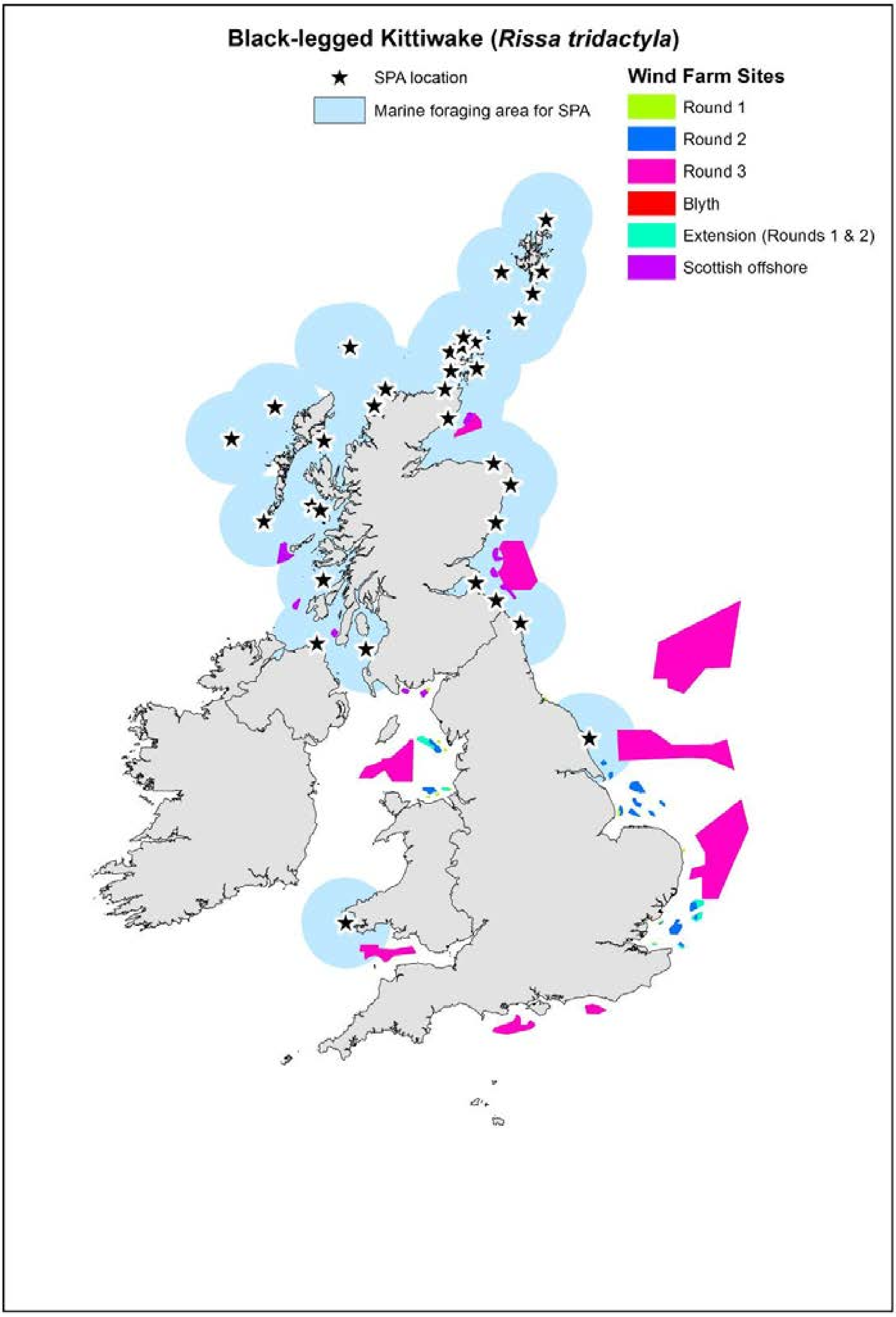

Figure 3.3.14 Potential foraging range of Black-legged Kittiwake *Rissa tridactyla* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

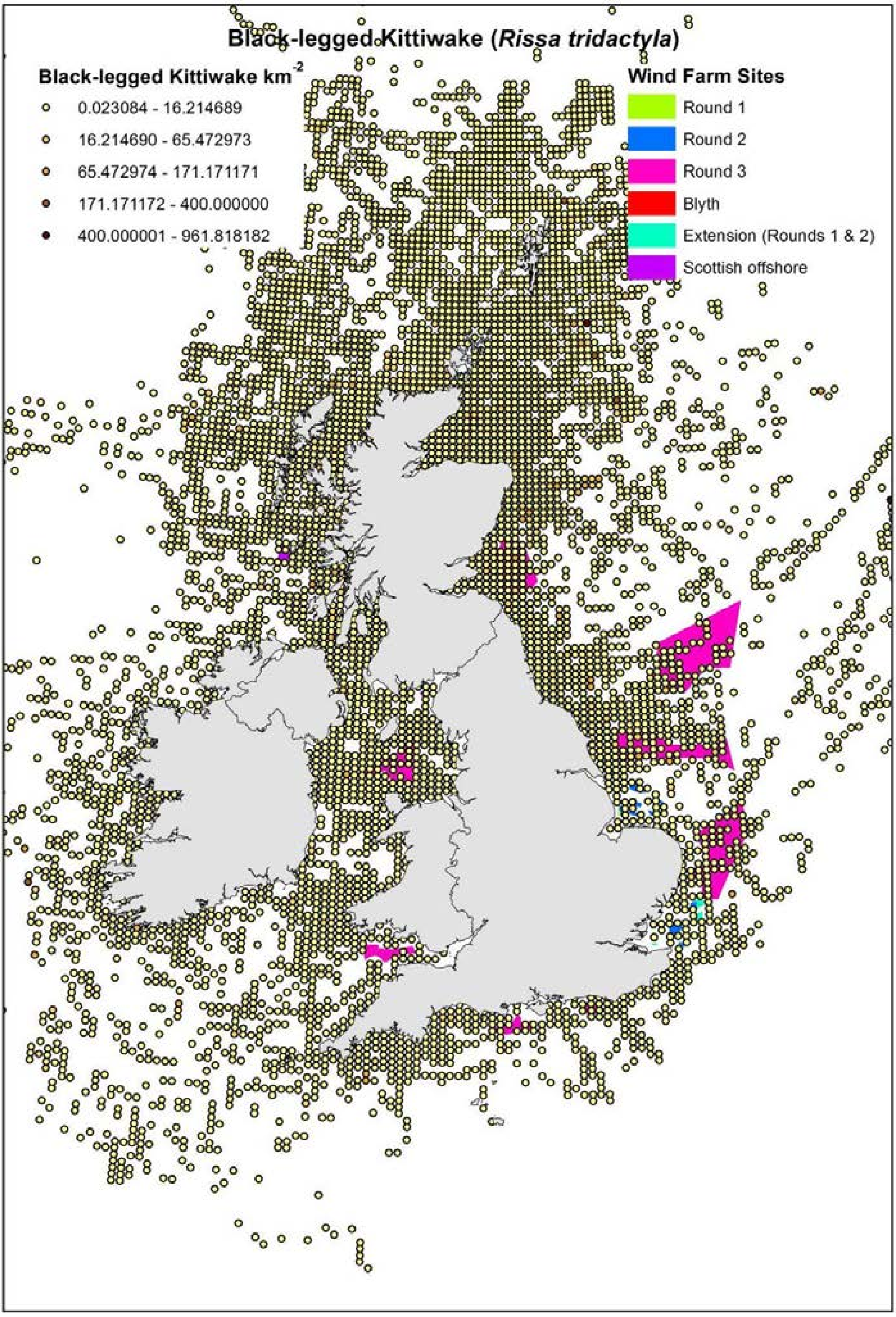

Figure 3.3.15 At-sea distribution of Black-legged Kittiwake *Rissa tridactyla* in relation to (constructed, consented and proposed) offshore wind farms.

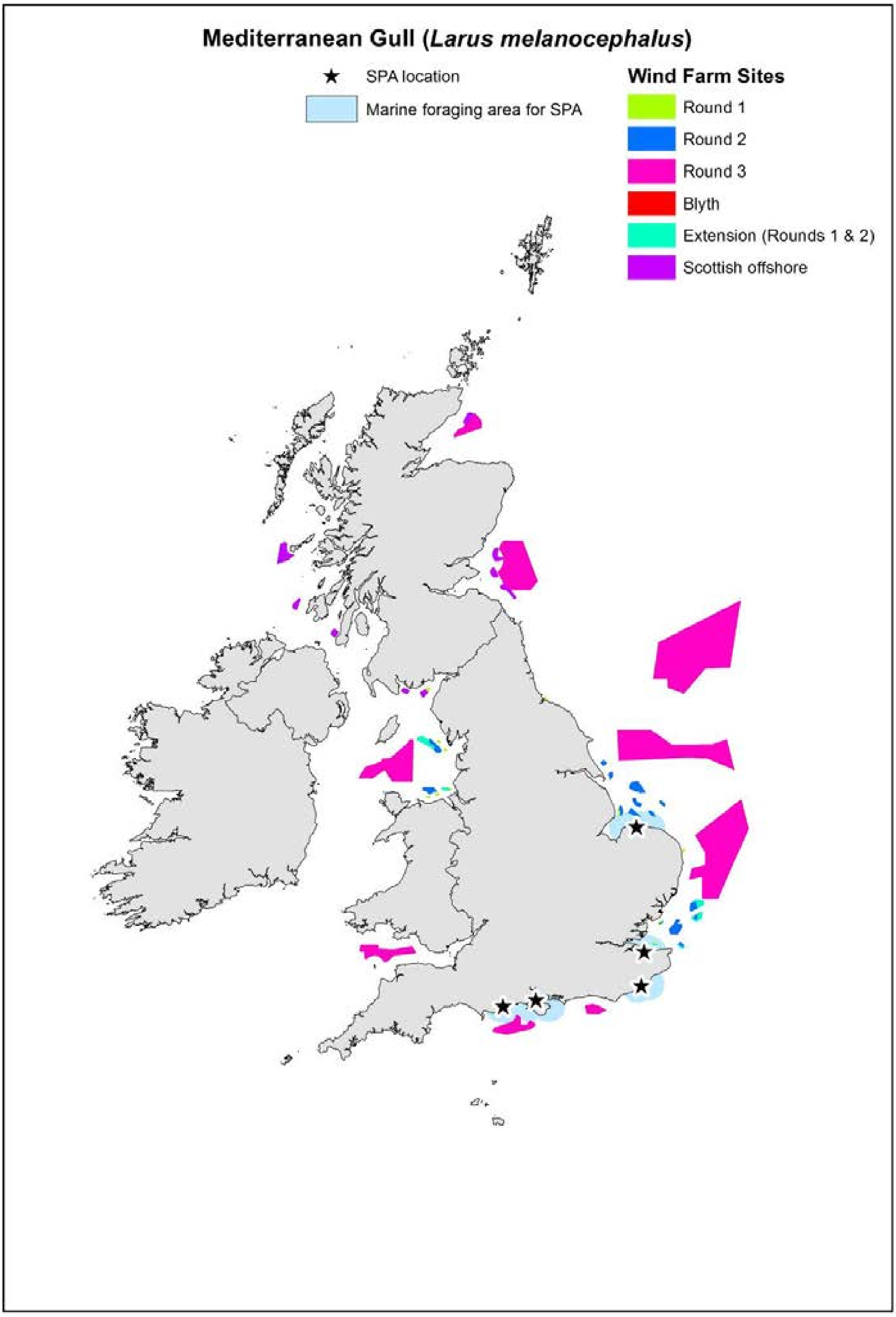

Figure 3.3.16 Potential foraging range of Mediterranean Gull *Larus melanocephalus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

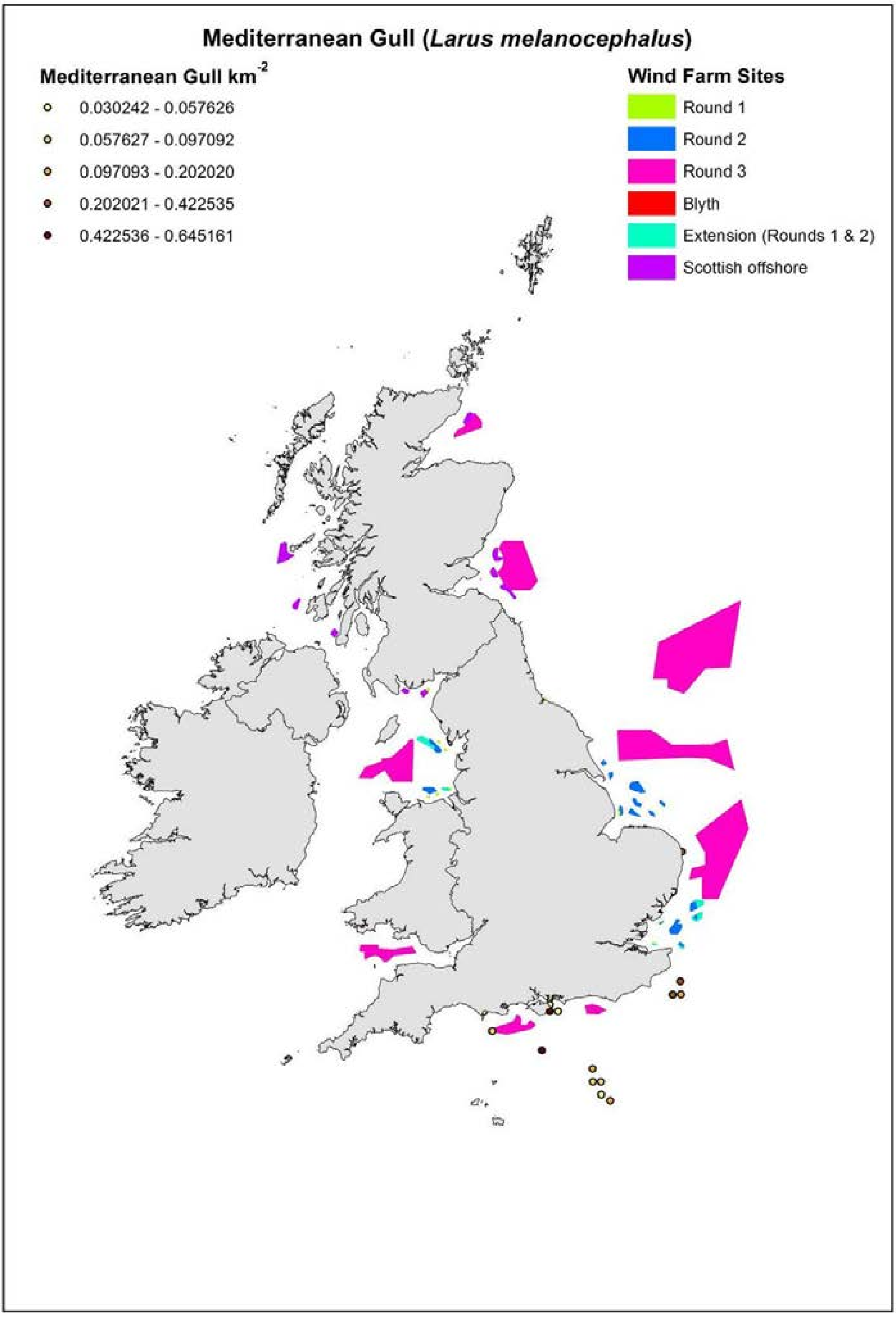

Figure 3.3.17 At-sea distribution of Mediterranean Gull *Larus melanocephalus* in relation to (constructed, consented and proposed) offshore wind farms.

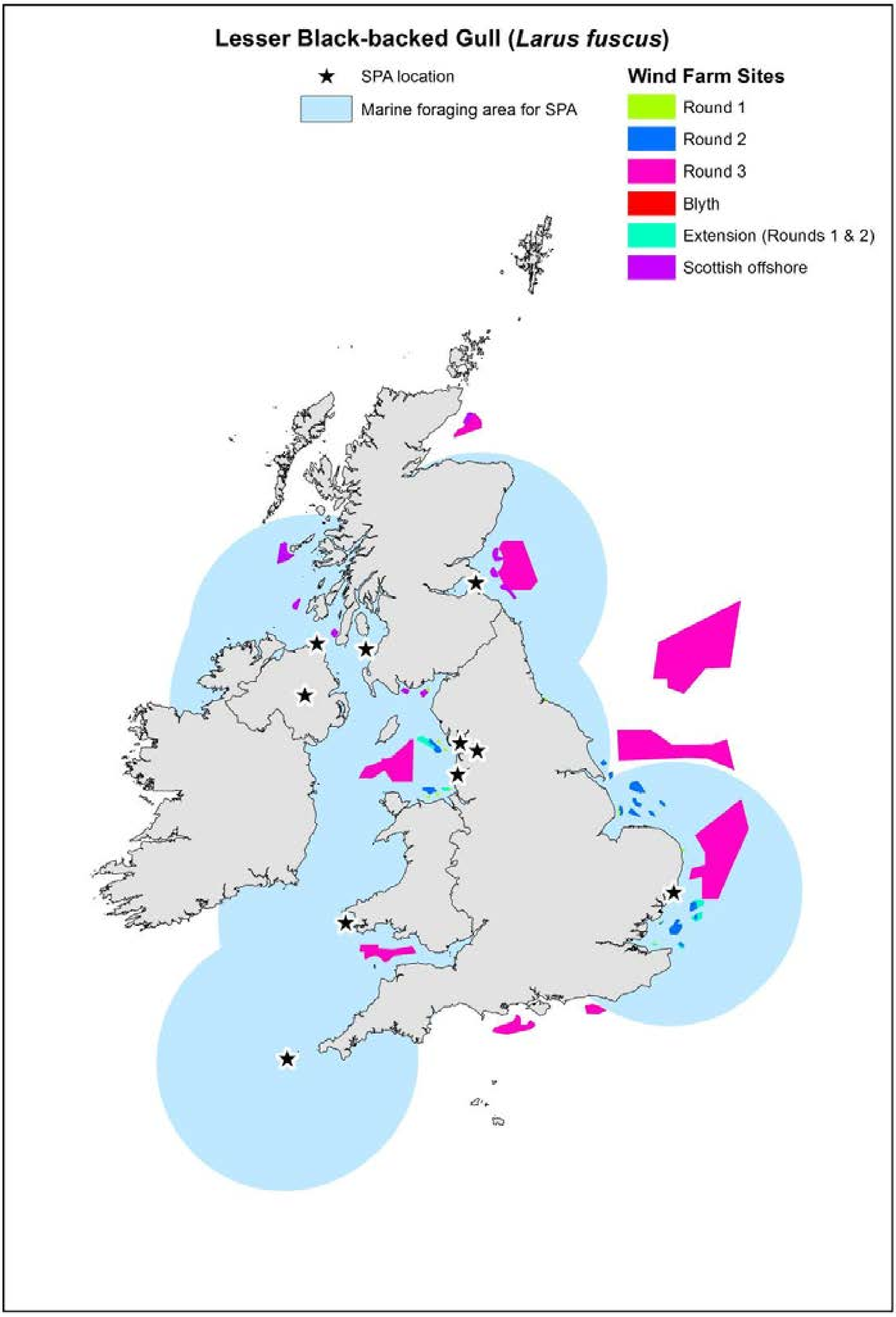

Figure 3.3.18 Potential foraging range of Lesser Black-backed Gull *Larus fuscus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

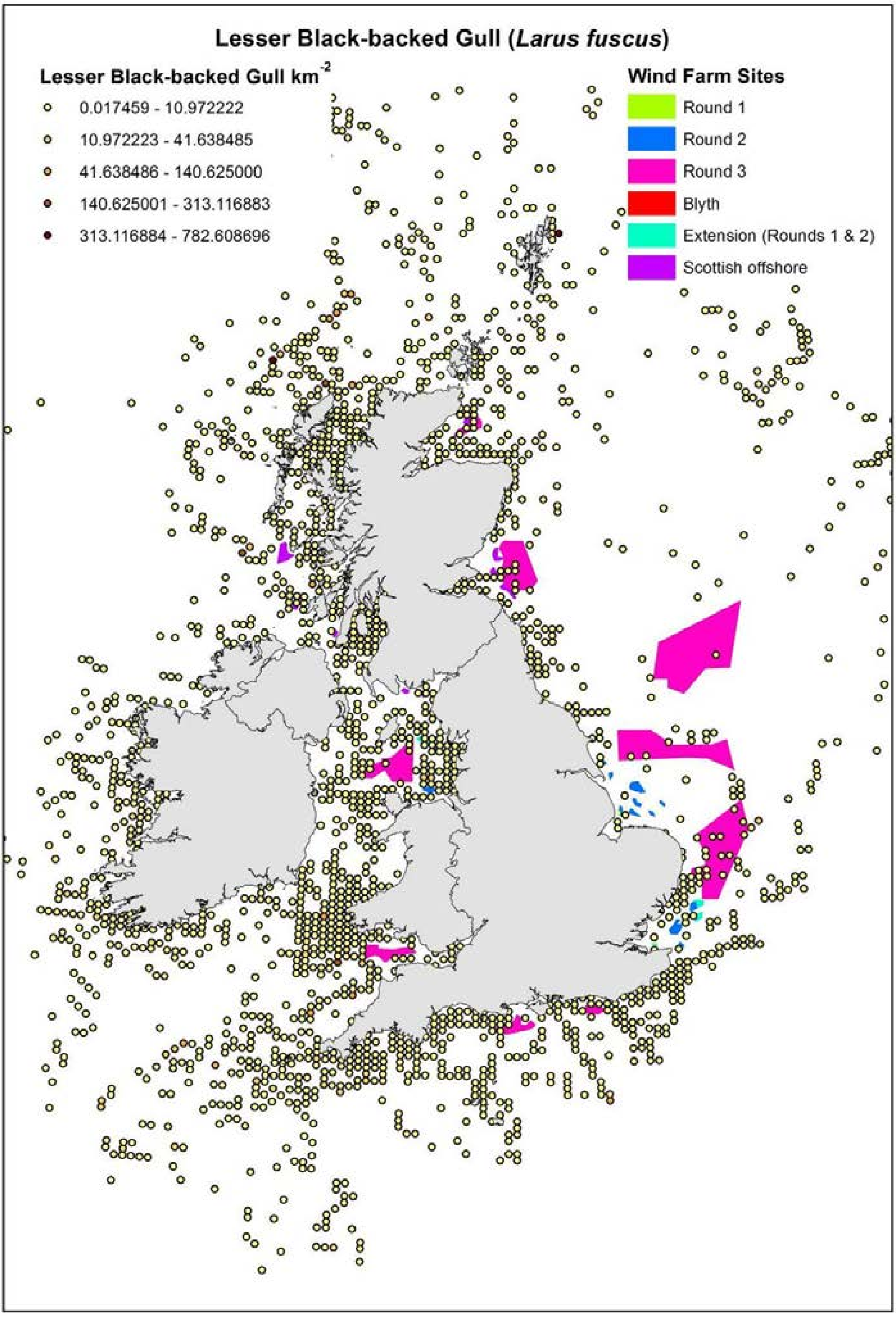

Figure 3.3.19 At-sea distribution of Lesser Black-backed Gull *Larus fuscus* in relation to (constructed, consented and proposed) offshore wind farms.

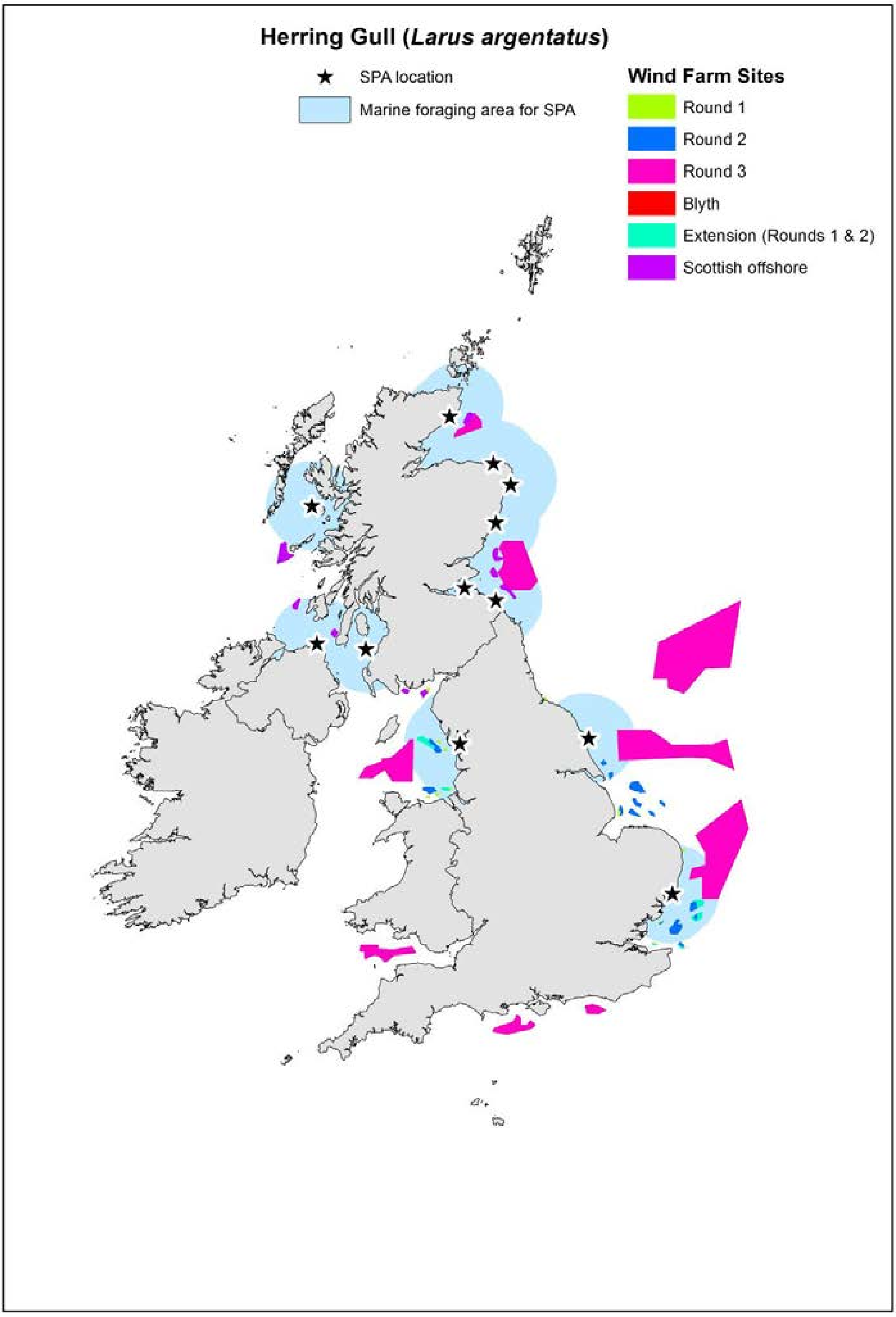

Figure 3.3.20 Potential foraging range of Herring Gull *Larus argentatus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

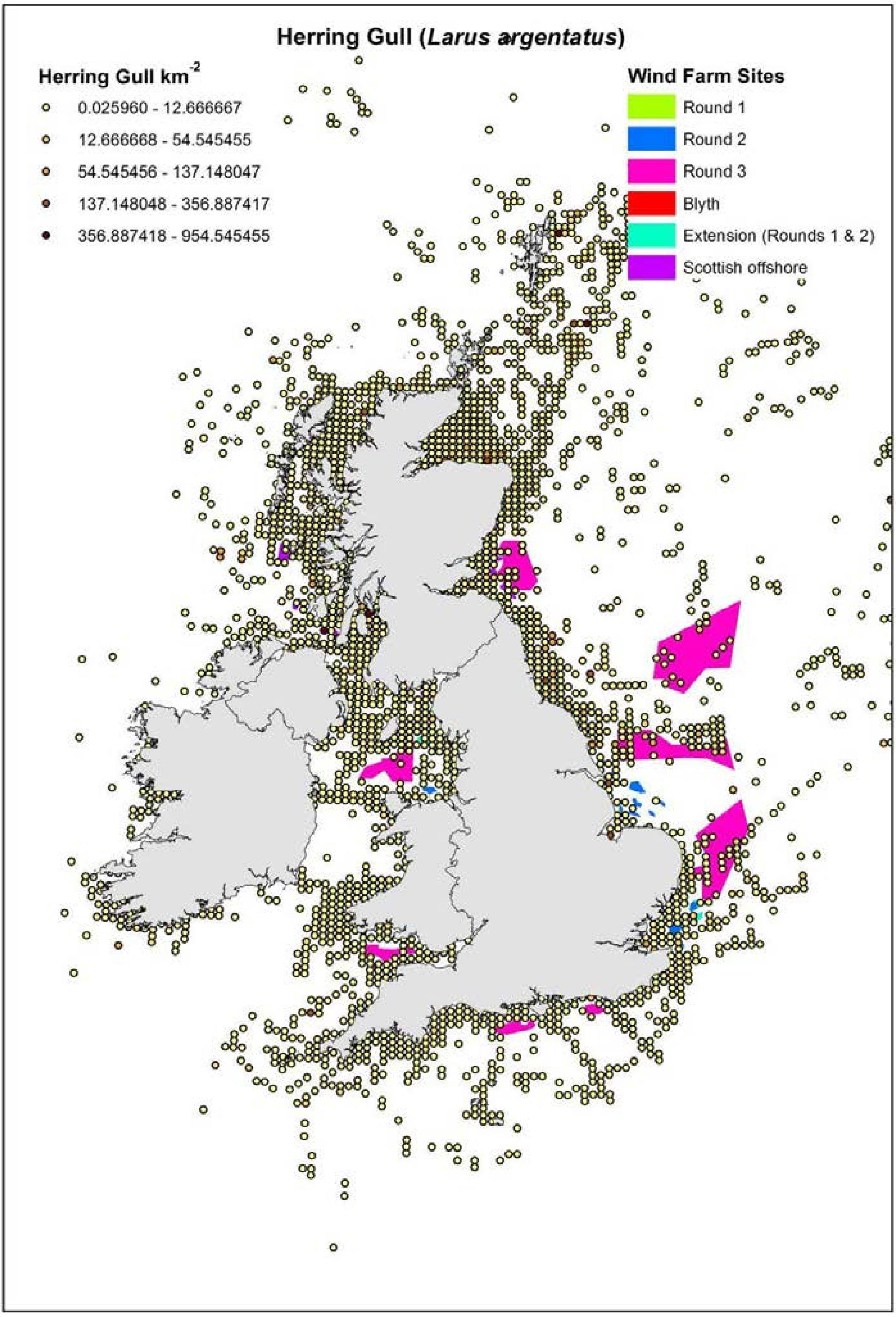

Figure 3.3.21 At-sea distribution of Herring Gull *Larus argentatus* in relation to (constructed, consented and proposed) offshore wind farms.

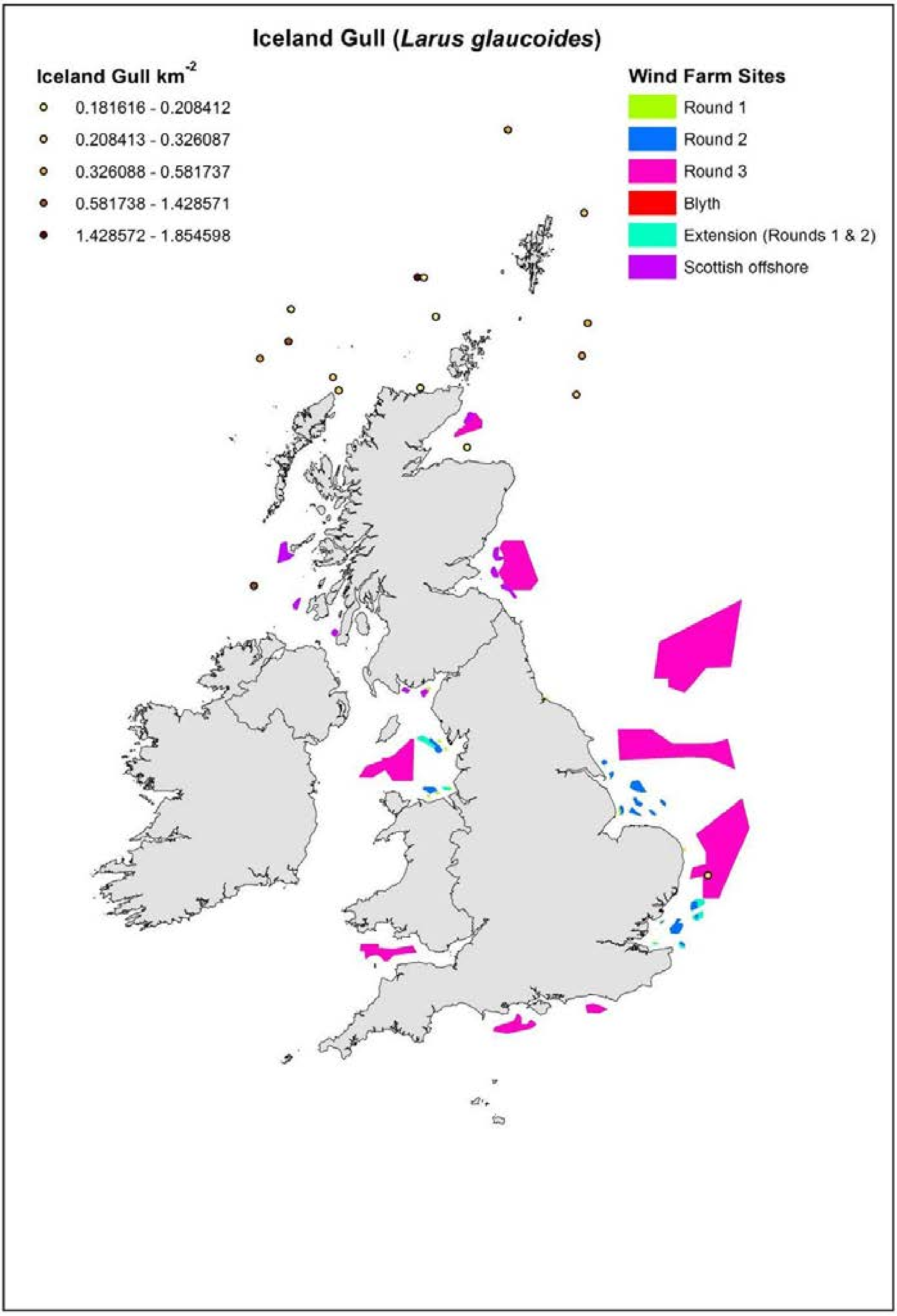

Figure 3.3.22 At-sea distribution of Iceland Gull *Larus glaucoides* in relation to (constructed, consented and proposed) offshore wind farms.

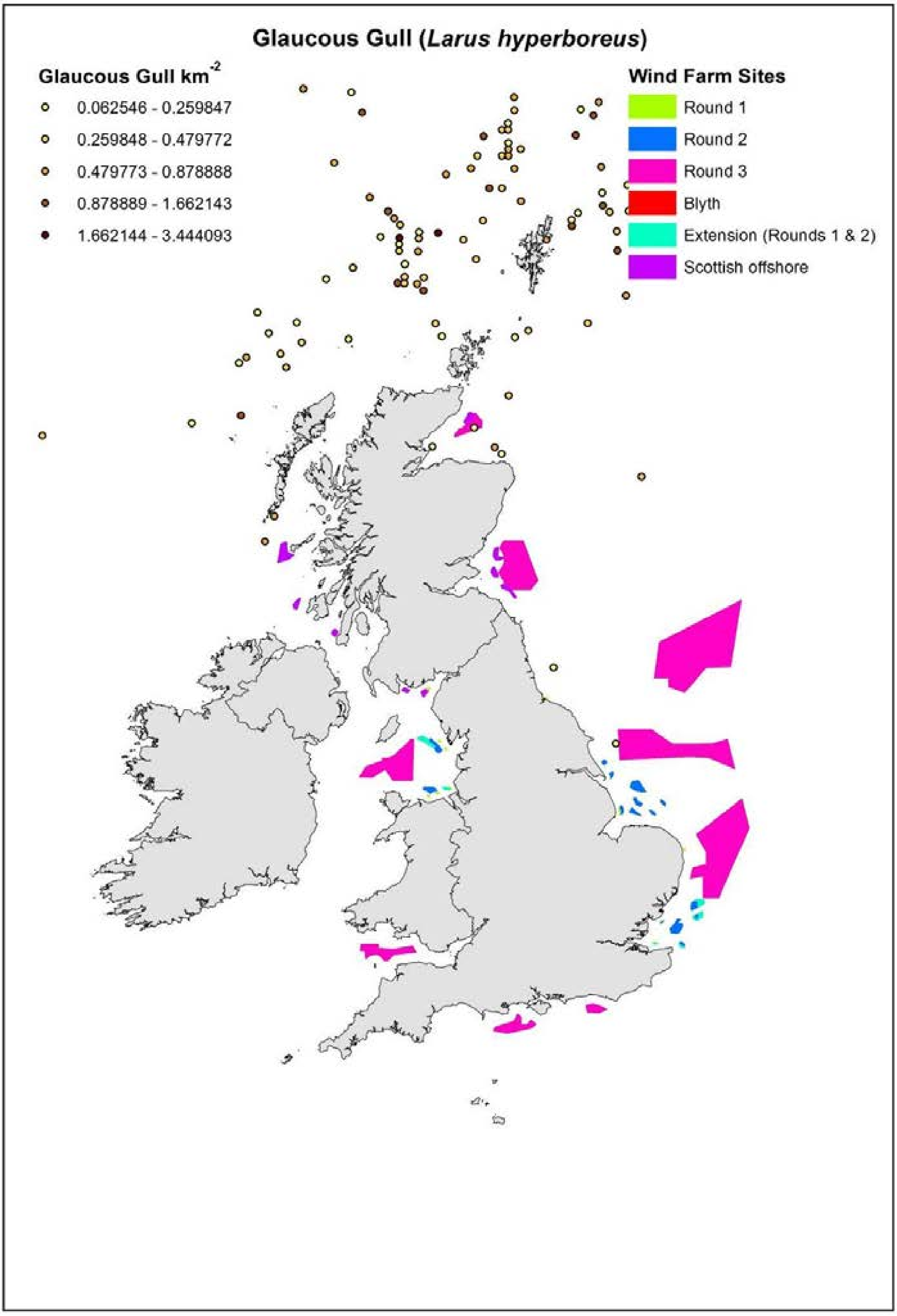

Figure 3.3.23 At-sea distribution of Glaucous Gull *Larus hyperboreus* in relation to (constructed, consented and proposed) offshore wind farms.

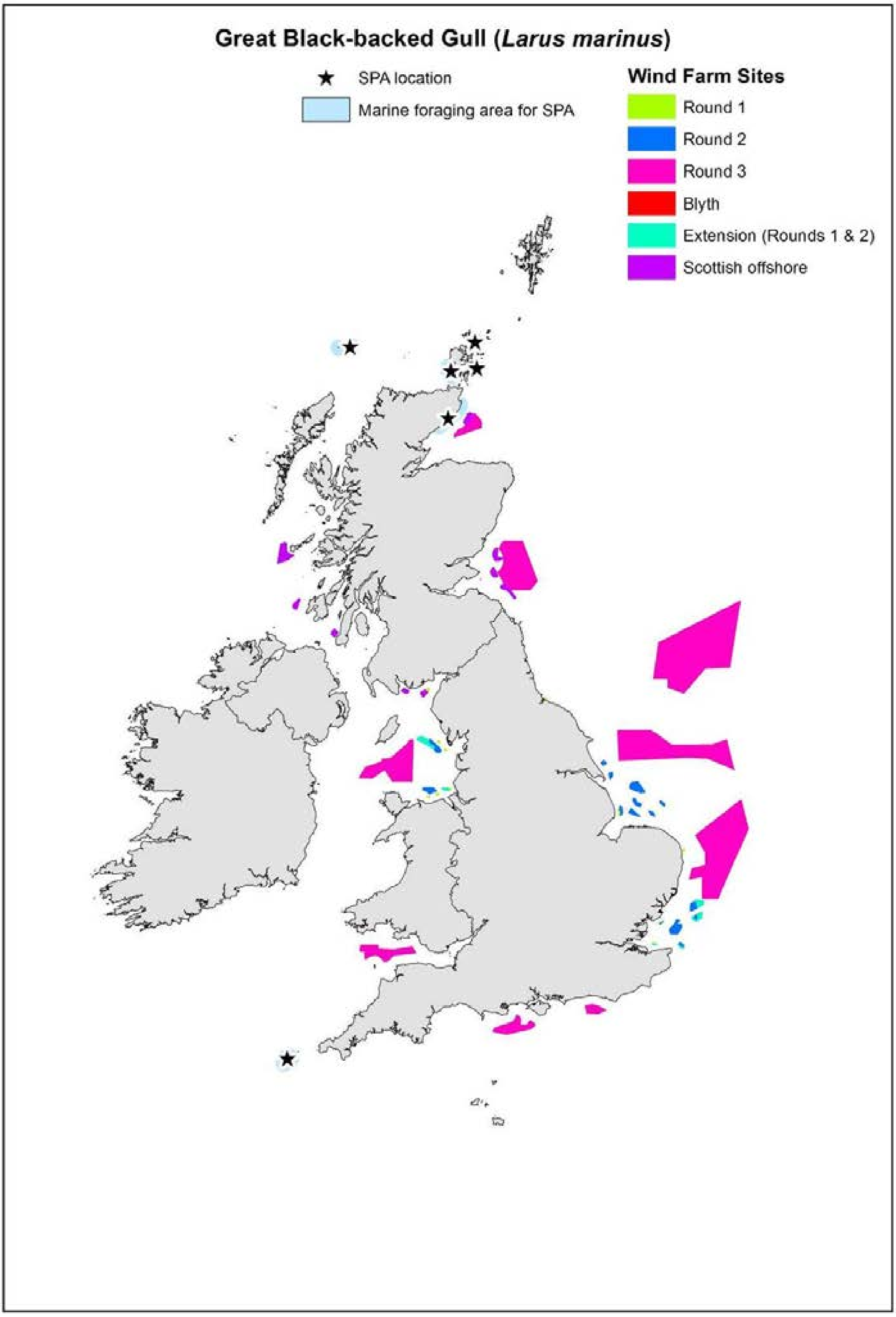

Figure 3.3.24 Potential foraging range of Great Black-backed Gull *Larus marinus* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

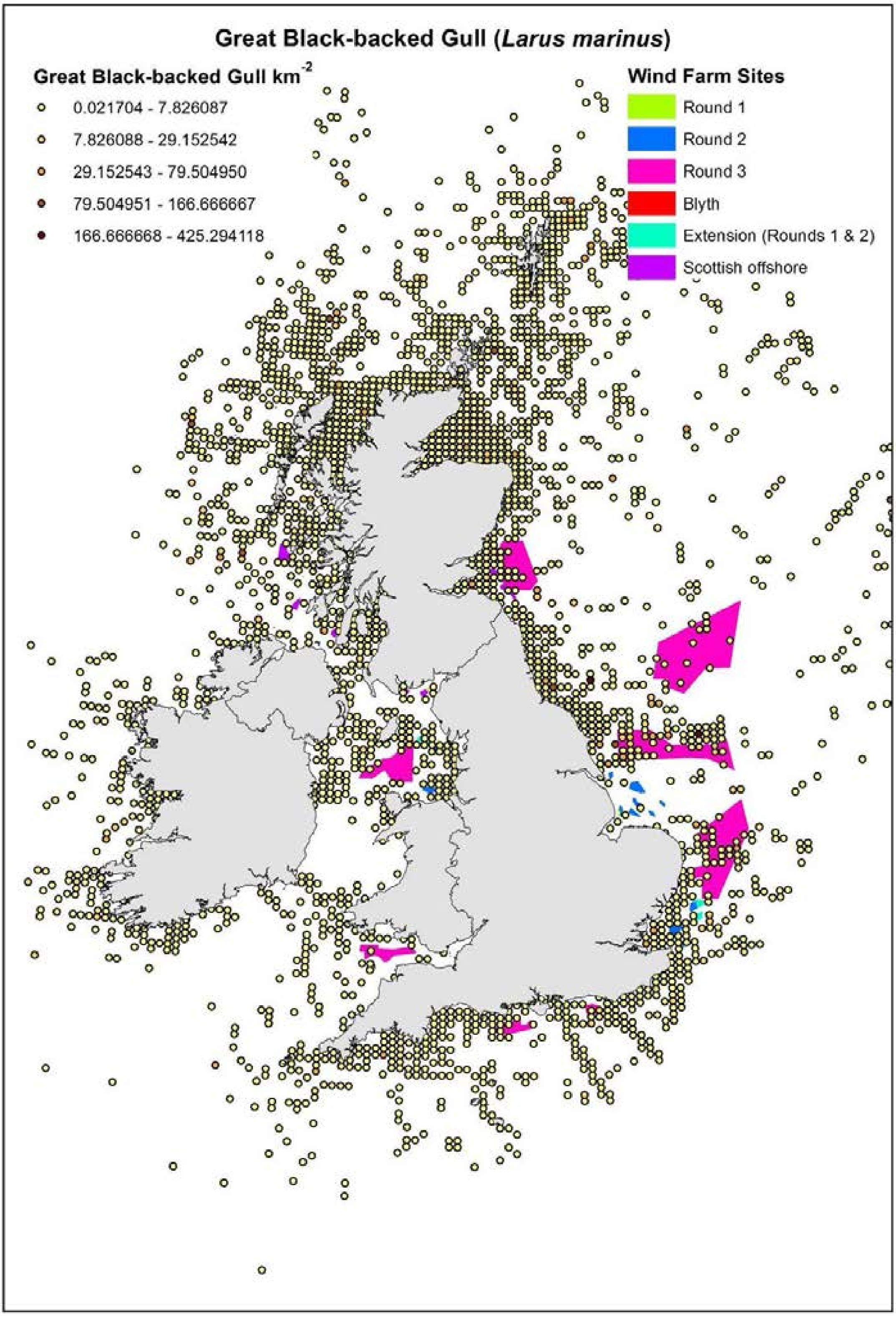

Figure 3.3.25 At-sea distribution of Great Black-backed Gull *Larus marinus* in relation to (constructed, consented and proposed) offshore wind farms.

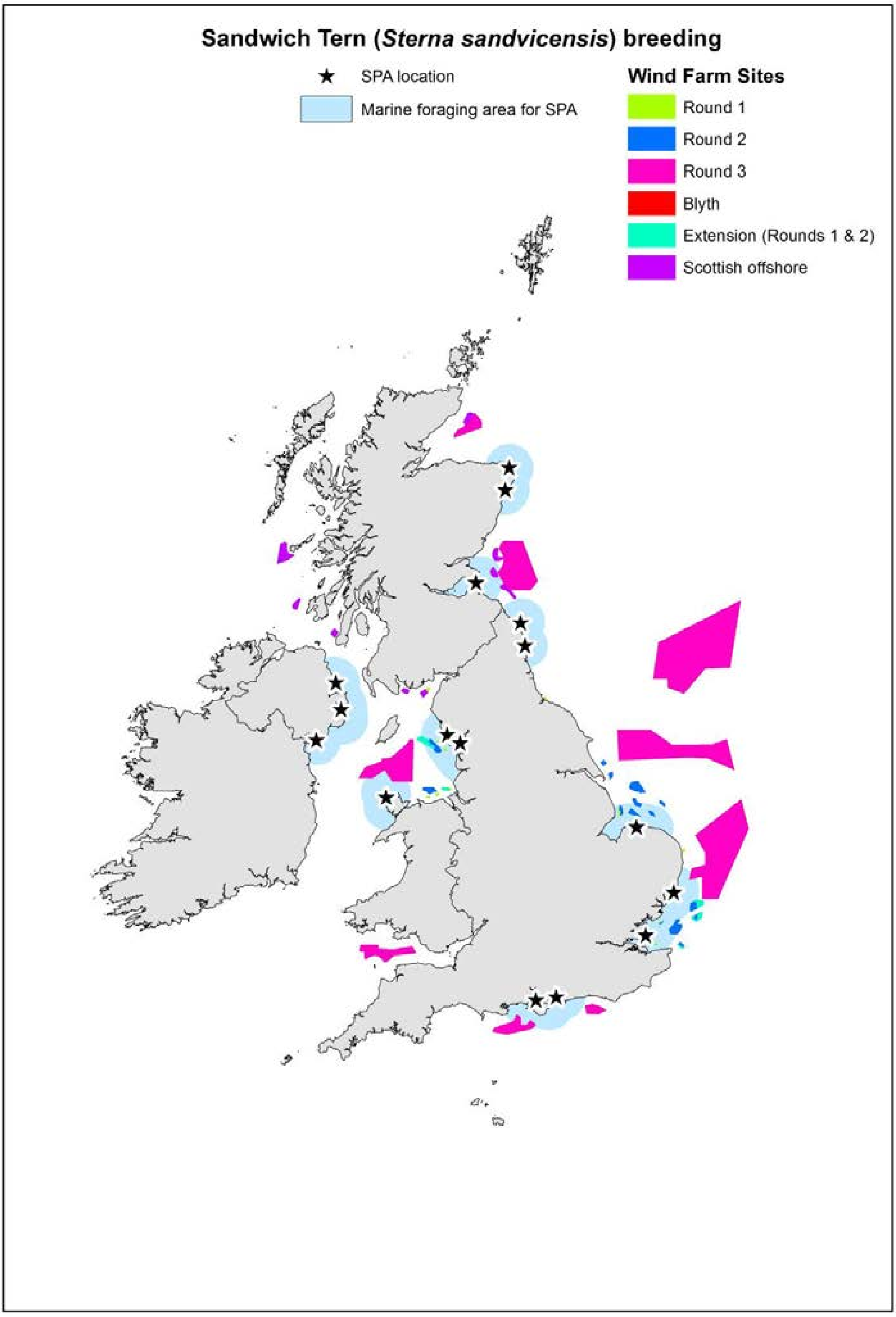

Figure 3.3.26 Potential foraging range of Sandwich Tern *Sterna sandvicensis* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

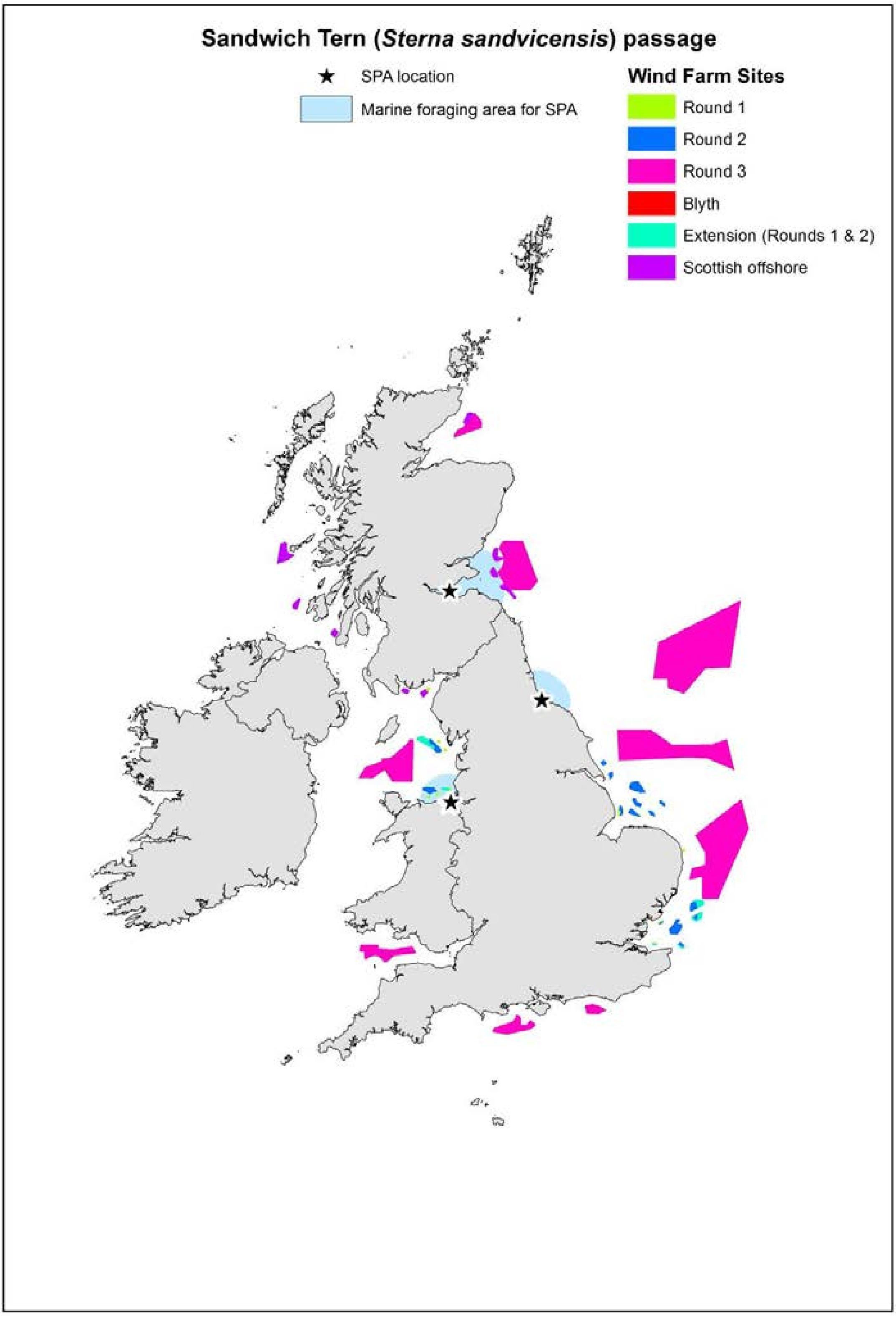

Figure 3.3.27 Potential foraging range of Sandwich Tern *Sterna sandvicensis* from passage site SPAs in relation to (constructed, consented and proposed) offshore wind farms.

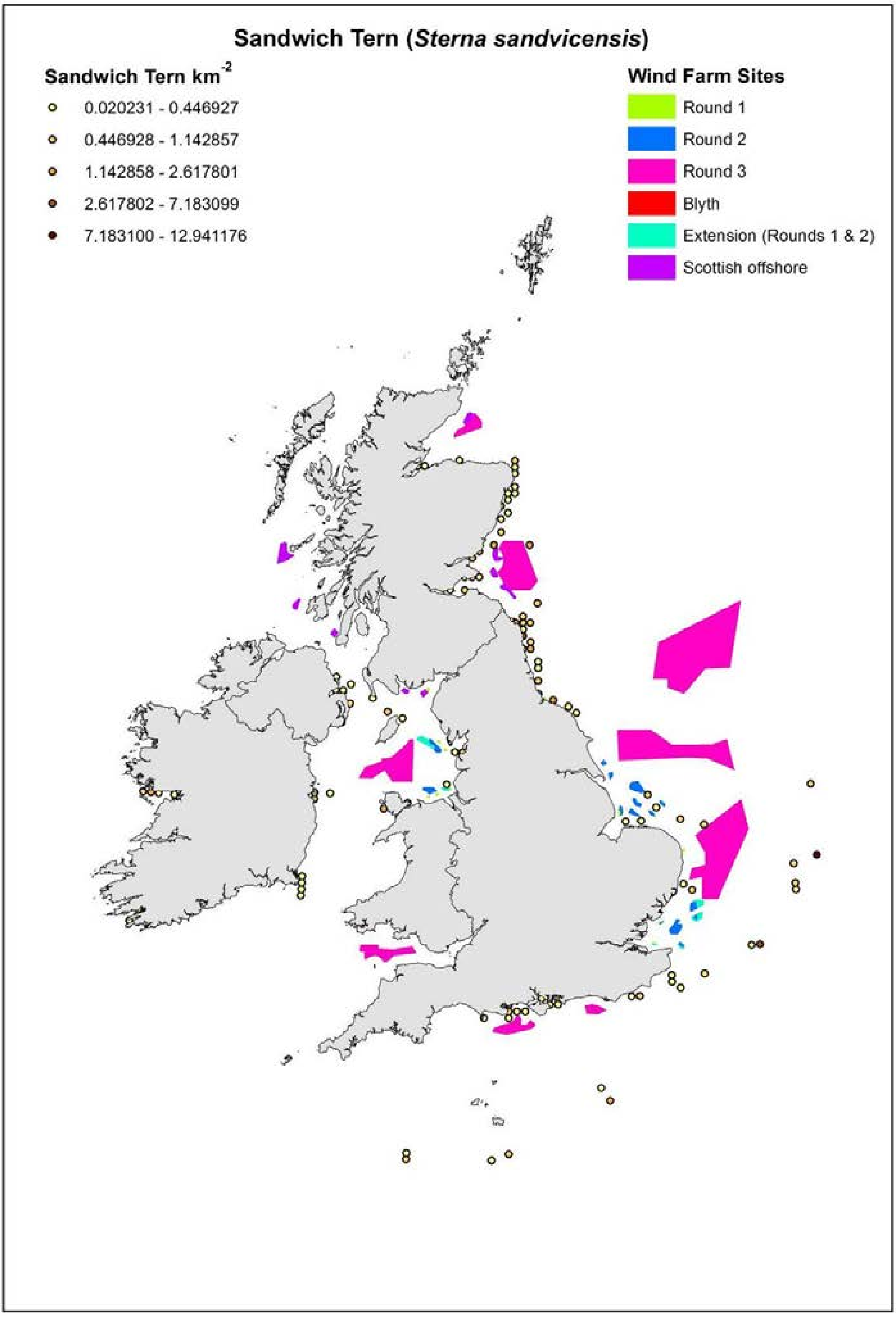

Figure 3.3.28 At-sea distribution of Sandwich Tern *Sterna sandvicensis* in relation to (constructed, consented and proposed) offshore wind farms.

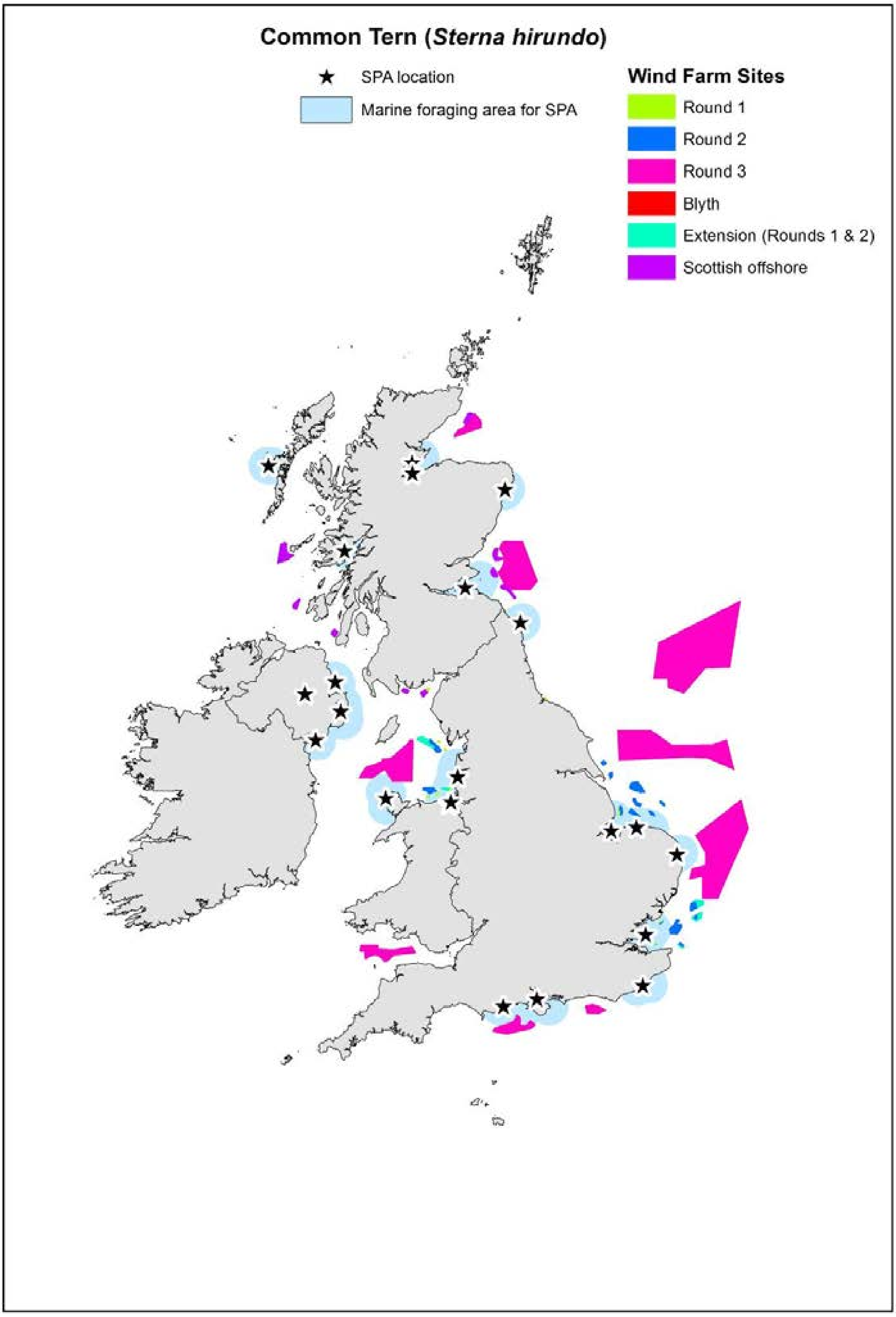

Figure 3.3.29 Potential foraging range of Common Tern *Sterna hirundo* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

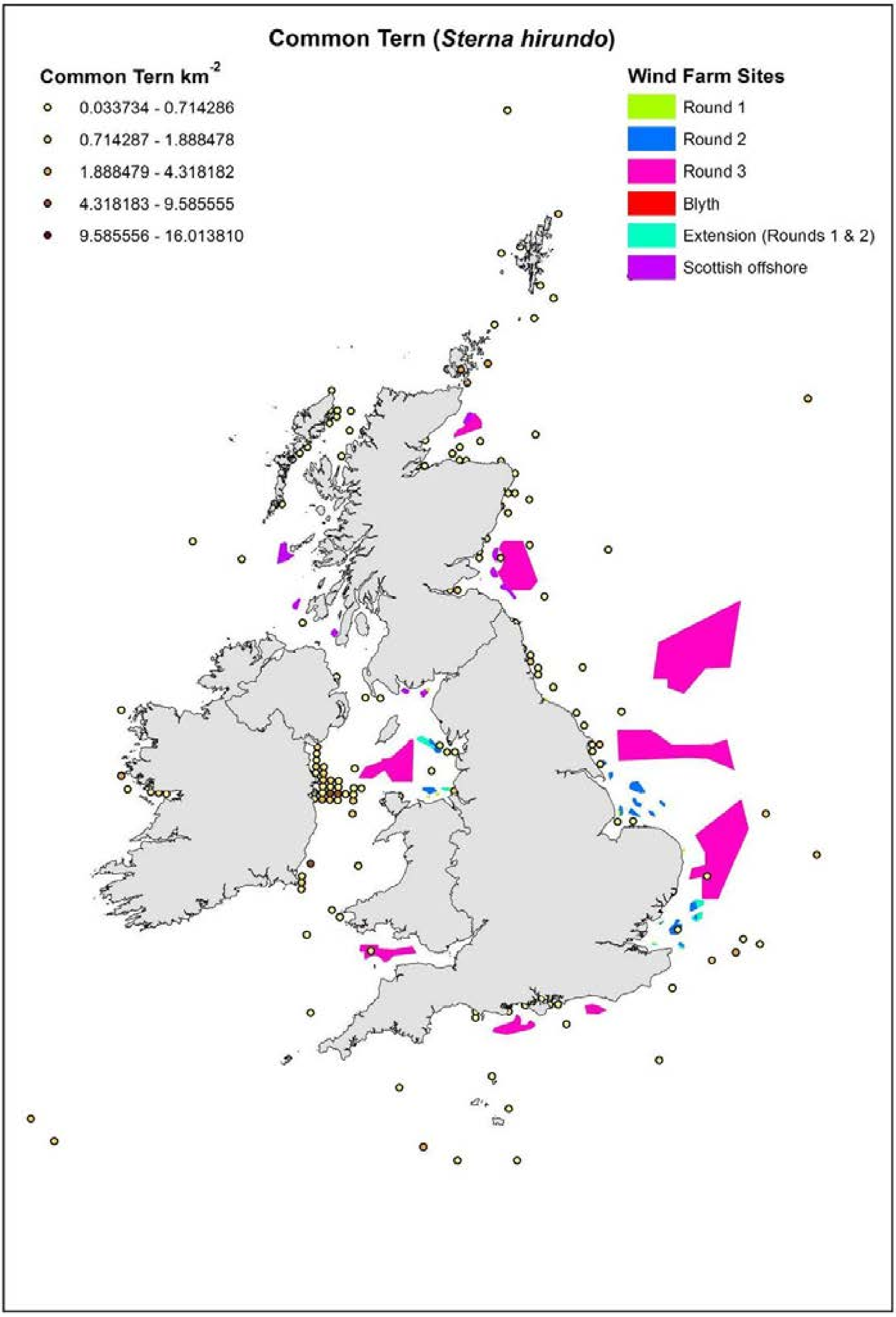

Figure 3.3.30 At-sea distribution of Common Tern *Sterna hirundo* in relation to (constructed, consented and proposed) offshore wind farms.

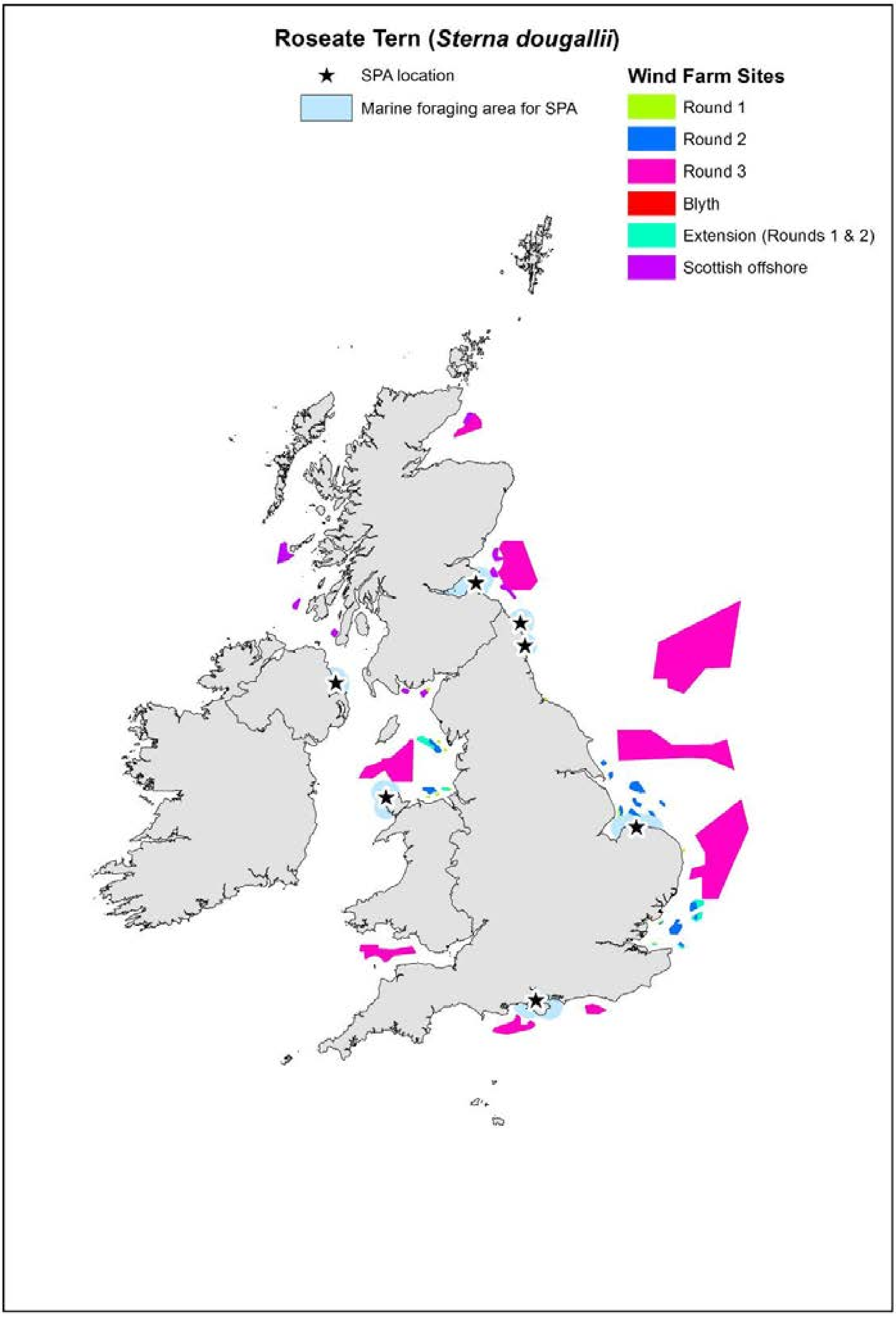

Figure 3.3.31 Potential foraging range of Roseate Tern *Sterna dougallii* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

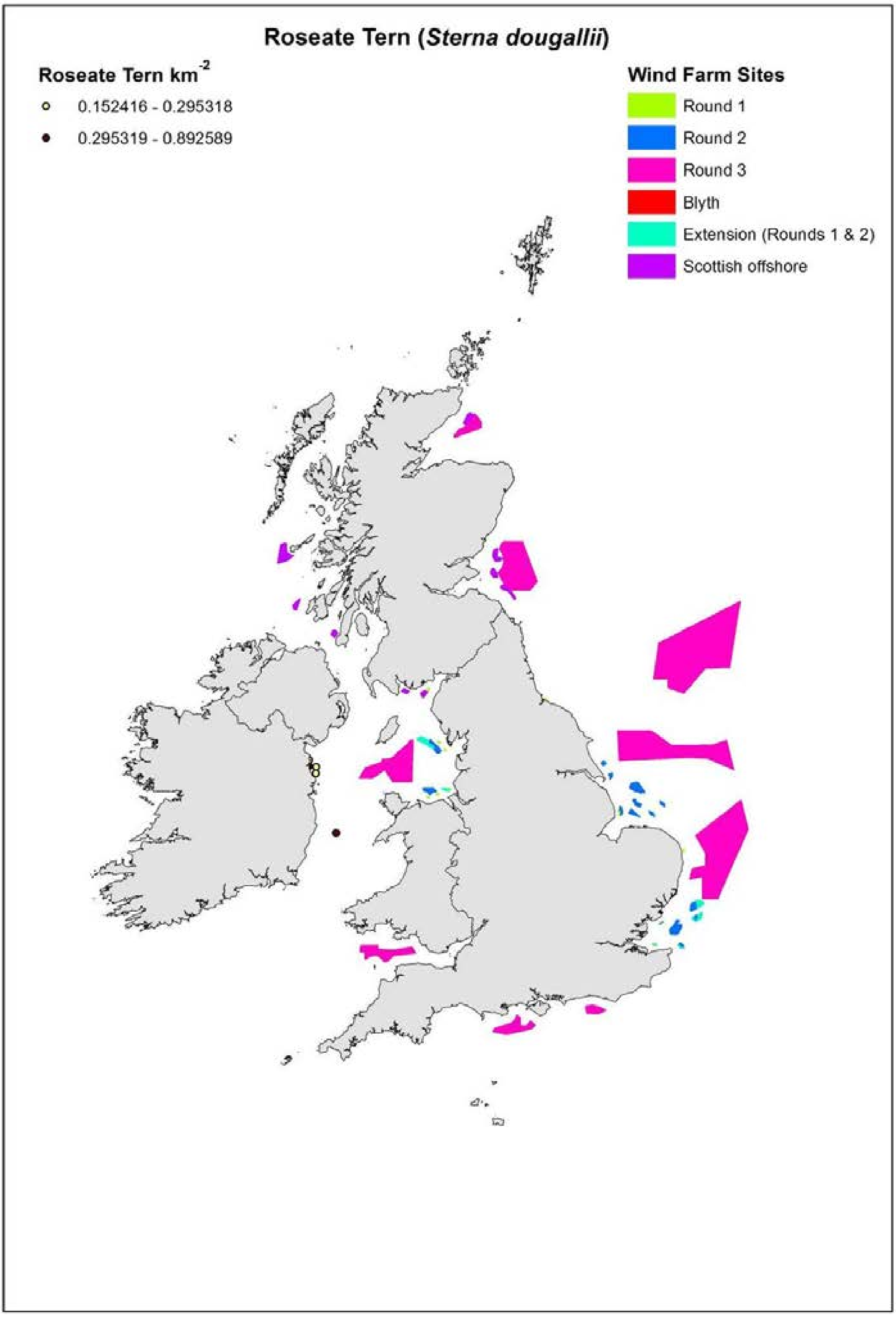

Figure 3.3.32 At-sea distribution of Roseate Tern *Sterna dougallii* in relation to (constructed, consented and proposed) offshore wind farms

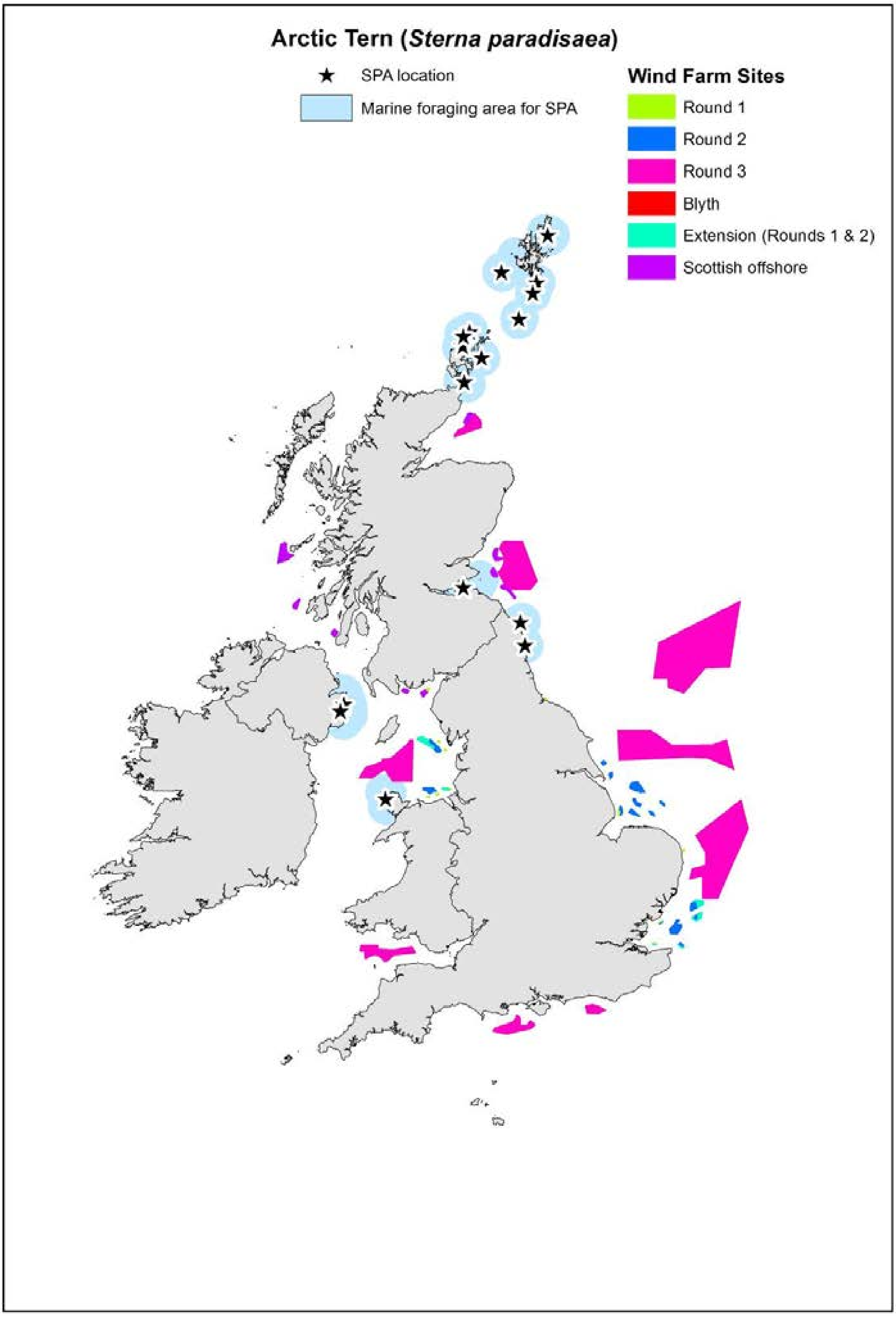

Figure 3.3.33 Potential foraging range of Arctic Tern *Sterna paradisaea* from breeding colony SPAs in relation to (constructed, consented and proposed) offshore wind farms.

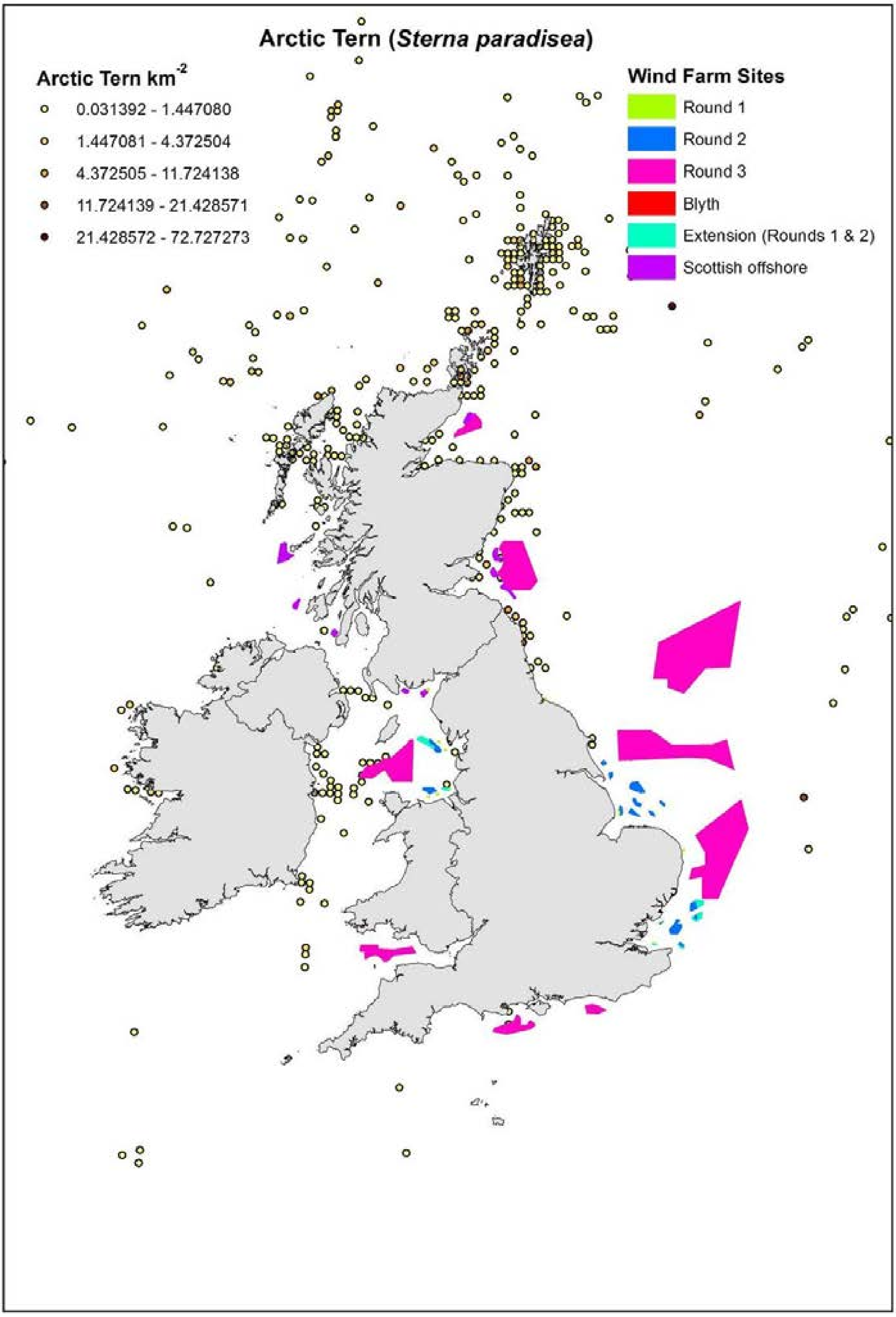

Figure 3.3.34 At-sea distribution of Arctic Tern *Sterna paradisaea* in relation to (constructed, consented and proposed) offshore wind farms

4. MODELLING OF COLLISION RISK IN RELATION TO THE MITIGATION OPTIONS IDENTIFIED

4.1 Introduction

The fourth objective of this work aims to investigate the cumulative risk of avian collision within wind farms in order to inform which of the shortlisted mitigation options might be of most benefit. Seven options are considered here, minimal use of lighting and auditory deterrents not being taken forward due to their respective low feasibility and effectiveness. Remote population monitoring is an approach that would be used in conjunction with other options, such as temporary shutdown, to maximise their effectiveness and thus is not considered directly in this chapter.

Using existing and proposed wind farms in the area of the Greater Wash as a case study, the established Band *et al*. (2007) model is here used to show how the shortlisted mitigation options might reduce the cumulative risk of avian collision in this area. Mitigation options may operate in a number of different ways, though in the majority of cases by increasing the level of avoidance of wind turbines. As the literature review in Chapter 2 has summarised, little is known as to how effective different measures may be in increasing avoidance and thus it is unlikely to be possible to compare with precision the different short-listed options. Further, there is still a large degree of uncertainty about the level of avoidance of wind turbines that birds demonstrate (the single most important factor in collision modelling: Chamberlain *et al.* 2005, 2006). The effects of temporary shut-down and changes to turbine design (i.e. lowering rotor speed and use of larger turbines), in contrast, can be more easily quantified.

Thus the modelling exercise undertaken here will help to identify the most promising mitigation measures, along with those that may be promising but that require further work to confirm their value.

4.2 Methodology

Data were available from the EIAs submitted for eight proposed wind farms in the Greater Wash – Dudgeon, Humber Gateway, Docking Shoal, LID6, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough (Figure 4.2.1: Centrica Energy 2009, Cutts *et al.* 2007, RES 2007, RPS 2009, 2010, Royal Haskoning. 2009, Scira Offshore Ltd 2006).

For each of these sites, a combination of aerial and boat based surveys had been carried out to provide estimates for the numbers of key bird species found within each proposed wind farm area (Table 4.2.1). These estimates, together with information on the proportion of individuals flying at a height which may bring them into contact with the turbine blades, were used within the EIAs to then estimate rates of collision with turbines for key species identified for each site.

Here, using the Band *et al*. (2007) model, we recalculate annual mortality estimates for 16 species in a consistent manner, with a standard set of avoidance rates, in order that the overall cumulative risk of avian collision within wind farms can be assessed and so that the possible effectiveness of the shortlisted mitigation options can be evaluated.

The results from this modelling were also used to inform Population Viability Analyses for seven species which breed within neighbouring SPAs.

A total of 17 seabird species were considered in Chapter 3 to be sensitive to the effect of collision mortality with offshore wind farms. While all of these are potentially exposed and thus should be considered vulnerable to the risk of collision with Round 1 and 2 developments, potential Round 1 and 2 extensions, Round 3 sites, or sites planned for Scottish Territorial Waters, only a subset are likely to be exposed to sites within the Greater Wash area. The sixteen species considered in this chapter included those species considered vulnerable that were reported on in the available EIAs, and in addition five species – Northern Fulmar *Fulmarus glacialis*, Black-headed Gull *Chroicocephalus ridibundus*, Common Gull *Larus canus*, Common Guillemot *Uria aalge* and Razorbill *Alca torda* – also recorded in these areas but not considered vulnerable. The latter were included by way of comparison to provide an indication of the levels of mortality that might be expected for species that only infrequently fly at the height of rotor blades.

Some further caveats ought to also be added regarding the analyses in this report. Notably, as data have been re-assessed for this analysis, it is important to note that the collision rates reported may differ from those published in the original EIAs. A number of further points ought to also be noted regarding the estimates of the numbers of birds from the EIAs that form the basis for the modelling. First, it should be noted that estimates of the maximum numbers of birds present in the area of each wind farm were used to provide a conservative (i.e. maximum possible) prediction of the likely mortality resulting from collision with wind turbines. The periods over which surveys were undertaken differed between each proposed wind farm area. While EIAs typically report on two years of data, the data collected may not be representative of long-term numbers. As numbers of birds may fluctuate from year to year (Maclean *et al.* 2006, 2007), caution is needed when comparing the numbers of birds, and thus predicted mortality, in each proposed wind farm area and in combining these estimates to provide a total estimate for the wider Greater Wash area. Further the survey methods used, and thus the estimates produced, may differ between the proposed wind farm areas

4.2.1 Collision Risk Modelling

To assess the cumulative annual mortality likely to result from collisions across each wind farm, the model of Band *et al.* (2007) was used. This model has been found to be mathematically sound (Chamberlain *et al.* 2005, 2006) and has been widely applied to the question of bird mortality at wind farms (e.g. Gill *et al.* 2002, Percival 2004, Madders 2004, Whitfield 2009). The model operates in two stages. Initially, the overall probability of a bird being hit when flying through a rotor is calculated. This probability is derived from the size and speed of the bird and the rotor diameter, chord width and period. Given that velocity and chord width will vary between the rotor hub and tip, collision probabilities are calculated at given intervals along the diameter of the blade and overall collision probability is calculated by summing these probabilities. This probability is then used in conjunction with avoidance rates and estimates of the numbers of birds within a wind farm area and the length of time they spend there to calculate the overall annual mortality associated with collisions with turbines.

The model derives a probability of collision (of a bird approaching a turbine, assuming no avoidance behaviour) for each species by combining data describing the structure and operation of the turbines with data describing the size and flight behaviour of the species concerned. By combining this probability of collision with estimates of the numbers of birds at risk and the rate at which birds take avoidance action in response to the presence of turbines, it is possible to calculate an annual mortality rate in relation to each wind farm. For a number of species, for example Razorbills and Common Guillemots, no individuals were observed flying at rotor height. Nevertheless, individuals of these species may occasionally fly at these heights, e.g. in response to disturbance. Consequently, for these species a precautionary principle was applied and it was assumed that 1 % of birds would fly at a height at which they would be at risk from collisions.

Here, the population estimates used were the distance corrected abundance values for each wind farm area, as presented within the relevant EIAs. Where multiple estimates were available (i.e. on a monthly basis) the maximum values were used in order to provide a conservative (i.e. maximum possible) prediction of the likely mortality resulting from collision with wind turbines. The surveys undertaken also noted the proportion of individuals flying at a height which may bring them into contact with the turbine blades (Table 4.2.2). Where no individuals from a species were observed flying at rotor height, a precautionary principle was applied and it was assumed that 1% of birds would fly at a height at which they would be at risk from collisions.

Data describing the size of the species concerned were obtained from 'BirdFacts' (Robinson 2005) and flight speeds were obtained from the published literature (Wakeling & Hodgson 1992, Ainley & Spear 1997, Pennycuik 1997) (Table 4.2.2). Flapping flight tends to be faster and more energetically costly than gliding flight. However, during the breeding season, birds are likely to be constrained in the length of time available for foraging by chick-rearing and are therefore likely to use flapping flight for foraging (Gaston 2004). At other times of year a mixture of both flapping and foraging flight may be used but as flapping flight increases the probability of collision (Band *et al.* 2007) a precautionary principle was applied and it was assumed all species used flapping flight within the wind farm areas.

In order to investigate the impacts of turbine design on avian collision risk, five different turbine sizes were considered (Table 4.2.3). In our analyses, the numbers of turbines used was varied depending on their capacity to generate power, so that the amount of electricity generated within each wind farm area remained approximately constant (Table 4.2.4). For each of these designs, it was assumed that turbines were equally spaced in rows perpendicular to the direction of travel of the majority of each bird species, with turbines facing the direction of travel. This assumption is in keeping with the precautionary principle described earlier as it will maximise the area over which birds are potentially exposed to turbine blades. Each row was assumed to be separated by a distance of one km.

The data describing the size and flight behaviour of the species concerned and turbine design were combined within the framework of the Band model to derive probabilities of collision (of a bird approaching a turbine, assuming no avoidance behaviour). These values were then used in conjunction with estimates of the numbers of birds at risk to determine an annual mortality rate for each species in each wind farm, with each turbine design assuming an avoidance rate of 0.99 (see discussion).

Calculation of the number of birds at risk of collision within the wind farm requires information on the passage rate of birds (derived from estimates of the numbers of birds using the area of each wind farm and the size of the area concerned) and the proportion at risk. The latter was determined by multiplying the proportion of birds in flight at risk height by the proportion of the "risk window" (*i.e.* the wind farm's frontal area) encompassed by the rotors. The proportion of birds flying at risk height was calculated as the modal value from those reported in the relevant EIAs. Where no birds were observed flying at risk height, a precautionary principle was applied and it was assumed that 1 % would fly at heights which placed them at risk of collision. Across EIAs, the reported proportion of birds flying at risk height remained fairly consistent. The size of the "risk window" was calculated as the length of the longest diagonal across the wind farm multiplied by the diameter of the turbine blades and the area presented by the wind farm rotors. The final figures calculated thus estimated the numbers of each species considered to be "at risk" of flying through the wind farm's rotors.

The potential effect of the short-listed mitigation options on avian mortality rates was then considered. Whilst the effects of temporary shut-down and changes to turbine design (i.e. lowering rotor speed and use of larger turbines) can be quantified, the likely efficacy of different measures that act by increasing the level of avoidance of wind turbines is not known with precision. Nevertheless, the effect of varying avoidance rates can still be simulated. To this end, following standard methodology, it was assumed that 3.6 MW turbines would be used within each wind farm.

The effects of avoidance rates of 0.9, 0.95, 0.99, 0.995, 0.9995 and 0.9999 on avian mortality were then considered and the results of these analyses discussed in relation to what is known as to each option's effectiveness.

4.2.2 Population Viability Analysis

To assess the potential impacts of mortality resulting from collision with wind farms on seabird populations, a simple Population Viability Analysis (PVA) approach was used, using the Unified Life Models software (Legendre & Clobert 1995). As only simple models were developed, factors previously shown to be important in the population dynamics of seabird colonies, for example density dependence, were disregarded. In practice, this may mean that the model allows populations to increase to unrealistic sizes. However, this was not felt to be important within the framework of the current study because it was concerned with the negative impacts of wind farms on seabird populations and in scenarios under which a populations carrying capacity was reached, collision related mortality is unlikely to be an important limiting factor. For seven study species that breed locally – Northern Gannet, Common Tern, Sandwich Tern, Lesser Black-backed Gull, Black-legged Kittiwake, Common Guillemot and Razorbill – population sizes at colonies neighbouring the Greater Wash were obtained from the Seabird 2000 population census (Mitchell *et al.* 2004). Estimates of survival and productivity for each of these species were then obtained from BirdFacts (Robinson 2005) and a review of the literature (Table 4.2.5).

As age at first breeding for seabird species is typically delayed for several years, it is necessary to know roughly what the age structure of the population of each species is likely to be. However, as juvenile and sub-adult birds are rarely seen at breeding colonies, neither data from the Seabird Monitoring Programme (http://jncc.defra.gov.uk/page-1550) nor the Seabird 2000 population census (Mitchell *et al.* 2004) are able to provide indications of the age structure of seabird populations in the Greater Wash area. Consequently, numbers of juvenile and sub-adult birds were calculated by assuming that the number of breeding pairs of each species at each colony within the study area had remained constant for the preceding years. The number of birds in each of the age classes up to first breeding was calculated by multiplying the number of breeding adults by productivity and the survival rate up to the age in question (Table 4.2.5). The populations thus presented are the sum of the breeding adults at each colony and the associated juvenile and sub-adult birds.

Initially, a baseline model was used to project likely population changes for each species in the absence of any wind farm. This model was used to validate the survival and productivity estimates used for each species. Modelled population growth rates were compared to the annual population growth rate at a regional level observed between the Seabird Colony Register census (1985-88) and the Seabird 2000 census (1998-2002) (Mitchell *et al.* 2004).

For each species, the annual baseline mortality rate was calculated by multiplying the species' annual adult survival rate by population size. Additional mortality due to collisions with wind turbines was calculated by summing the annual collision rates at all wind farms. This information was added to the baseline mortality rate to determine an annual survival rate in response to the presence of offshore wind farms and this was used within the PVA framework to determine the potential impact of wind farm-related mortality on regional populations of these seven seabird species. This analysis was carried out for wind farms containing 3.6 MW turbines assuming avoidance rates of 0.9, 0.95, 0.99, 0.995, 0.9995 and 0.9999.

4.3 Results

4.3.1 Northern Fulmar

Important wind farm areas for Fulmars Estimates of numbers of Northern Fulmars were reported in EIAs for five of the proposed wind farm areas – Dudgeon, LID6, Lincs, Race Bank and Sheringham Shoal – where they were present throughout the year. They were most abundant within the area of the proposed Race Bank wind farm, with a maximum estimate of 83 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 MW turbines (Figure 4.3.1).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Northern Fulmar colliding with a turbine in the absence of avoidance action is 0.069 (Table 4.3.1). The highest mortality rates are likely to occur within the Lincs wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.2). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through a wind turbine, then collision-related mortality is unlikely to occur at any of the locations featured on an annual basis (Figure 4.3.2). Were avoidance action to be taken on 99% of flights through the wind farm, collision-related mortality within the area of the Greater Wash as a whole is likely to remain in single figures on an annual basis, with a maximum of around 6 deaths within the Lincs wind farm attributable to collisions with wind turbines.

4.3.2 Northern Gannet

Important wind farm areas for Gannets Estimates of numbers of Northern Gannets were reported in EIAs for all eight proposed wind farm areas, where they were present throughout the year. They were most abundant within the areas of the Sheringham Shoal and Race Bank wind farms, with maximum estimated populations of 128 and 148 individuals respectively (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines at all sites (Figure 4.3.3).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Northern Gannet colliding with a turbine in the absence of avoidance action is 0.085 (Table 4.3.1). The highest mortality rates are likely to occur within the Race Bank wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.4). Assuming birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, on an annual basis collision related-mortality is likely to be limited to a 13 birds, of which 3 are likely to be found in each of the Docking Shoal and Race Bank wind farms. As the proportion of birds taking avoidance action decreases to 99%, annual collision-related mortality at wind farms in the vicinity of the Greater Wash is likely to increase to around 273 birds, of which around 60 are likely to occur at the Race Bank wind farm (Figure 4.3.4).

Population Viability Results from the baseline PVA indicate that the Bempton Cliffs Northern Gannet breeding colony is increasing in size (Figure 4.3.5). If avoidance action is taken on 99.95% of flights through the wind farms, it is likely that this population trend will be unaffected. A lower rate of avoidance of 99.5% is likely to cause the population to stabilise, and below this level is likely to contribute to a population decline. Were avoidance action to be taken on only 95%, or fewer, flights through the wind farms, collision-related mortality may contribute to a severe decline in the Northern Gannet population at the Bempton Cliffs SPA.

4.3.3 Red-throated Diver

Important wind farm areas for Red-throated Divers Estimates of numbers of Red-throated Divers were reported in EIAs for five of the proposed wind farm areas – Humber Gateway, LID6, Lincs, Race Bank and Sheringham Shoal – where they were present from September to March. They were most abundant within the area of the Lincs wind farm, with a maximum estimate of 93 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines seen at the LID6 and Lincs wind farms (Figure 4.3.6).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Red-throated Diver colliding with a turbine in the absence of avoidance action is 0.069 (Table 4.3.1). The highest mortality rates are likely to occur within the LID6 wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.7). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then collision-related mortality is unlikely at any of the locations featured on an annual basis (Figure 4.3.7). Were avoidance action to be taken on 99% of flights through the wind farm, collision-related mortality within the area of the Greater Wash as a whole is likely to remain in single figures on an annual basis, with a maximum of around 6 deaths within the LID6 wind farm attributable to collisions with wind turbines.

4.3.4 Arctic Skua

Important wind farm areas for Arctic Skuas Estimates of numbers of Arctic Skuas were reported in EIAs for three of the proposed wind farm areas – Docking Shoal, Lincs and Sheringham Shoal – where they were present throughout the year. They were most abundant within the area of the Docking Shoal wind farm, with a maximum estimate of 39 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). However, assuming at least 99% of birds take avoidance action whilst flying through the wind farms, no collision-related mortality is expected in relation to any of the turbine designs considered within this study.

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Arctic Skua colliding with a turbine in the absence of avoidance action is 0.068 (Table 4.3.1). If avoidance action is taken on at least 95 % of flights within wind farms, collision-related mortality is likely to be limited to a single bird within the Docking Shoal wind farm (Figure 4.3.8).

4.3.5 Great Skua

Important wind farm areas for Great Skuas Estimates of numbers of Great Skuas were reported in EIAs for the Docking Shoal and Lincs wind farm areas, where they occurred throughout the year with a maximum estimate of 11 and 17 birds respectively (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). However, assuming at least 99% of birds take avoidance action whilst flying through the wind farms, no collision-related mortality is expected in relation to any of the turbine designs considered within this study.

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Great Skua colliding with a turbine in the absence of avoidance action is 0.072 (Table 4.3.1). Collision-related mortality is only likely within the wind farms considered within this study is only likely if avoidance action is taken on less than 95% of the flights through the wind farms (Figure 4.3.9).

4.3.6 Common Tern

Important wind farm areas for Common Terns Estimates of numbers of Common Terns were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, LID6, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present from April to October. They were most abundant within the area of the Sheringham Shoal wind farm, with a maximum estimate of 51 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.10).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Common Tern colliding with a turbine in the absence of avoidance action is 0.068 (Table 4.3.1). The highest mortality rates are likely to occur within the Westernmost Rough wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.11). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then annual collision-related mortality is likely to be limited to a single bird at the Westernmost Rough wind farm (Figure 4.3.11). Were avoidance action to be taken on 99% of flights through the wind farm, collision-related mortality within the area of the Greater Wash as a whole is likely to be in the region of 35 birds per year, with 12 of those deaths occurring within the Westernmost Rough wind farm.

Population Viability Results from the baseline PVA indicate that the populations of Common Tern within the North Norfolk Coast and The Wash SPAs are declining (Figure 4.3.12). If avoidance action is taken on 99.99% of flights through the wind farms, it is unlikely that this rate of decline will be dramatically altered. However, were the avoidance rate to be 99.95% or less, this rate of decline starts to increase such that an avoidance rate of 95% or less may contribute to losses of Common Tern breeding colonies in The Wash and North Norfolk Coast SPAs within 25 years.

4.3.7 Sandwich Tern

Important wind farm areas for Sandwich Terns Estimates of numbers of Sandwich Terns were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, Humber

Gateway, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present from April to September. They were most abundant within the area of the Docking Shoal wind farm, with a maximum estimated population of 705 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.13).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Sandwich Tern colliding with a turbine in the absence of avoidance action is 0.065 (Table 4.3.1). The highest mortality rates are likely to occur within the Docking Shoal wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.14). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then annual collision-related mortality is likely to be limited to seven birds within the Docking Shoal wind farm and three birds each within each of the Dudgeon and Race Bank wind farms (Figure 4.3.14). Were avoidance action to be taken on 99% of flights through the wind farm, collision-related mortality within the area of the Greater Wash as a whole is likely to be in the region of 207 birds per year, with 144 of those deaths occurring within the Docking Shoal Wind farm.

Population Viability Results from the baseline PVA indicate that the populations of Sandwich Tern within the North Norfolk Coast SPA are increasing (Figure 4.3.12). Assuming avoidance action is taken on at least 99% of flights through the wind farms, this rate of increase is unlikely to be significantly affected. However, with avoidance action taken on less than 95% of flights through the wind farms, this rate of increase is likely to slow.

4.3.8 Black-headed Gull

Important wind farm areas for Black-headed Gulls Estimates of numbers of Black-headed Gulls were reported in EIAs for four of the proposed wind farm areas – Docking Shoal, Dudgeon, Lincs and Sheringham Shoal – where they were present throughout the year. They were most abundant within the area of the Dudgeon wind farm, with a maximum estimate of 74 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Black-headed Gull colliding with a turbine in the absence of avoidance action is 0.064 (Table 4.3.1). The highest mortality rates are likely to occur within the Dudgeon wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.2). However, if birds take avoidance action on at least 99% (an avoidance rate of 0.99) of flights through the wind farms, then collision-related mortality is likely to be limited to two birds at the Dudgeon and Lincs wind farms (Figure 4.3.16).

4.3.9 Common Gull

Important wind farm areas for Common Gulls Estimates of numbers of Common Gulls were reported in EIAs for five of the proposed wind farm areas – Docking Shoal, LID6, Lincs Sheringham Shoal and Westernmost Rough – where they were present from October to May. They were most abundant within the area of the Lincs wind farm, with a maximum estimate of 282 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 MW turbines (Figure 4.3.17). It should be noted that the high mortality rate observed in the Lincs wind farm is likely to be caused by the "worst-case" scenario assumption that turbines are sited facing the direction most of the birds under consideration fly in, which for Common Gulls here is typically east-west rather than the north-south corridor used by most other species.

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Common Gulls colliding with a turbine in the absence of avoidance action is 0.073 (Table 4.3.1). For the reasons stated above, the highest mortality rates are likely to occur within the Lincs wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.18). Assuming a 99.95% avoidance rate, around 64 collisions would be expected at the Lincs wind farm on an annual basis. Whilst fewer collisions would be expected at the remaining wind farms, up to 15 are likely, even assuming an avoidance rate of 99.95% (Figure 4.3.18).

4.3.10 Little Gull

Important wind farm areas for Little Gulls Estimates of numbers of Little Gulls were reported in EIAs for six of the proposed wind farm areas – Docking Shoal, Humber Gateway, LID6, Lincs, Race Bank and Sheringham Shoal – where they were present from September to March. They were most abundant within the area of the Docking Shoal wind farm, with a maximum estimate of 479 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.19).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Little Gull colliding with a turbine in the absence of avoidance action is 0.059 (Table 4.3.1). The highest mortality rates are likely to occur within the Race Bank wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 3.20). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then collision-related mortality is likely to be limited to three birds within the Docking Shoal and Race Bank wind farms (Figure 4.3.20). An avoidance rate of 99% would lead to a collision-related mortality rate of 67 around birds per year, of which around 34 would be expected within the Docking Shoal Bank wind farm.

4.3.11 Lesser Black-backed Gull

Important wind farm areas for Lesser Black-backed Gulls Estimates of numbers of Lesser Black-blacked Gulls were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, LID6, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present from April to September. They were most abundant within the area of the LID6 wind farm, with a maximum estimate of 151 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.21).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Lesser Black-backed Gulls colliding with a turbine in the absence of avoidance action is 0.073 (Table 4.3.1). The highest mortality rates are likely to occur within the LID6 wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.22). If birds take avoidance action on 99.99% (an avoidance rate 0f 0.9999) of flights through the wind farms, collision-related mortality would be expected on an annual basis within the LID6 and Race Bank wind farms (Figure 4.3.22). With avoidance action taken on 99% of flights through the wind farms, the annual collision-related mortality rate is likely to rise to 266 birds.

Population Viability Results from the baseline PVA indicate that the populations of Lesser Black-backed Gull surrounding the Greater Wash are increasing (Figure 4.3.23). Assuming avoidance action is taken on at least 99% of flights through the wind farms, this rate of increase is unlikely to be significantly affected. However, were avoidance action taken on 95% or less of the flights through the wind farm, the population would be likely to stabilise.

4.3.12 Herring Gull

Important wind farm areas for Herring Gulls Estimates of numbers of Herring Gulls were reported in EIAs for four of the proposed wind farm areas – Docking Shoal, Lincs, Sheringham Shoal and Westernmost Rough – where they were present throughout the year. They were most abundant within the area of the Lincs wind farm, with a maximum estimate of 125 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 MW turbines (Figure 4.3.24).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Herring Gulls colliding with a turbine in the absence of avoidance action is 0.079 (Table 4.3.1). The highest mortality rates are likely to occur within the Lincs wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.25). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then collision-related mortality is likely to be limited to 4 birds at the Docking Shoal, Lincs and Westernmost Rough wind farms (Figure 4.3.25). An avoidance rate of 99% would lead to a collision-related mortality rate of around 95 birds per year, of which around 41 would be expected within the Lincs wind farm.

4.3.13 Great Black-backed Gull

Important wind farm areas for Great Black-backed Gulls Estimates of numbers of Great Black-backed Gulls were reported in EIAs for four of the proposed wind farm areas – Docking Shoal, Lincs, Sheringham Shoal and Westernmost Rough – where they were present throughout the year. They were most abundant within the area of the Lincs wind farm, with a maximum estimate of 147 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 MW turbines (Figure 4.3.26).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Great Black-backed Gulls colliding with a turbine in the absence of avoidance action is 0.082 (Table 4.3.1). The highest mortality rates are likely to occur within the Westernmost Rough wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.2). However, if birds take avoidance action on at least 99.95% (an avoidance rate of 0.9995) of flights through the wind farms, then collision-related mortality is likely to be limited to eight birds at the Docking Shoal, Lincs and Westernmost Rough wind farms (Figure 4.3.25). An avoidance rate of 99% would lead to a collision-related mortality rate of around 215 birds per year, of which around 108 would be expected within the Westernmost Rough wind farm.

4.3.14 Black-legged Kittiwake

Important wind farm areas for Black-legged Kittiwakes Estimates of numbers of Black-legged Kittiwakes were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, Humber Gateway, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present throughout the year. They were most abundant within the area of the Race Bank wind farm, with a maximum estimate of 225 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.21).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Black-legged Kittiwakes colliding with a turbine in the absence of avoidance action is 0.066 (Table 4.3.1). The highest mortality rates are likely to occur within the Westernmost Rough wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.22). If birds take avoidance action on 99.99% (an avoidance rate 0f 0.9999) of flights through the wind farms, collision-related mortality would be expected on an annual basis within the Docking Shoal and Westernmost Rough wind farms (Figure 4.3.22). With avoidance action taken on 99% of flights through the wind farms, the annual collision-related mortality rate is likely to rise to 194 birds.

Population Viability Results from the baseline PVA indicate that the Black-legged Kittiwake breeding colony at the Flamborough Head and Bempton Cliffs SPA is declining (Figure 4.3.30). Assuming avoidance action is taken on at least 99% of flights through the wind farm, collision-related mortality is unlikely to contribute to this decline. However, were avoidance action to be taken on fewer than 95% of flights through the wind farms, this rate of decline may increase.

4.3.15 Common Guillemot

Important wind farm areas for Common Guillemots Estimates of numbers of Common Guillemots were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, LID6, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present throughout the year. They were most abundant within the area of the Docking Shoal wind farm, with a maximum estimate of 1649 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.31).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Common Guillemot colliding with a turbine in the absence of avoidance action is 0.059 (Table 4.3.1). The highest mortality rates are likely to occur within the LID6 wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 3.32). If birds take avoidance action on 99.99% (an avoidance rate 0f 0.9999) of flights through the wind farms, collision-related mortality would be expected on an annual basis within the LID6 wind farm (Figure 4.3.32). With avoidance action taken on 99% of flights through the wind farms, the annual collision-related mortality rate is likely to rise to 182 birds.

Population Viability Results from the baseline PVA indicate that the Common Guillemot breeding colony at the Flamborough Head and Bempton Cliffs SPA is increasing (Figure 4.3.33). Assuming avoidance action is taken on at least 99% of flights through the wind farm, this trend is unlikely to be affected by collision-related mortality. However, were avoidance action to be taken on fewer than 95% of flights through the wind farms, this rate of increase may slow.

4.3.16 Razorbill

Important wind farm areas for Razorbills Estimates of numbers of Razorbills were reported in EIAs for seven of the proposed wind farm areas – Docking Shoal, Dudgeon, LID6, Lincs, Race Bank, Sheringham Shoal and Westernmost Rough – where they were present throughout the year. They were most abundant within the area of the Sheringham Shoal wind farm, with a maximum estimate of 1786 individuals (Table 4.2.1).

Collision probability and turbine size A comparison of the probabilities of collision associated with different turbine sizes indicates that collision is more likely with smaller turbines than with larger turbines (Table 4.3.1). This is reflected in the high annual collision related mortality rates associated with the 3 and 3.6 MW turbines (Figure 4.3.34).

Annual mortality rates For a wind farm with 3.6 MW turbines, the probability of Razorbill colliding with a turbine in the absence of avoidance action is 0.060 (Table 4.3.1). The highest mortality rates are likely to occur within the Docking Shoal wind farm, due to the numbers of birds found there, their flight patterns and the potential number of turbines (Figure 4.3.35). If birds take avoidance action on 99.95% (an avoidance rate 0f 0.9999) of flights through the wind farms, collision-related mortality on an annual basis would be restricted to 2 birds within each of the Docking Shoal and Sheringham Shoal wind farms (Figure 4.3.35). With avoidance action taken on 99% of flights through the wind farms, the annual collision-related mortality rate is likely to rise to 82 birds.

Population Viability Results from the baseline PVA indicate that the Razorbill breeding colony at the Flamborough Head and Bempton Cliffs SPA is increasing (Figure 4.3.33). Assuming avoidance action is taken on at least 99% of flights through the wind farm, this trend is unlikely to be affected by collision-related mortality. However, were avoidance action to be taken on fewer than 95% of flights through the wind farms, this rate of increase may slow and, with an avoidance rate of only 90 %, populations may start to decline.

4.4 Discussion

The degree to which species' populations are affected by collisions with turbines is influenced by their flight behaviour and turbine design. For a 3.6 MW turbine, assuming no avoidance action is taken, the overall probability of collision varies from 5.9% of flights in the Little Gull and Common Tern to 8.4% of flights in the Northern Gannet. While these values decrease as turbine size increases, motion smear may mean that larger, slower turbines are actually less visible to birds than smaller, faster turbines – see section 4.4.2 below.

In terms of total annual collision-related mortality, the most affected species are likely to be Northern Gannet, Common Gull, Lesser Black-backed Gull, Great Black-backed Gull, Black-legged Kittiwake and Common Guillemot. However, results from PVA highlight that a high annual mortality rate resulting from collisions with wind turbines may not necessarily lead to a decline in populations. For example, species such as Black-legged Kittiwake and Common Guillemot are likely to have a high annual collision-related mortality rate. However, this mortality rate is unlikely to have much impact on the underlying population trends for these species. In contrast, the Common Tern population in the area of the Greater Wash is declining and the additional mortality due to collisions with turbines would increase this decline further.

Fox *et al.* (2006) highlight the fact that the ability to accurately model collision risk is severely hampered by a lack of species specific information on avoidance rates. For this study a range of rates, from 90% to 99.99% were considered, and these indicated a linear relationship between avoidance and collision-related mortality rates. Whilst for many species collision avoidance in an offshore environment is poorly understood, a variety of studies are indicative of what may be realistic values. Collision and mortality rates have been calculated for gulls and terns at a variety of offshore wind farms and typically range from 0.14 – 0.03 % of flights (Everaert & Stienen 2006; Everaert & Kuijken 2007; Krijgsveld *et al.* 2009). These values would translate to avoidance rates of 99.86 – 99.97 respectively. As these values fail to consider individuals that fail to take avoidance action but do not collide with turbines, they are likely to be over-estimates of actual avoidance. However, comparisons with avoidance rates obtained for alternative situations, for example the avoidance of power lines (i.e. Henderson *et al.* 1996), suggest that these values may not be inaccurate.

Desholm & Kahlert (2005) used radar to investigate avoidance behaviour in response to an offshore wind farm by migrating waterfowl (primarily Eider and geese). In their study only 0.9 % of birds passed close enough to turbines to collide during the night and 0.6 % passed close enough to turbines to collide during the day, corresponding to avoidance rates of 99.1 % and 99.4 % respectively. Studies of collision avoidance by geese in the US also showed avoidance rates in excess of 99 % (Pendlebury 2006). The above studies suggest that using a baseline avoidance rate of 99 % would be realistic, and sufficiently precautionary, for many species of seabird and seaduck. However, for some species such as the Red-throated Diver, a lower value of 98 % may be more appropriate (Jackson *et al.* in prep). .

It should be noted that the existing methodology has been developed for use in situations where birds are passing through an area, for example on migration. For most seabird interactions with offshore wind farms, birds are likely to behave differently. Some species will fly through wind farms en route between foraging areas and breeding colonies. In this instance individuals may pass through a wind farm on multiple occasions during a single day. In contrast, the collision risk model assumes that each individual bird will pass through a wind farm just once, hence the ability of the model to predict a larger number of fatalities on an annual basis than the total population size of some species. Furthermore, some species may forage within wind farms, and thus spend more time within them than is required to simply travel through them, as is assumed by the model.

The potential of the seven shortlisted mitigation options, that either directly reduce the probability of collision or which aim to increase avoidance rates, are discussed below in light of the results of the modelling outlined above.

4.4.1 Temporary shut down

A temporary shutdown of turbines is likely to reduce collision-related mortality during shutdown periods by close to 100% (a small number of birds might still collide with static turbines). The best timing of any shut-down measures will vary between species, and given that shut down periods can seriously impact the financial viability of wind farm proposals, any implemented would have to be highly targeted to specific periods.

For some species, such as terns which are only present during the breeding season, shut down periods targeted to the nestling periods when adult birds need to forage for their young might be most effective. Targeting shutdowns to the post-fledging period when young birds may be more likely to collide with anthropogenic structures (Mathiasson 1993, Henderson *et al.* 1996) might also be beneficial for such species. Shut downs might also be timed to coincide with migration periods when increased number of certain species may be present.

A range of options could be considered, for example shutting turbines down for a number of days, or at times when bird activity was high. These shut downs are likely to result in a proportional decrease in the annual collision-related mortality rate. For example, were turbines shut down for 15 days the collision related mortality rate might be predicted to fall by ca. 4% for resident species (15/365) or 8% for species present only during the breeding season (15/183). Similarly, were turbines shutdown for 30 days, the fall in collision-related mortality might be predicted to be ca. 8% and 16% for resident species and species only present during the breeding season respectively. Such temporary shut downs would reduce the annual collision-related mortality rates for some species, for example, applied across all the wind farms considered, a 30 day shut down may translate to the deaths of 238 fewer Lesser Black-backed Gulls if is assumed that there is an avoidance rate of 99% at other times.

4.4.2 Increasing visibility

There is often little difference in birds' avoidance behaviour in response to turbines which are turning and those which are not (Larsen & Guillemette 2007). This implies that often birds do not see the blades of operational turbines until it is too late to take avoidance action. By making turbines more visible it is likely that avoidance action will be stimulated earlier and more often, thus reducing the number of casualties.

4.4.2.1 Lower rotor speed and larger turbines

Larger turbines spin at a lower speed than smaller turbines, consequently decreasing the probability of collisions, while altering the size of the turbines may also impact species avoidance rates – as indicated by the results in Table 4.3.1.

However, these effects are likely to involve a series of complex interactions. Initially, the larger, slower turbines may be more visible to birds, potentially stimulating earlier avoidance action. Despite this, motion smear may mean that larger, slower turbines are actually less visible to birds than smaller, faster turbines – see Chapter 2.

Motion smear occurs when an object becomes progressively blurred as it moves across the retina. It is apparent at the tips of turbine blades as the observer approaches the turbine, but not within the central region. Despite the fact that the tips (distal) and central (proximal) regions are rotating at the same rate, the linear velocity of the blades is greater towards the tips than within the central region. The higher linear velocity of the distal region of the blades is such that the image cannot be resolved by the retina and instead, it appears as a transparent blur. The portions of the blade whose movement is below this velocity can be seen. As an observer approaches an object, the size of the object relative to the retina increases. Consequently the linear velocity of the object's image, across the retina, also increases as a greater distance across the retina is covered within the same time period. This means that as an observer approaches a rotating turbine, the point along the blade's length at which motion smear occurs decreases and so less of the blade is visible. This was demonstrated by Hodos (2003) who showed that as turbine diameter increased and rotor speed decreased, the distances below which the blades could not be detected because of motion smear increased.

Hodos (2003) shows that for a constant rotation speed, the distance at which visibility of the turbine tip begins to be lost increases linearly. Under the scenarios envisaged within this study, the maximum number of rotations per minute varies from 12.8 (for 3 MW turbines) to 7.6 (for 7 MW turbines). Taking an average value of 10 rotations per minute for these turbines and extending the values from Hodos (2003), the distance at which the turbine tip begins to lose visibility increases to 23 m for a turbine with a diameter of 90 m, 27 m for a diameter of 105 m, 31 m for a 120 m diameter, 32 m for a 125 m diameter and 38 m for a 150 m diameter. As visibility of the turbine tip begins to be lost, the hazard to the bird is likely to increase. Assuming that the likelihood of taking avoidance action is directly proportional to the ability of a bird to see the whole object, this is likely to mean that collision risk compared to that predicted for a 90 m diameter turbine, is likely to be 17% higher for a 105 m diameter turbine, 34% higher for a 120 m diameter turbine, 39% higher for a 125 m diameter turbine and 65% higher for a 150 m diameter turbine.

If it is assumed that for a 90 m diameter turbine there is a avoidance rate of 99%, these figures are likely to translate to a 98.83% avoidance rate for a 105 m diameter turbine, a 98.66% avoidance rate for a 120 m diameter turbine, a 98.61% avoidance rate for a 125 m diameter turbine and a 98.35% avoidance rate for a 150 m turbine. These decreased avoidance rates may result in dramatic increases in the collision-related mortality rates for some species. For instance a 150 m diameter turbine could result in an additional 96 deaths on an annual basis in comparison to a 90 m turbine for the Black-legged Kittiwake. However, the lower probability of collision associated with larger turbines means that around 72 fewer collisions would be expected at the 150 m turbine than at a 90 m turbine. It is likely that the decreased avoidance rate associated with the smaller turbines would be largely, or entirely, cancelled out by the increased probability of collision with an turbine of this size.

4.4.2.2 Anti-smear pattern

As a bird approaches a turbine, it is likely to perceive a transparent blur through which the bird believes it can pass safely (Hodos 2003), a phenomenon, as described above, known as 'motion smear'. Studies into the efficacy of anti-smear patterns have been largely theoretical and lab-based and thus the efficacy of this measure cannot be quantified. Despite this, early results suggest that by having a single black and two white blades, the distance at which the rotating turbine blades become visible is increased significantly, allowing avoidance action to be taken earlier, potentially reducing collision-related mortality. Hodos (2003) highlights the need for a long-term study to investigate the impact of an anti-smear pattern on avoidance behaviour.

Assuming baseline avoidance rate of 99% in the absence of any mitigation measure, were anti-smear patterns to reduce the number of birds that fail to take avoidance action by 50%, the avoidance rate would rise to 99.5%. Such a change might have a significant effect on the numbers of birds predicted to collide with turbines. For example, applied across all wind farms, it may result annually in the deaths of 114 fewer Northern Gannets and 118 fewer Lesser Black-backed Gulls.

4.4.2.3 Ultra-violet paint

The use of ultra-violet paint has been shown to reduce collisions with windows by up to 50% (Klem 2009). However, when tested in comparison to other materials within a wind farm environment, no significant differences were observed. However, there was a trend for fewer collisions when the effects of different habitats were adjusted for (Young *et al.* 2003). However, as ultra-violet paint is reliant on the presence of light from the ultra-violet spectrum, this is unlikely to be effective at night. Furthermore, it is likely that many of the paints that are already used on wind turbines are likely to reflect ultra-violet light to some extent.

Assuming a best case scenario, whereby the values obtained by Klem (2009) were replicated for offshore turbines collision-related mortality rates would drop by 50%. However, as ultra-violet paint would be unlikely to be visible at night and some species of seabird may remain at sea over night, particularly during the winter, it may be safer to assume a drop in collision-related mortality rates of around 25%. This mitigation is likely to be more effective for breeding species, for example terns, than for wintering species, such as divers, as the proportion of daylight will determine how long the ultra-violet paint will increase the visibility of the turbine blades.

Assuming a baseline avoidance rate of 99% in seabirds, a drop in collision-related mortality would be equivalent to an avoidance rate of around 99.25%, although this is likely to vary throughout the year and be higher during the summer than the winter. Such a change might have a significant effect on the numbers of birds predicted to collide with turbines. For example, applied across all wind farms, this would result in the deaths of 16 fewer Sandwich Terns and 56 fewer Great Black-backed Gulls.

4.4.2.4 Use of lighting

Safety concerns for shipping and aviation mean that lighting cannot be eliminated from wind farms. Further, if used incorrectly, changes in the use of lighting may attract birds to wind farms and consequently contribute to an increase in the annual collision-related mortality rate. In particular, steady burning red and white light has been shown to attract birds (Poot *et al.* 2008). Nevertheless, alternatives to solid red or white lights are available which may help to increase avian avoidance of turbines. By replacing steady burning lights with flashing lights, collisions may be reduced by 50-70% (Gehring *et al.* 2009). Different coloured lighting may also serve to reduce collisions with blue or green lights likely to be able to reduce collisions by up to 65% (Poot *et al.* 2008). Assuming a baseline avoidance rate of 99% these values would represent an increase in the avoidance rate to 99.50 – 99.70% for flashing lights and 99.65% for blue or green lights.

These changes to avoidance rates would result in dramatic changes to the annual collision-related mortality rates for a number of species. An increase of 0.5% in the avoidance rate of Sandwich Terns around wind farms in the Greater Wash would represent a reduction in the annual collision-related mortality rate from 63 birds to 32 birds, an increase of 0.7% would prompt a further decline to 19 birds per annum.

4.4.2.5 Use of lasers

Lasers have been used in wildlife management to disperse birds from airfields (Baxter 2007) and urban areas (Sherman & Barras 2004). In some species they can reduce the numbers of birds within an area significantly (Blackwell 2002) and they can be effective over large distances (Baxter 2007). However, they may be ineffective during daylight and do not disperse birds long distances.

Lasers are most likely to be effective at preventing species such as gulls from roosting within wind farm areas. Due to day length, lasers are likely to be more effective at dispersing wintering species than breeding species, and may thus be best targeted at species such as auks and divers. Providing they are used continually, lasers can be very effective, deterring 80-100% of birds within terrestrial environments (Blackwell 2002, Werner & Clark 2006). Assuming a baseline 99% avoidance rate, lasers might thus potentially increase the avoidance rate to 99.4% (assuming the number of birds that fail to take avoidance action is decreased by 80%, but that lasers are only effective at night).

This would translate into a significant reduction in the annual collision-related mortality rates in a number of species with up to 60 fewer Black-legged Kittiwakes killed on an annual basis.

4.4.3 Decoy towers

Some species show a strong avoidance of turbines regardless of whether they are in motion or not, and of decoy structures. When a series of dummy turbines where constructed around the periphery of an offshore wind farm, Eider Duck where shown to be up to 60% less likely to enter the turbine area (Larsen & Guillemette 2007). However, these towers are only likely to deter species, such as auks and divers, which show displacement in response to wind farms.

Assuming a baseline avoidance rate of 99%, decoy towers may boost the avoidance rate to 99.6%, but only for species such as auks, seaduck and divers. As a result, the deployment of decoy towers may result in a drop in the annual collision-related mortality rate for species such as Red-throated Diver, Common Guillemot and Razorbill.

4.4.4 Conclusions and recommendations

Measures to reduce avian collisions with wind farms are highly variable in their efficacy. Amongst the most effective, based on the available evidence from the literature, might be a switch from steady burning red lights (designed to warn aircraft and shipping) to lights which flash, or the use of blue/green lights steady warning lights. However, this switch would be in conflict with legislation requiring steady burning red lights on turbines for aircraft safety (CAA 2010c). A similar issue may determine the feasibility of the use of lasers to deter birds from offshore wind farms as these may be construed as lights that can dazzle or distract pilots (CAA 2010c).

Of the other methodologies considered, the use of decoy towers has shown promise (Larsen & Guillemette 2007) in deterring birds from turbine areas. However, their efficacy is likely to be limited to species such as divers, seaduck and auks which show active displacement from wind farms, rather than gulls and terns, which may even be attracted to wind farm areas (Petersen 2005). As these are species whose flight behaviour puts them at low risk of collision, the overall effectiveness of decoy towers may be minimal for seabirds.

Similarly, alterations to turbine size are likely to have a minimal impact. Increasing turbine size reduces the overall probability of collision. However, the effects of motion smear mean that turbines with large diameters are likely to be less visible to approaching seabirds, resulting in a reduced avoidance rate and consequently negligible net change to the overall collision rate.

There is a lack of evidence into the efficacy of ultra-violet paint and anti-smear patterns for reducing avian collision risk. Ultra-violet paint has been shown to be effective at reducing bird collisions with windows (Klem 2009), but field trials at wind farms have shown no significant differences (Young *et al.* 2003). This is likely to be because other materials used also reflect ultra-violet to some extent and consequently the 50% reduction in collisions considered within this study should be treated with caution. The use of anti-smear patterns to reduce avian collisions has shown promise in lab-based studies, significantly reducing the distance at which blades lose visibility (Hodos 2003). There is an urgent need to test the efficacy of such patterns in reducing avian collisions in the field.

Lastly, a temporary shut down of turbines is likely to be near 100% effective for the time in which it occurs, but financial constraints are likely to highly restrict the length of shut down periods. Targeted shut downs for restricted key periods, perhaps further restricted to times of day when key species are most active, represent a possible option given these constraints and would be worth exploring on a site by species basis. A potential four-stage strategy for implementing shut downs to mitigate against the risk of collisions by avian migrants has recently been proposed by Kube (2011). This strategy would use 1) a pre-warning model; 2) a large-scale real time evaluation of nocturnal migration using weather radar; 3) a local real time evaluation of low altitude nocturnal migration using fixed beam radar and 4) a local real time analysis of bird attraction in the vicinity of turbines using video tracking systems.

Of the short-listed mitigation options, those most likely to reduce avian collision risk are a temporary shut down of turbines, the deployment of decoy towers and the use of anti-smear patterns on turbine blades. However, the deployment of decoy towers is only likely to have an impact in areas where there are large concentrations of auks and divers. Research is urgently needed both to test the efficacy of anti-smear patterns in the field, and to model the impacts of different and realistic shut down strategies on seabirds. A universal solution to the problem of avian collisions with offshore turbines is unlikely to be found and consideration must be given to using mitigation methodologies appropriate to the species frequenting the area of concern.

Table 4.2.1 Estimates of the numbers of birds found in each of the proposed offshore wind farms in the vicinity of the Greater Wash and the time periods during which these species were present.

Site	Northern Fulmar[1]	Northern Gannet[1]	Red-throated Diver[2]	Arctic Skua[1]	Great Skua[1]	Common Tern[3]	Sandwich Tern[4]	Black-headed Gull[1]	Common Gull[5]	Little Gull[2]	Lesser Black-backed Gull[4]	Herring Gull[1]	Great Black-backed Gull[1]	Black-legged Kittiwake[1]	Common Guillemot[1]	Razorbill[1]
Docking Shoal	22	95	13	39	11	38	705	13	67	479	56	50	81	225	1649	1786
Dudgeon	54	95				34	141	74			81			79	876	175
Humber Gateway		35	17				20			364				79	92	231
LID6	47	57	50			33			136	70	151				1396	134
Lincs	79	128	93	18	17	23	65	31	282	137	123	125	147	98	475	116
Race Bank	83	148	6			12	222			432	77			189	1023	222
Sheringham Shoal	28	107	6	11		51	27	14	30	103	64	19	16	69	1105	1690
Westernmost Rough		21				39	2		86		15	11	53	106	219	100

[1] All year; [2] Sep-Mar; [3] Apr-Oct; [4] Apr-Sep; [5] Oct-May. Figures are estimates of the maximum numbers of birds present in the area of each wind farm during specified periods.

Table 4.2.2 Size and flight behaviour of the bird species considered in modelling.

Species	Body length	Wingspan	Mean speed of powered flight	Proportion flying at rotor height[2]
Northern Fulmar	48	107	13.0	0.01
Northern Gannet	94	172	14.9	0.18
Red-Throated Diver	61	111	16.7	0.05
Arctic Skua	44	118	13.3	0.01
Great Skua	56	136	14.9	0.01
Common Tern	33	88	9.1	0.15
Sandwich Tern	38	100	13.0	0.20
Black-headed Gull	36	105	14.1	0.01
Common Gull	41	120	9.2	0.37
Little Gull[1]	26	78	14.1	0.06
Lesser Black-backed Gull	58	142	14.5	0.39
Herring Gull	60	144	11.3	0.38
Great Black-backed Gull	71	158	12.4	0.35
Black-legged Kittiwake	39	108	13.1	0.14
Common Guillemot	40	67	19.1	0.01
Razorbill	38	66	16.0	0.01

[1] No estimate of flight speed available for Little Gull, so value for Black-headed Gull used.

[2] A modal value from those reported in the EIAs for each species is used. Where no individuals from a species were observed flying at rotor height, a precautionary principle was applied and it was assumed that 1% of birds would fly at a height at which they would be at risk from collisions.

Table 4.2.3 Turbine design parameters considered by this study.

Generating capacity (MW)	Blades	Diameter	Chord	Pitch	Period
3	3	90	3.4	10	4.7
3.6	3	104	3.9	10	5.4
4.5	3	120	4.5	10	6.3
5	3	125	4.7	10	6.5
7	3	150	5.7	10	7.9

Table 4.2.4 Potential number of turbines in each wind farm area.

Dudgeon	Humber Gateway	LID6	Lincs	Race Bank	Sheringham Shoal	Westernmost Rough
500	300	21	250	500	325	180

Table 4.2.5. Life history values used within Population Viability Analysis framework to determine the potential impacts of collision related mortality on seabird population in the vicinity of the Wash

	Age at First Breeding	Clutch Size	Juvenile (1st year) Survival	2nd Year/Immature Survival	3rd Year Survival	4th Year Survival	Adult Survival	Sources
Gannet	5	1	0.424	0.829	0.891	0.895	0.919	Robinson 2005; Wanless *et al.* 2006
Common Tern	3	1	0.68				0.9	Robinson 2005
Sandwich Tern	3	2	0.358	0.741	0.741	**NA**	0.898	Robinson 2005, 2010
Lesser Black-backed Gull	4	3	0.73				0.91	Nagar *et al.* 2000; Robinson 2005
Kittiwake	4	2	0.70	0.76			0.82	Aebischer & Coulson 1990; Danchin & Monnat 1992; Cann & Monnat 2000; Bull *et al.* 2001; Robinson 2005
Common Guillemot	5	1	0.56	0.79	0.91	0.93	0.96	Harris *et al.* 2000 a,b; Bull *et al.* 2001; Sandvik *et al.* 2005; Robinson 2005
Razorbill	4	1	0.38				0.91	Lloyd 1974; Chapdelaine 1997; Bull *et al.* 2001; Sandvik 2005; Robinson 2005

Table 4.3.1 Overall probabilities of collision (of a bird approaching a turbine, assuming no avoidance behaviour) associated with different turbine sizes (i.e. generating capacities) for each study species.

Species	3 MW	3.6 MW	4.5 MW	5 MW	7MW
Northern Fulmar	0.073	0.069	0.066	0.065	0.062
Northern Gannet	0.092	0.085	0.080	0.079	0.073
Red-Throated Diver	0.073	0.069	0.066	0.065	0.062
Arctic Skua	0.072	0.068	0.065	0.065	0.062
Great Skua	0.076	0.072	0.068	0.067	0.064
Common Tern	0.071	0.068	0.064	0.064	0.061
Sandwich Tern	0.069	0.065	0.062	0.062	0.059
Black-headed Gull	0.068	0.064	0.062	0.061	0.059
Common Gull	0.078	0.073	0.069	0.069	0.065
Little Gull	0.062	0.059	0.057	0.057	0.055
Lesser Black-backed Gull	0.078	0.073	0.069	0.069	0.065
Herring Gull	0.084	0.079	0.074	0.073	0.069
Great Black-backed Gull	0.088	0.082	0.077	0.076	0.071
Black-legged Kittiwake	0.070	0.066	0.063	0.063	0.058
Common Guillemot	0.061	0.059	0.057	0.057	0.053
Razorbill	0.063	0.060	0.058	0.058	0.056

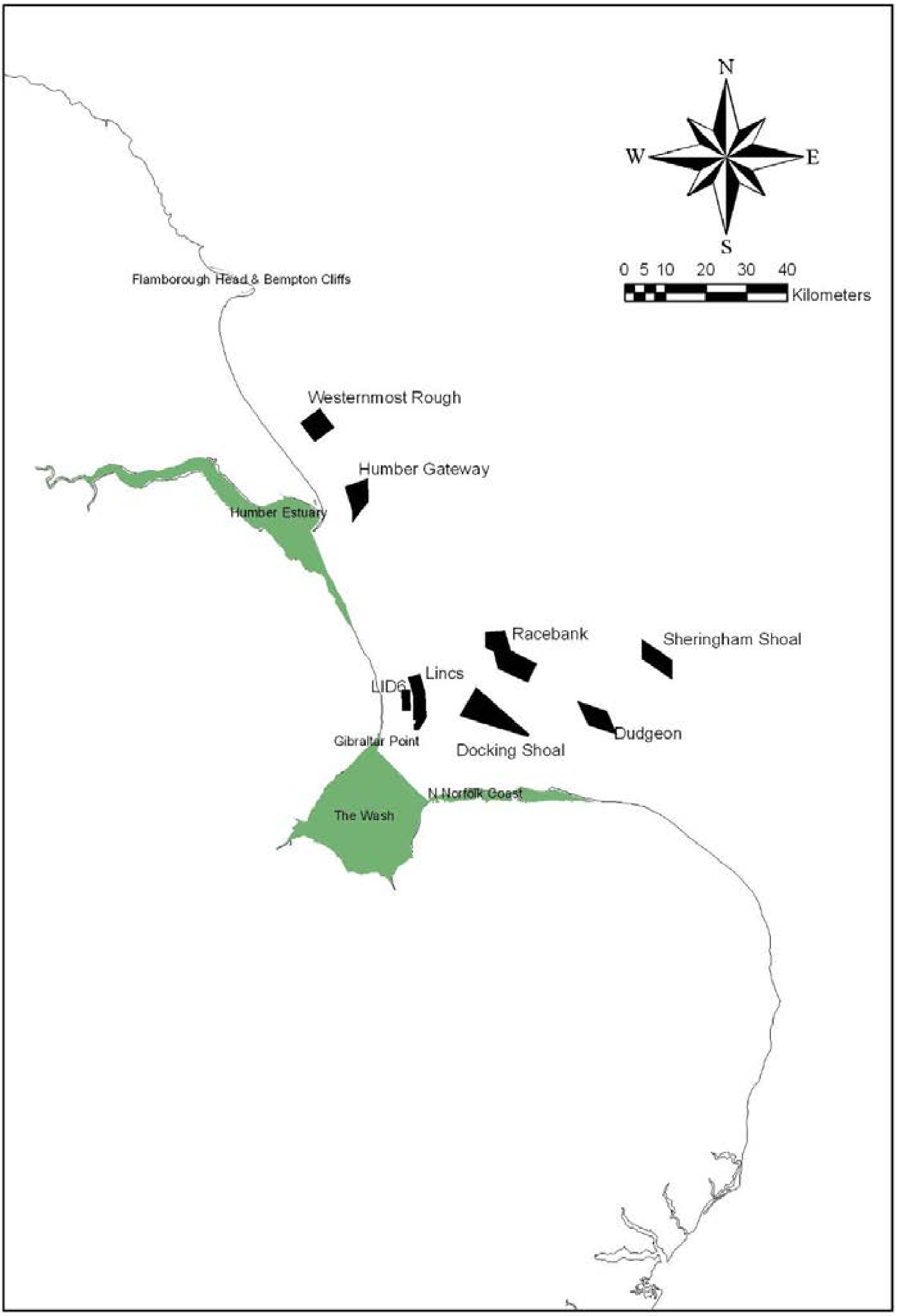

Figure 4.2.1 Locations of proposed offshore wind farms and existing SPAs, of which breeding seabirds are features, in the vicinity of the Greater Wash.

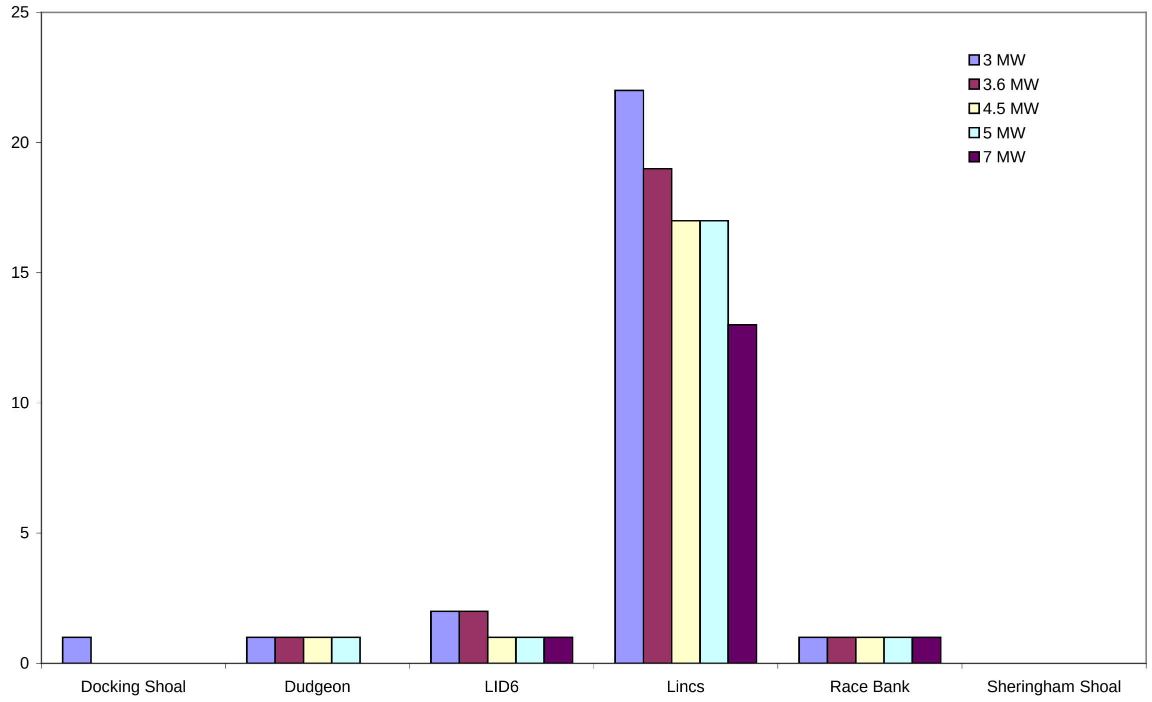

Figure 4.3.1 Northern Fulmar mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

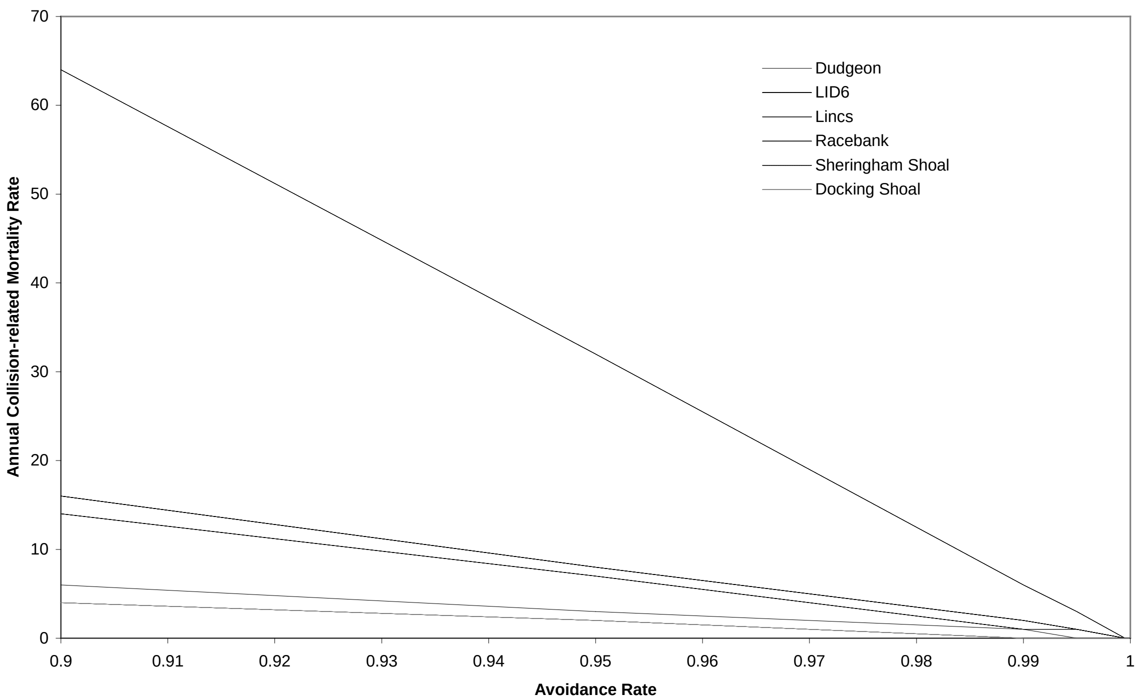

Figure 4.3.2 Modelled annual collision-related mortality rates for Northern Fulmar within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

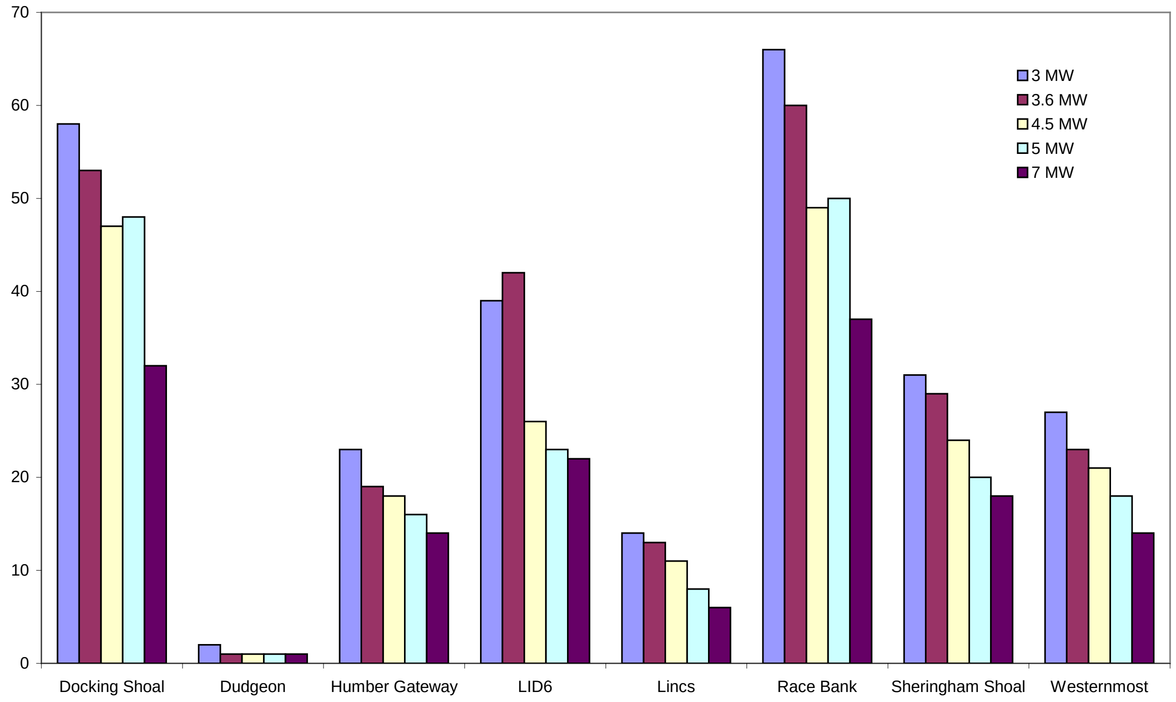

Figure 4.3.3 Northern Gannet mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

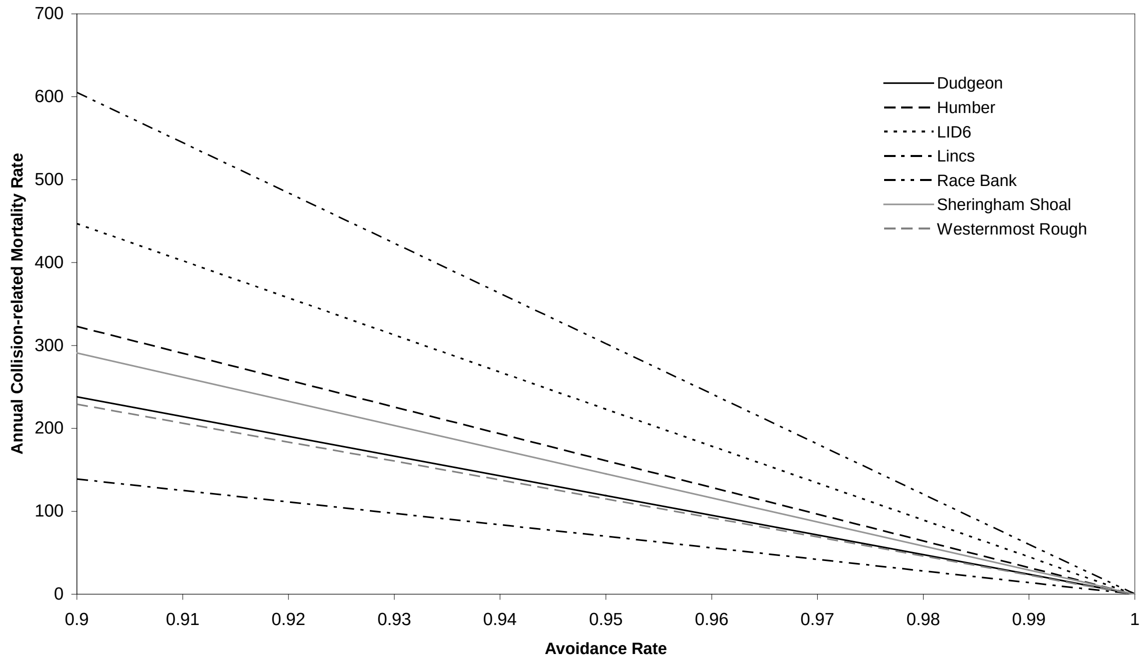

Figure 4.3.4 Modelled annual collision-related mortality rates for Northern Gannet within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

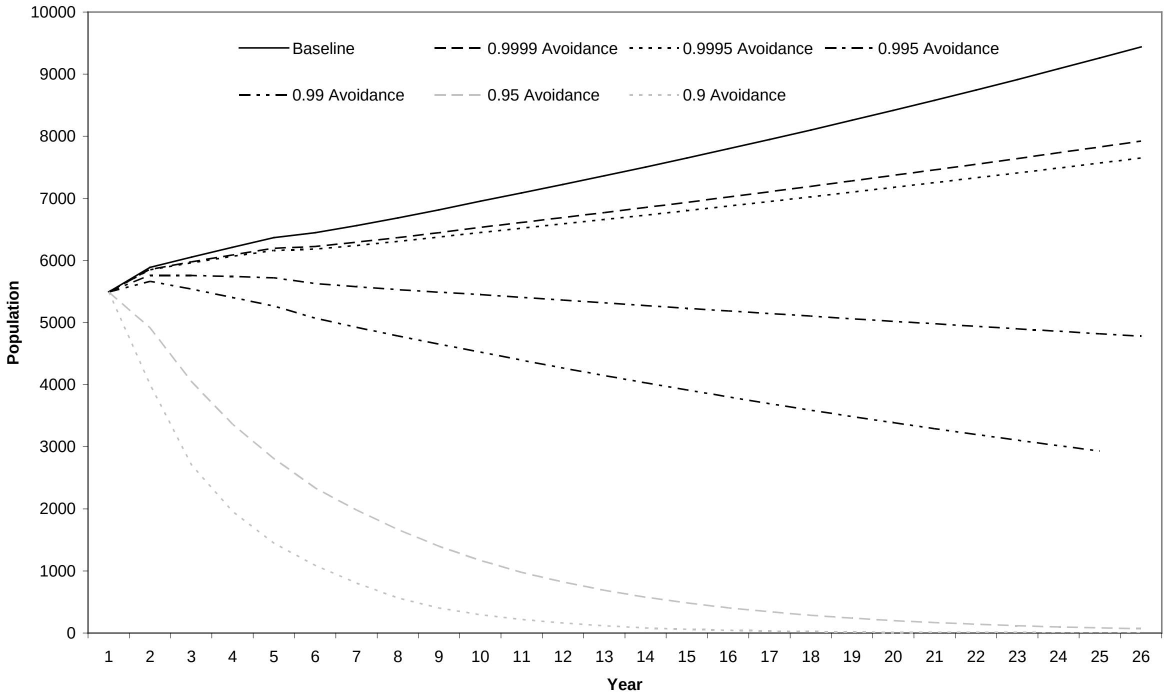

Figure 4.3.5 Impacts of collision-related mortality on the Northern Gannet breeding colony at Flamborough Head and Bempton Cliffs SPA assuming a range of avoidance rates assessed using Population Viability Analysis.

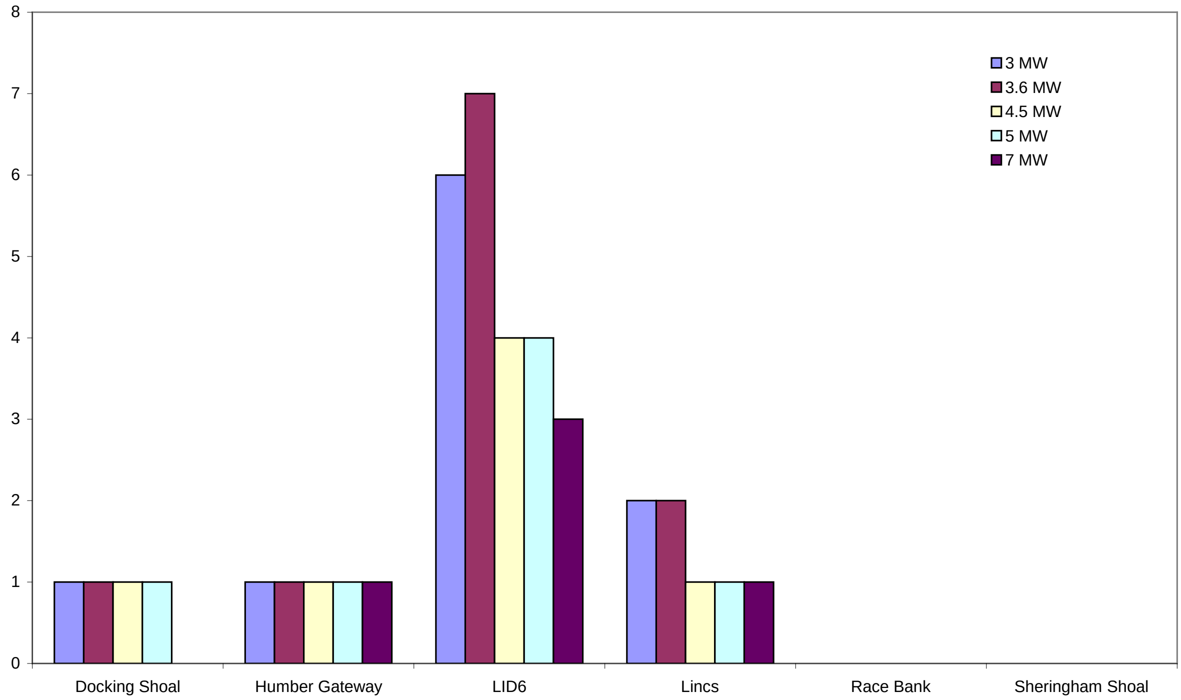

Figure 4.3.6 Red-throated Diver mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

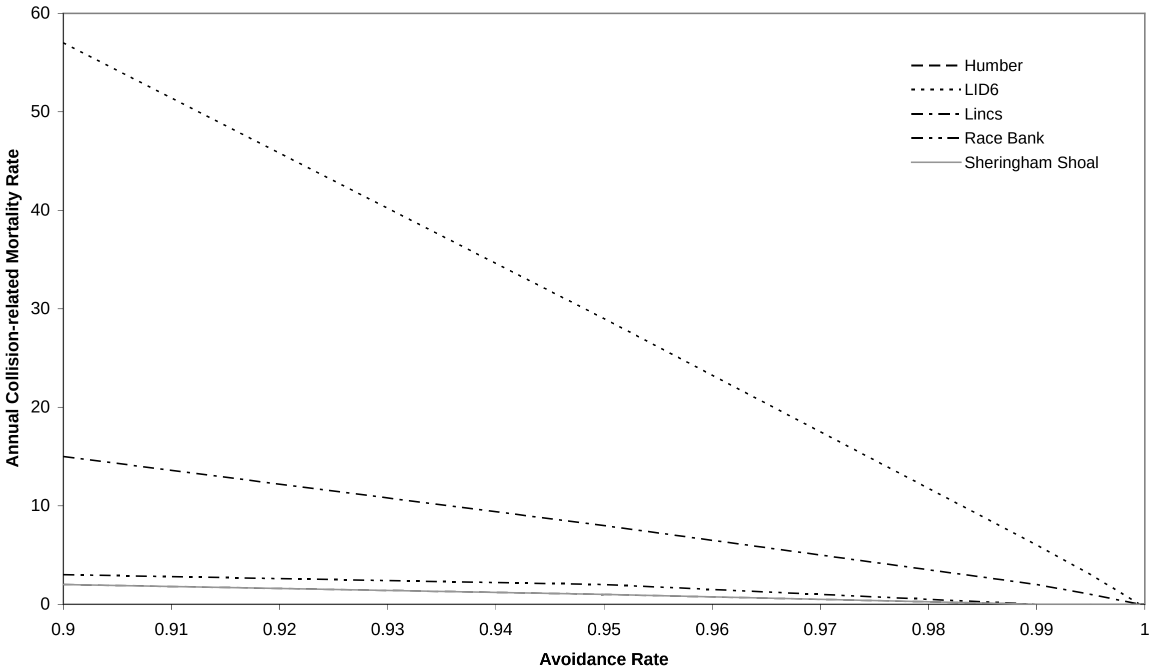

Figure 4.3.7 Modelled annual collision-related mortality rates for Red-throated Diver within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

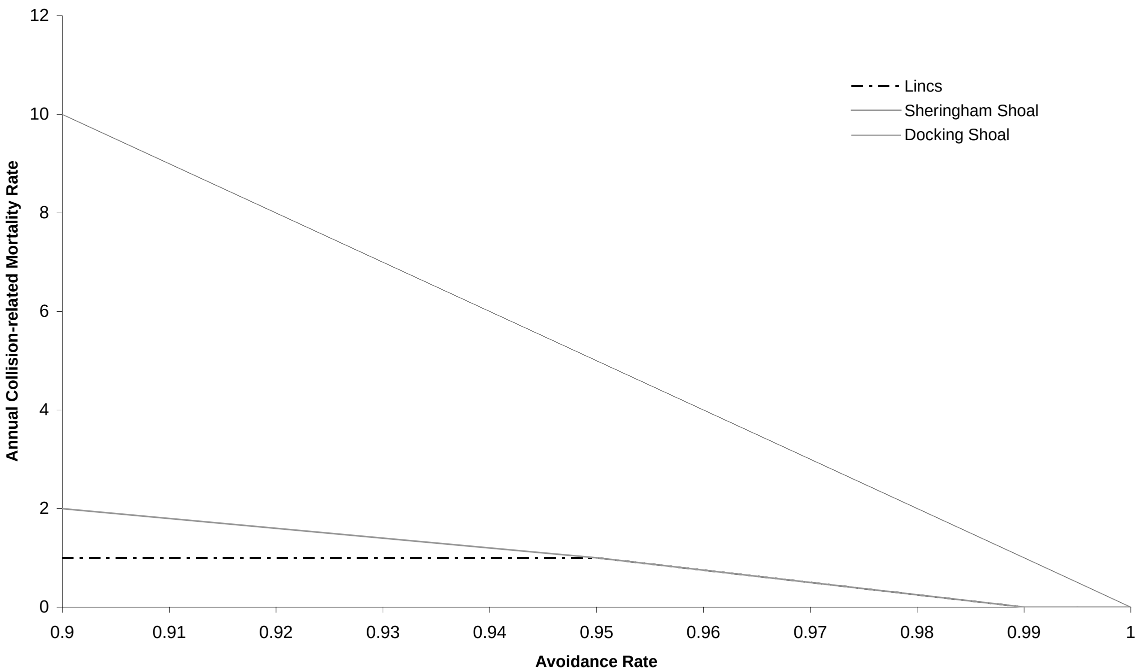

Figure 4.3.8 Modelled annual collision-related mortality rates for Arctic Skua within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

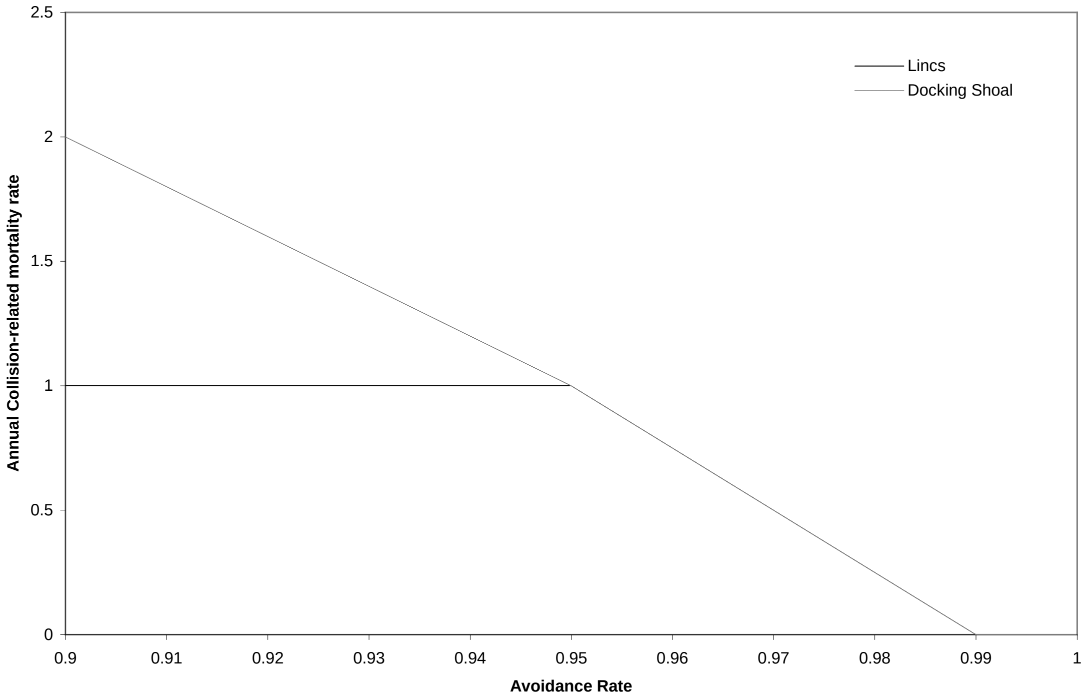

Figure 4.3.9 Modelled annual collision-related mortality rates for Great Skua within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

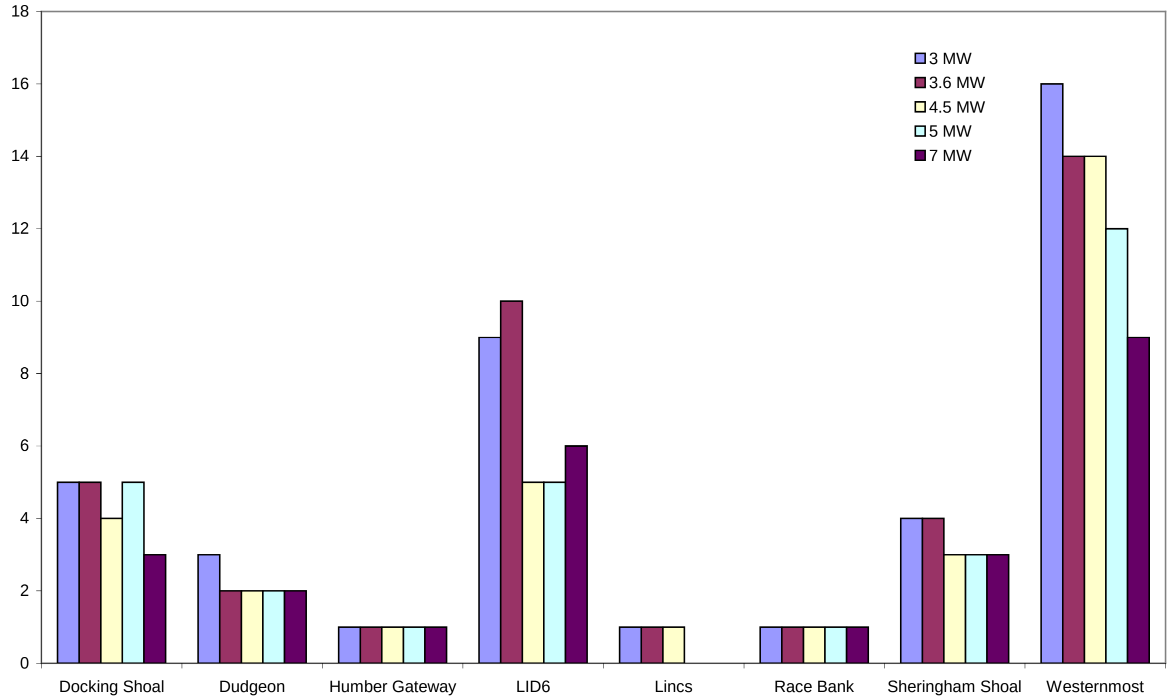

Figure 4.3.10 Common Tern mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

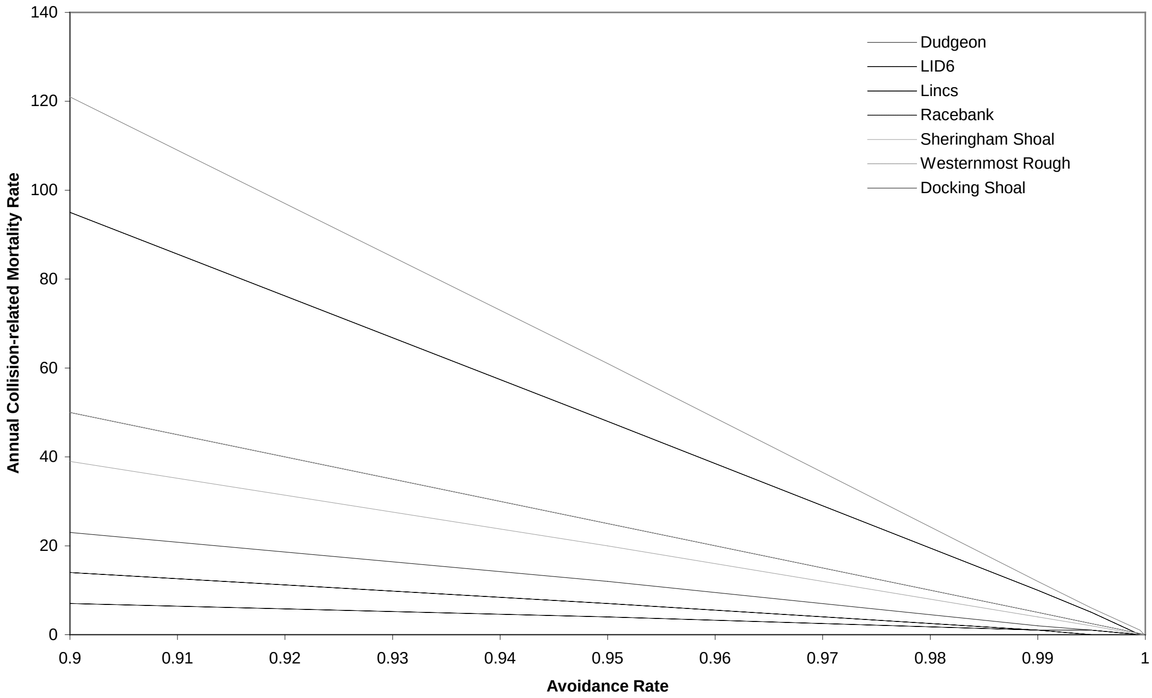

Figure 4.3.11 Modelled annual collision-related mortality rates for Common Tern within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

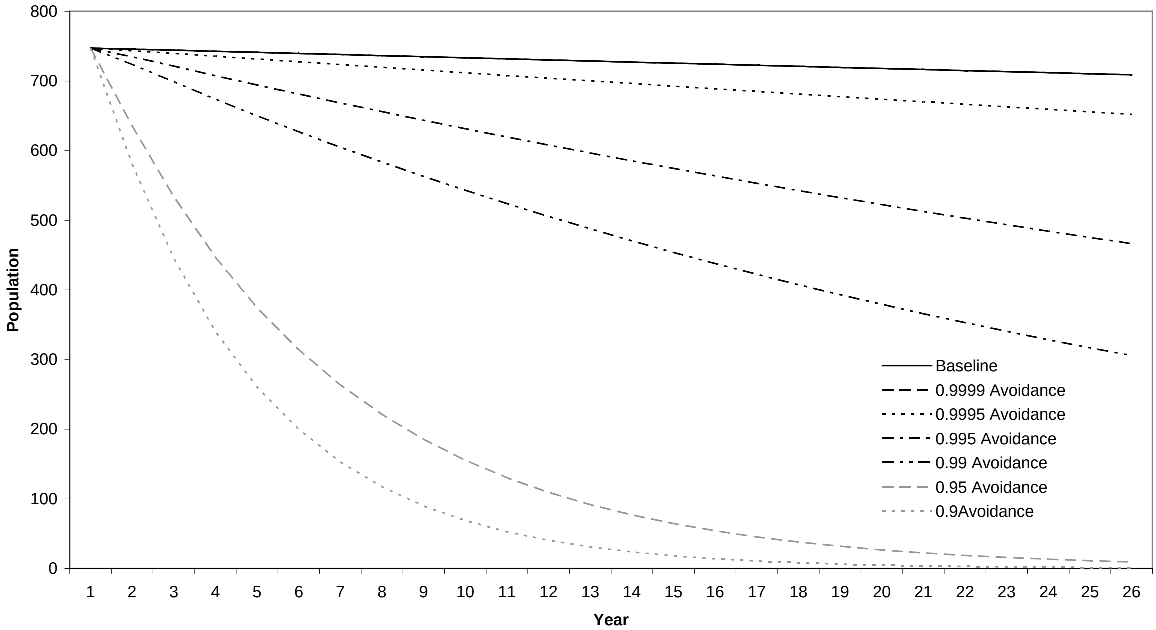

Figure 4.3.12 Impacts of collision-related mortality on the Common Tern breeding colonies on the North Norfolk Coast and the Greater Wash SPAs assuming a range of avoidance rates assessed using Population Viability Analysis.

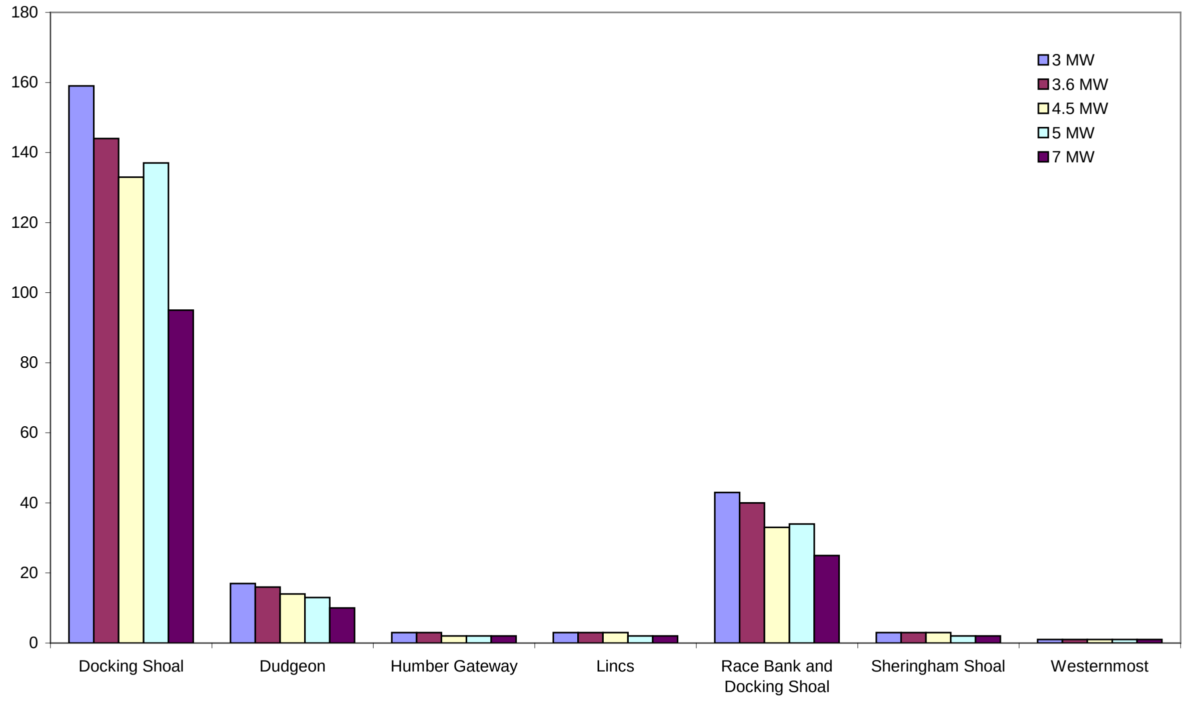

Figure 4.3.13 Sandwich Tern mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

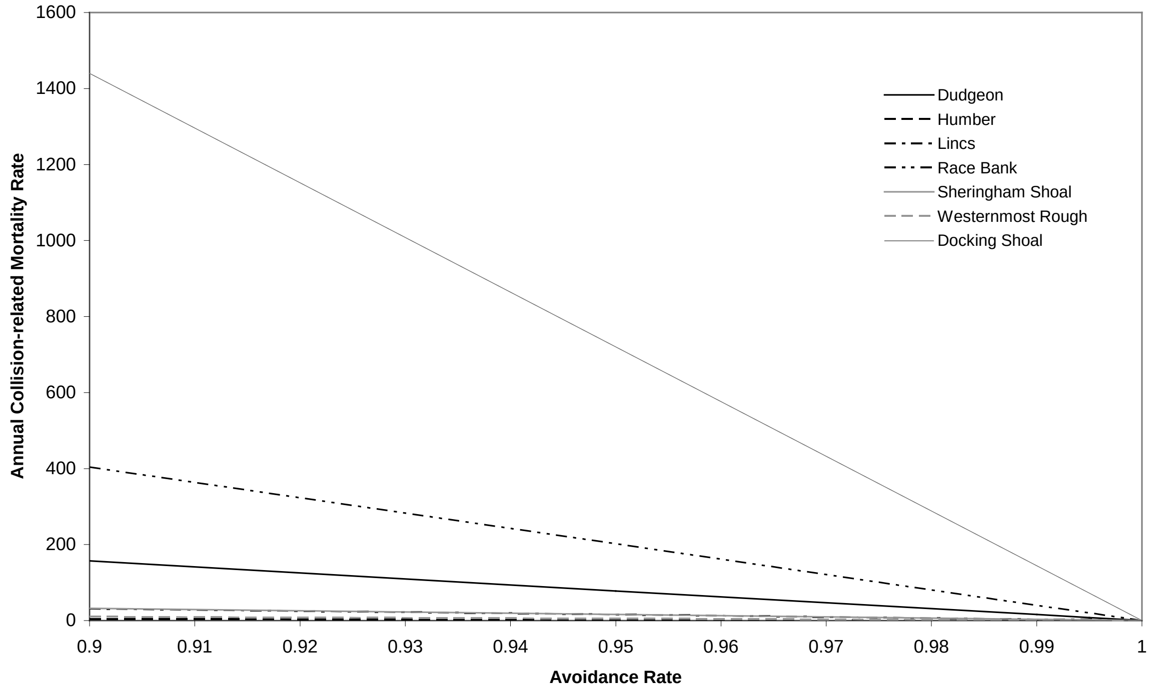

Figure 4.3.14 Modelled annual collision-related mortality rates for Sandwich Tern within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

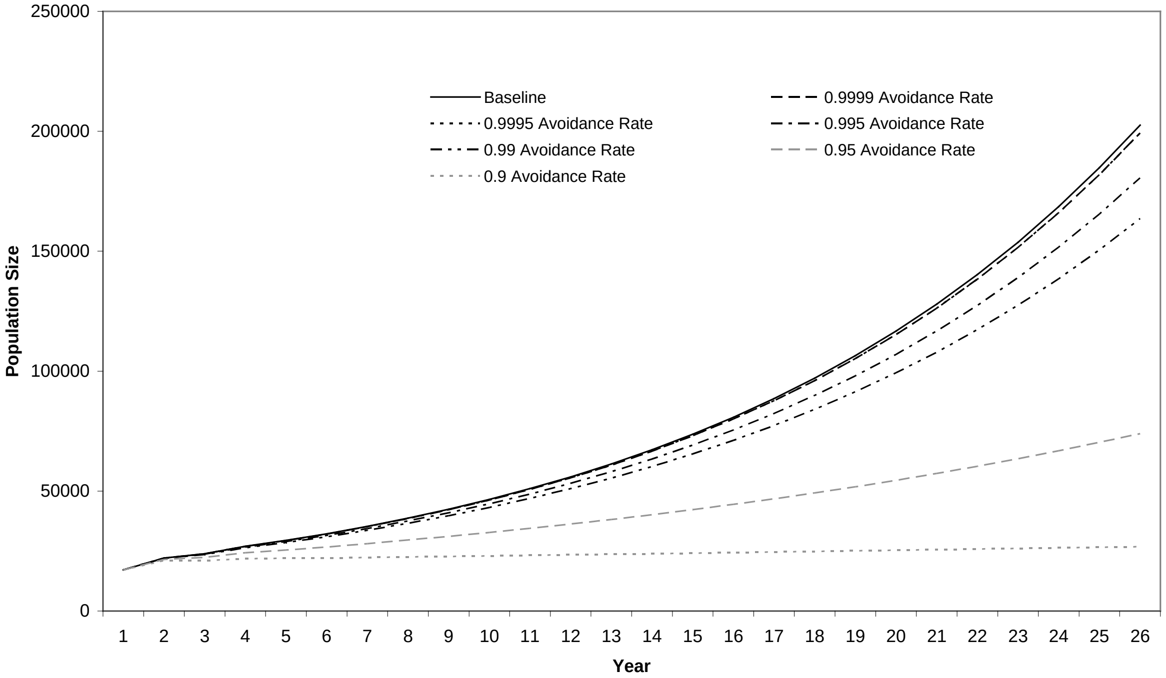

Figure 4.3.15 Impacts of collision-related mortality on the Sandwich Tern breeding colonies in the North Norfolk Coast SPA assuming a range of avoidance rates assessed using Population Viability Analysis.

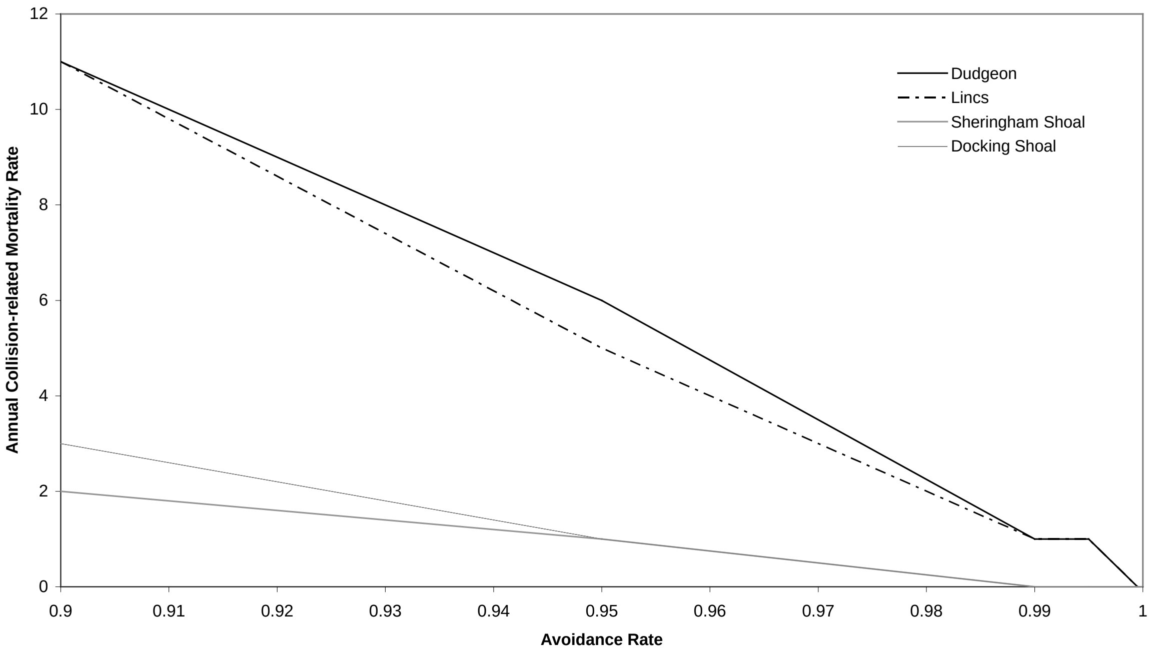

Figure 4.3.16 Modelled annual collision-related mortality rates for Black-headed Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

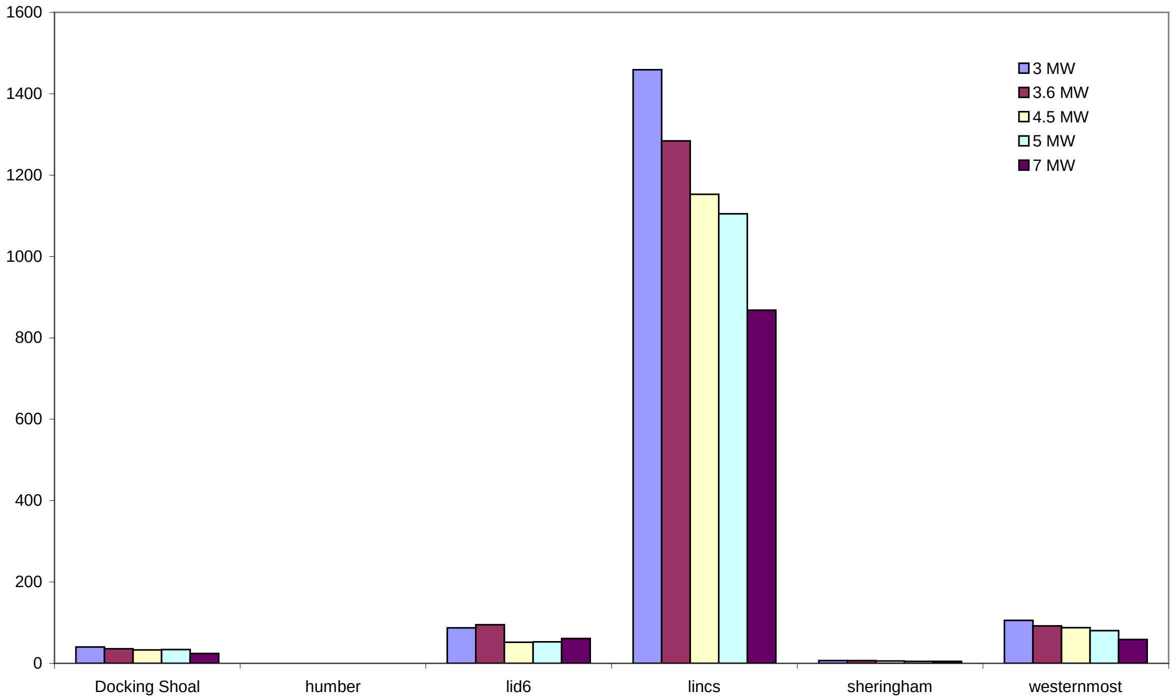

Figure 4.3.17 Common Gull mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

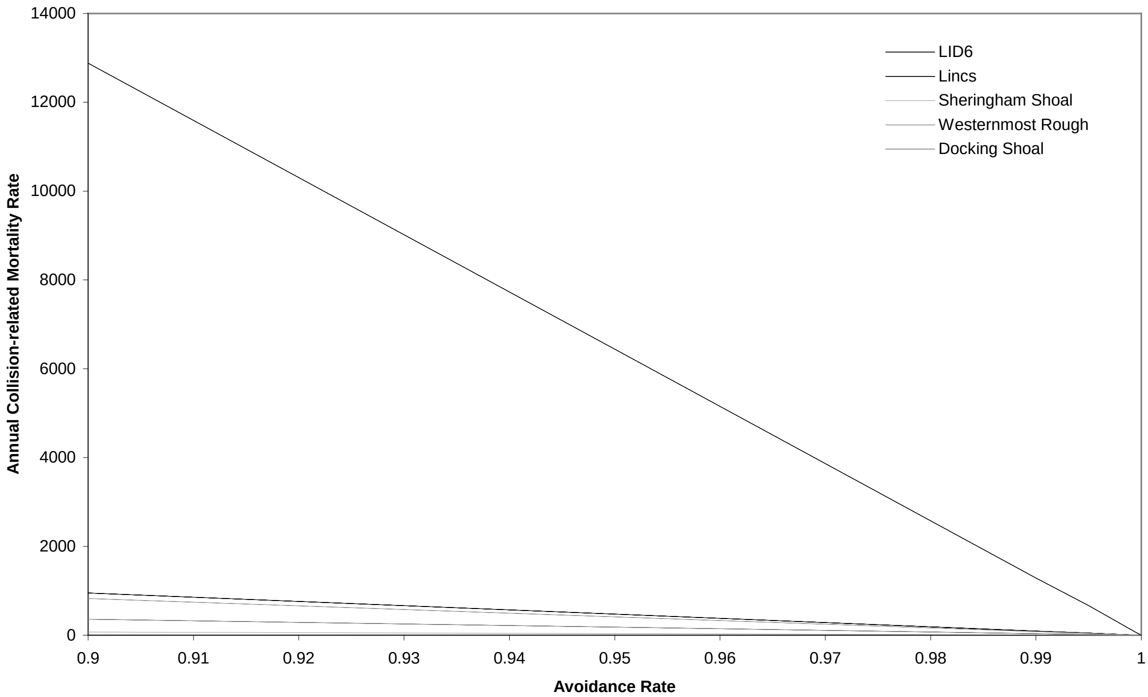

Figure 4.3.18 Modelled annual collision-related mortality rates for Common Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

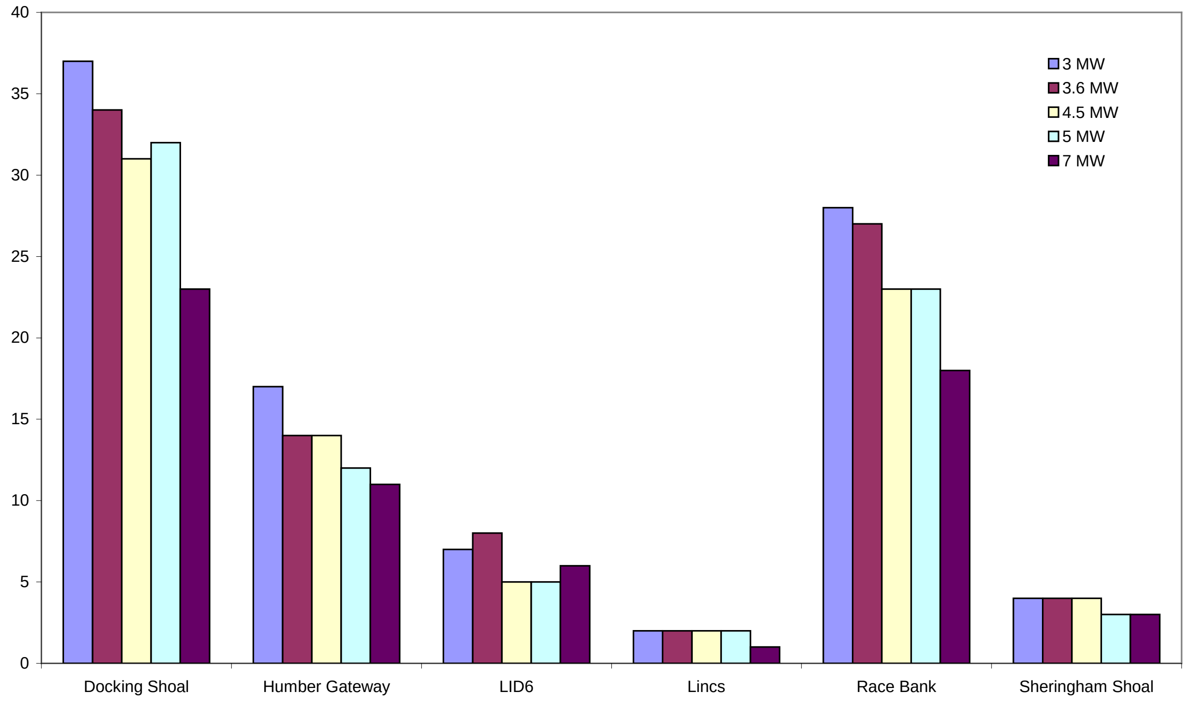

Figure 4.3.19 Little Gull mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

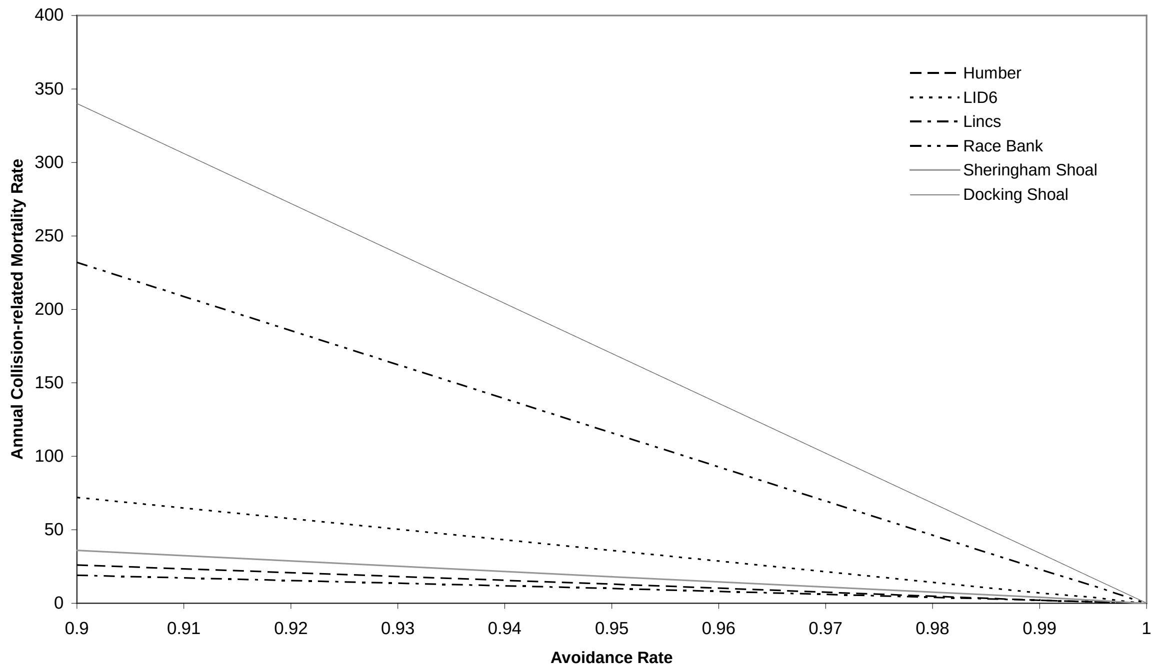

Figure 4.3.20 Modelled annual collision-related mortality rates for Little Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

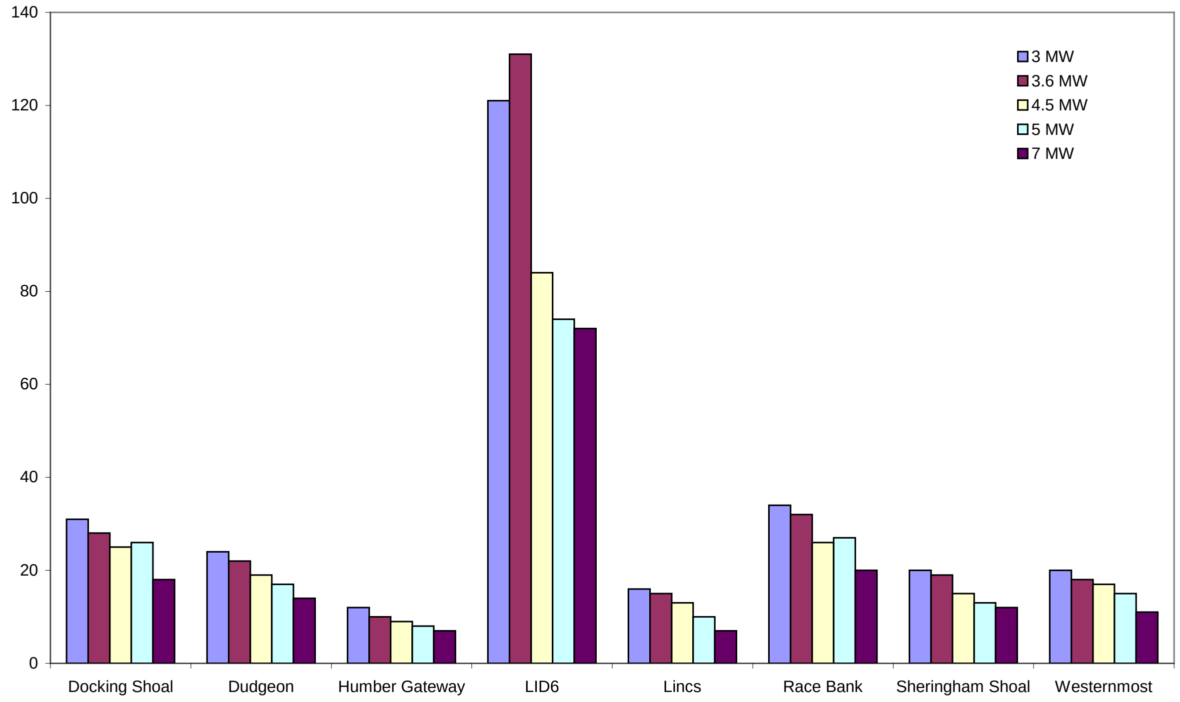

Figure 4.3.21 Lesser Black-backed Gull mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

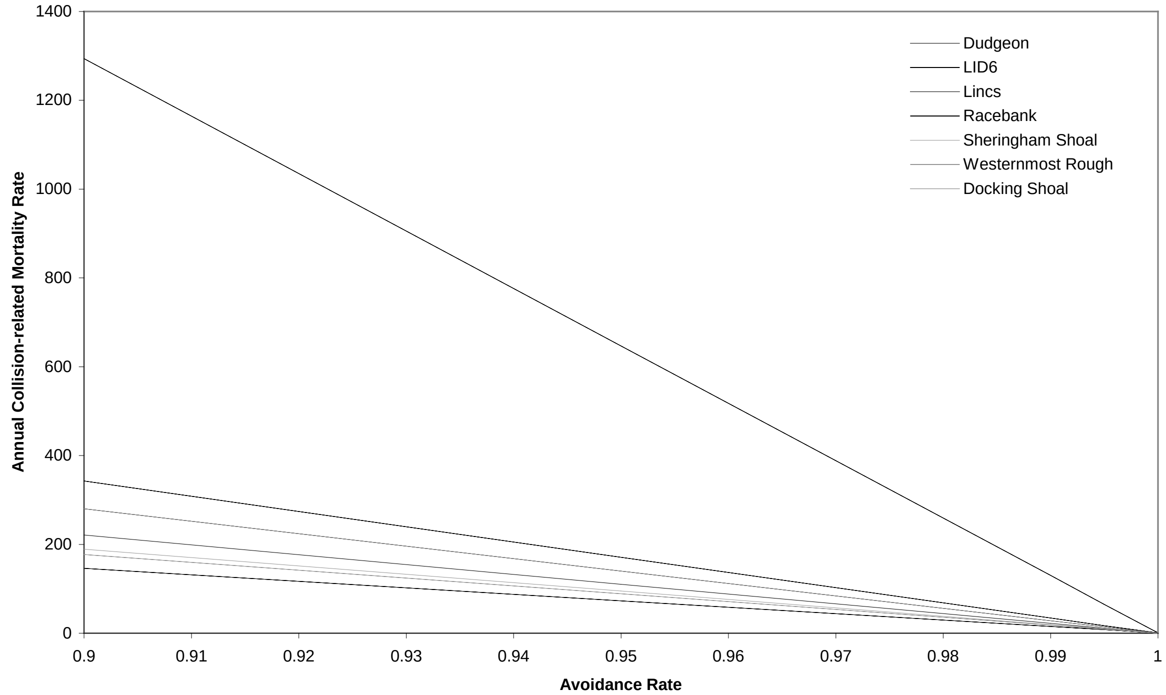

Figure 4.3.22 Modelled annual collision-related mortality rates for Lesser Black-backed Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

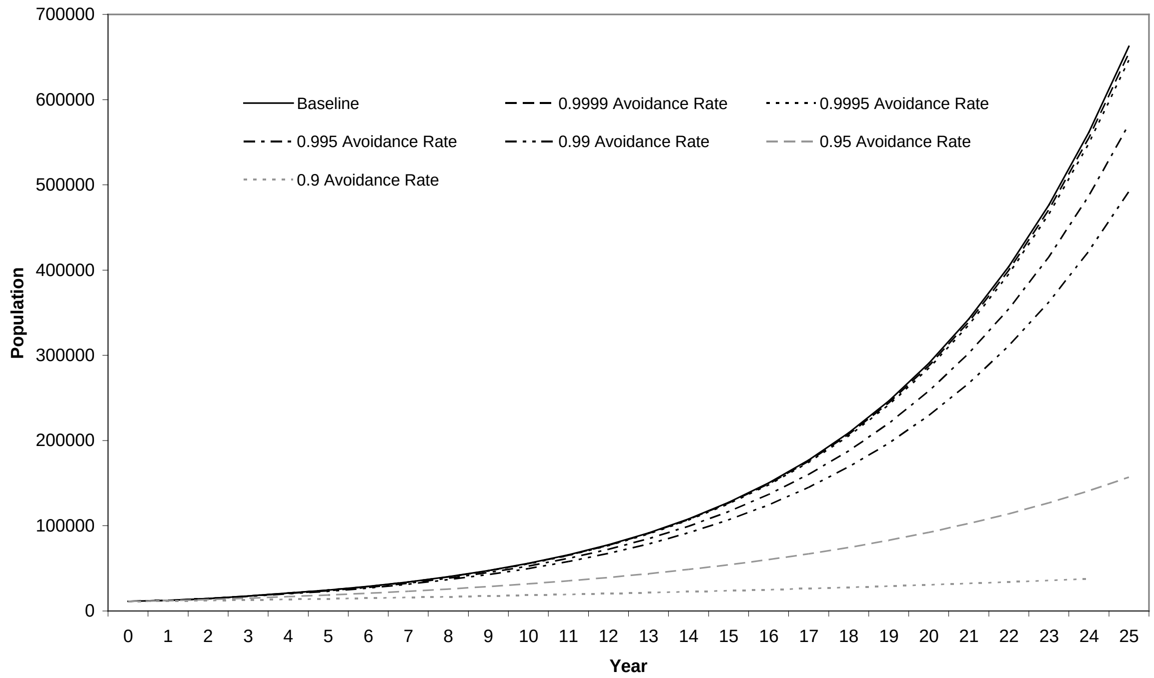

Figure 4.3.23 Impacts of collision-related mortality on the Lesser Black-backed Gull breeding colonies in the vicinity of the Greater Wash assuming a range of avoidance rates assessed using Population Viability Analysis.

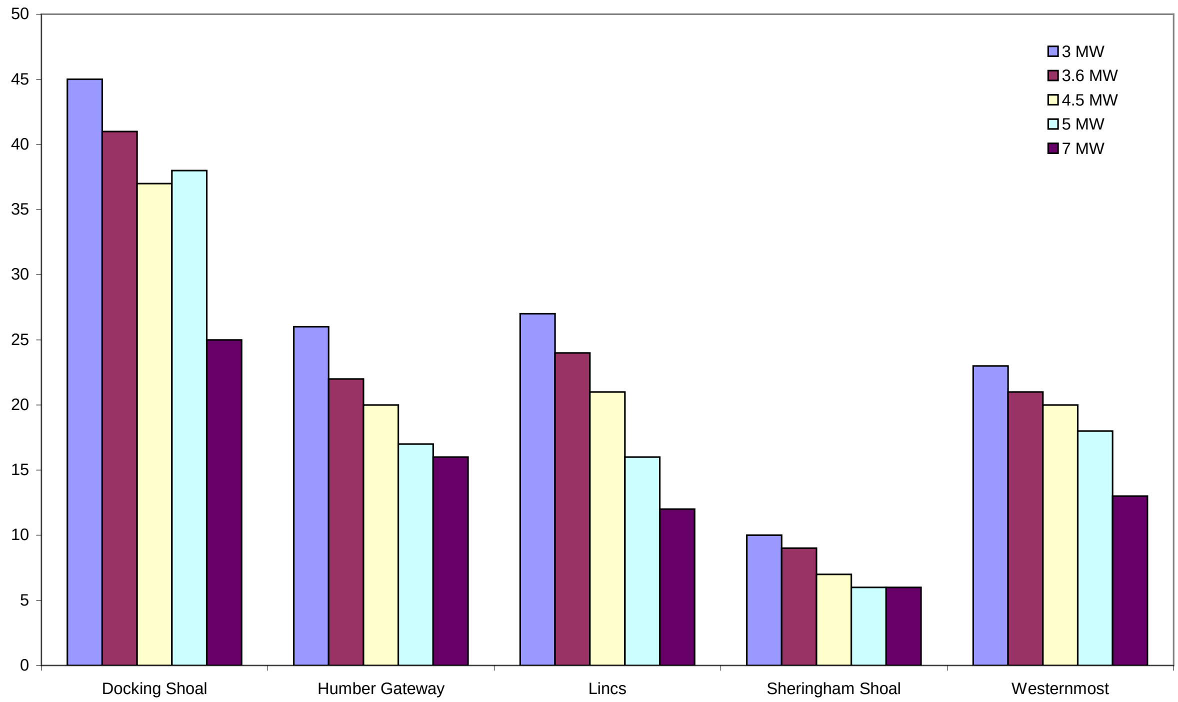

Figure 4.3.24 Herring Gull mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

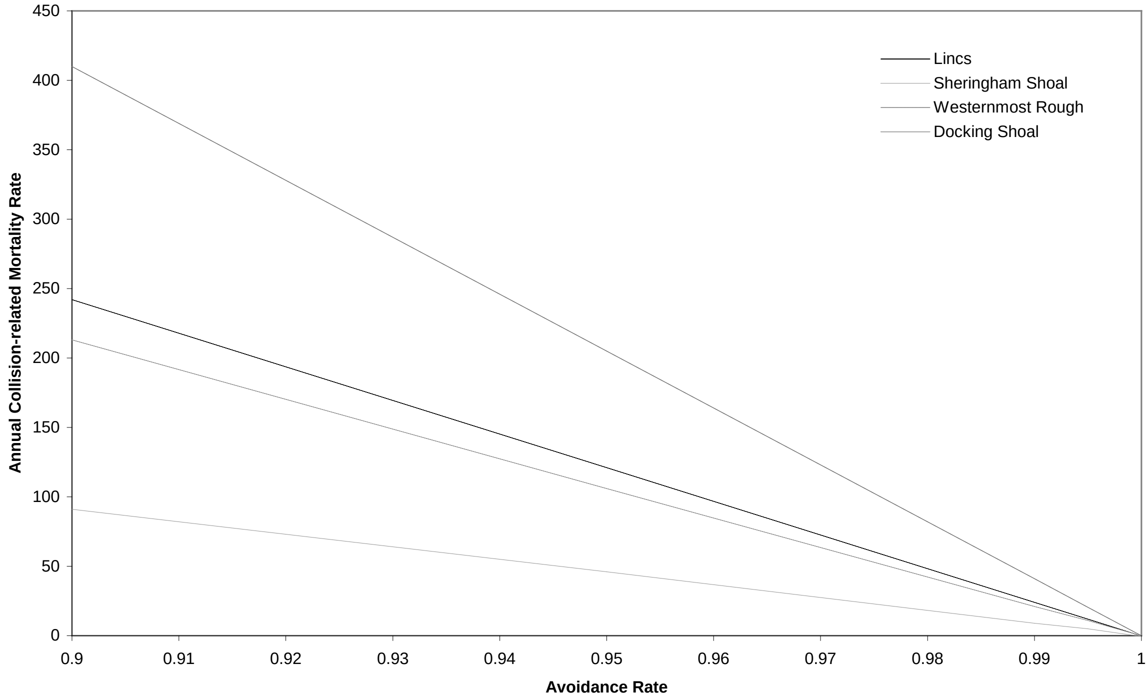

Figure 4.3.25 Modelled annual collision-related mortality rates for Herring Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

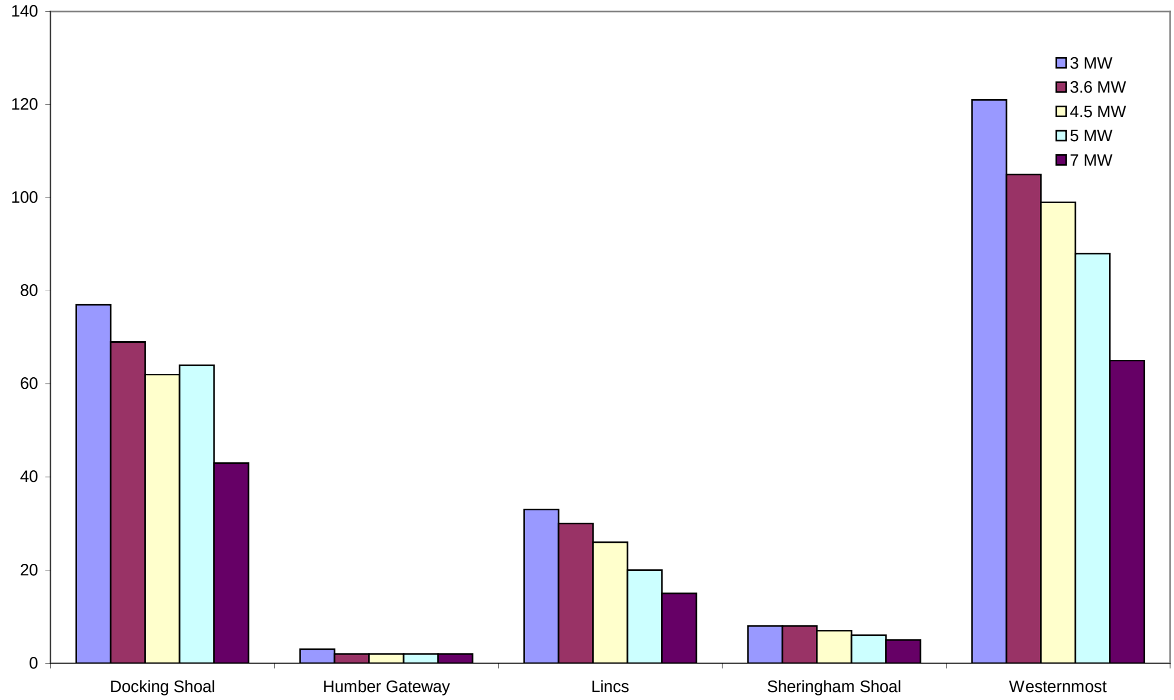

Figure 4.3.26 Great Black-backed Gull mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

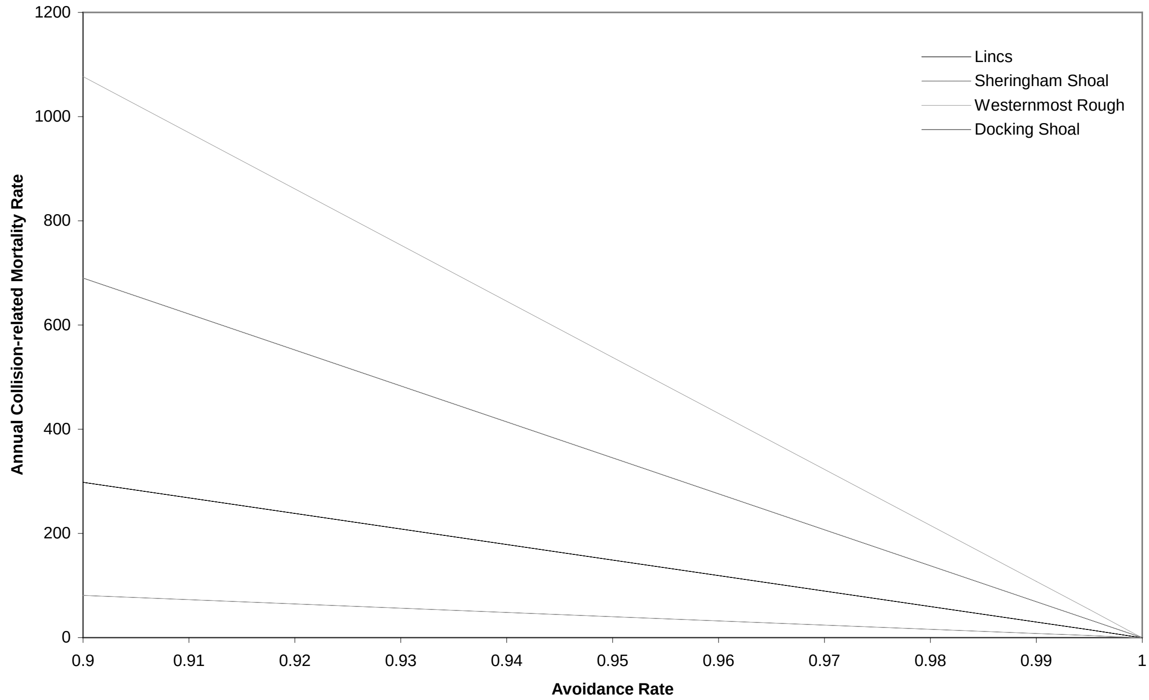

Figure 4.3.27 Modelled annual collision-related mortality rates for Great Black-backed Gull within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

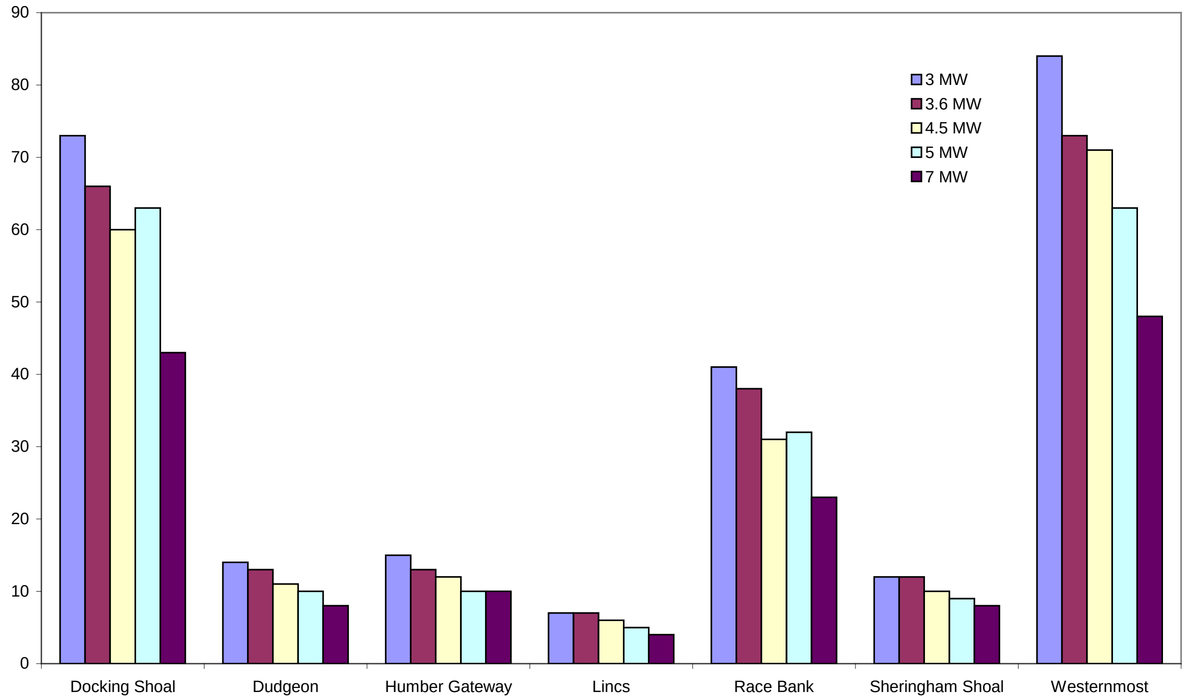

Figure 4.3.28 Black-legged Kittiwake mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

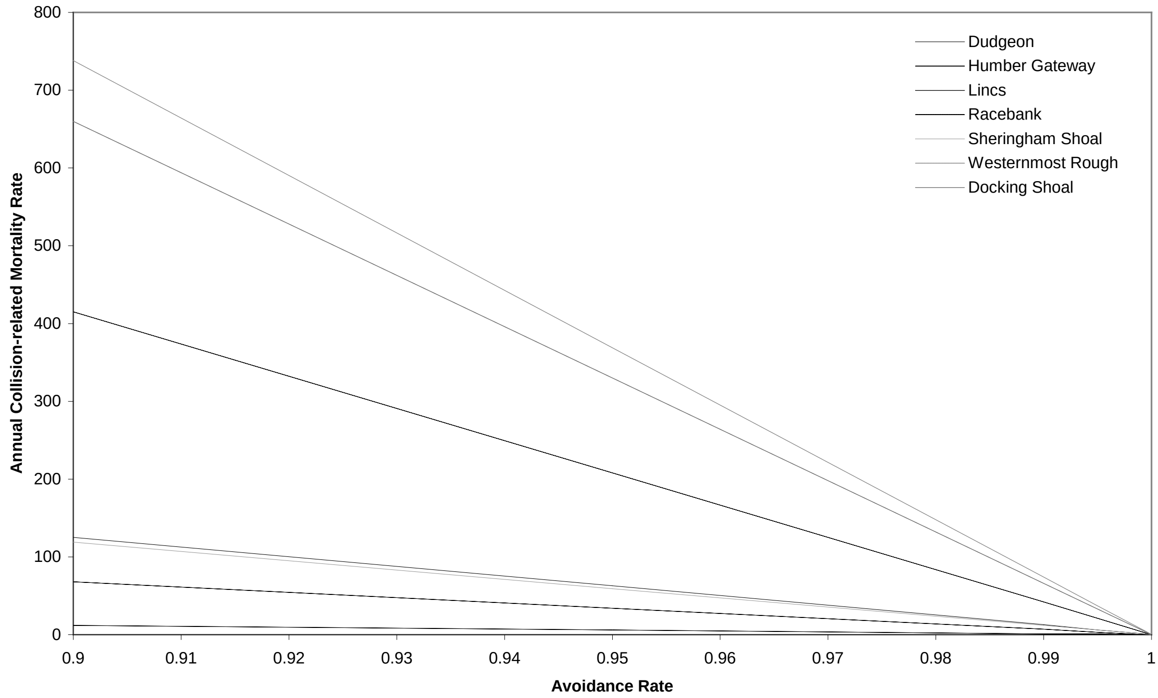

Figure 4.3.29 Modelled annual collision-related mortality rates for Black-legged Kittiwake within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

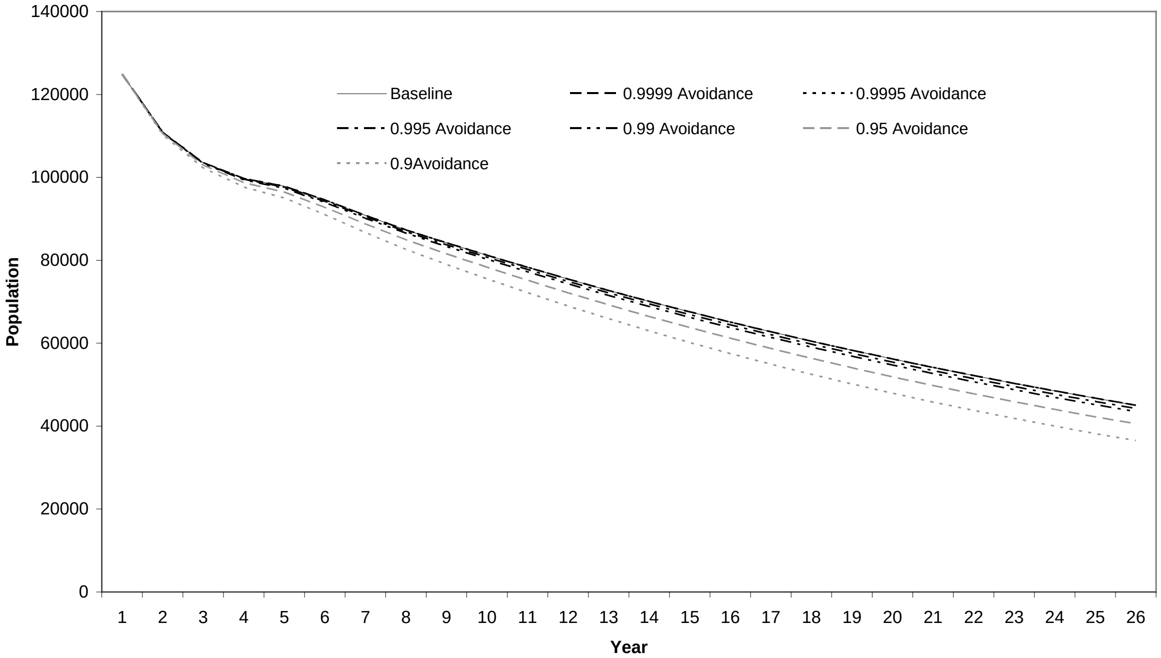

Figure 4.3.30 Impacts of collision-related mortality on the Black-legged Kittiwake breeding colony at Flamborough Head and Bempton Cliffs SPA assuming a range of avoidance rates assessed using Population Viability Analysis.

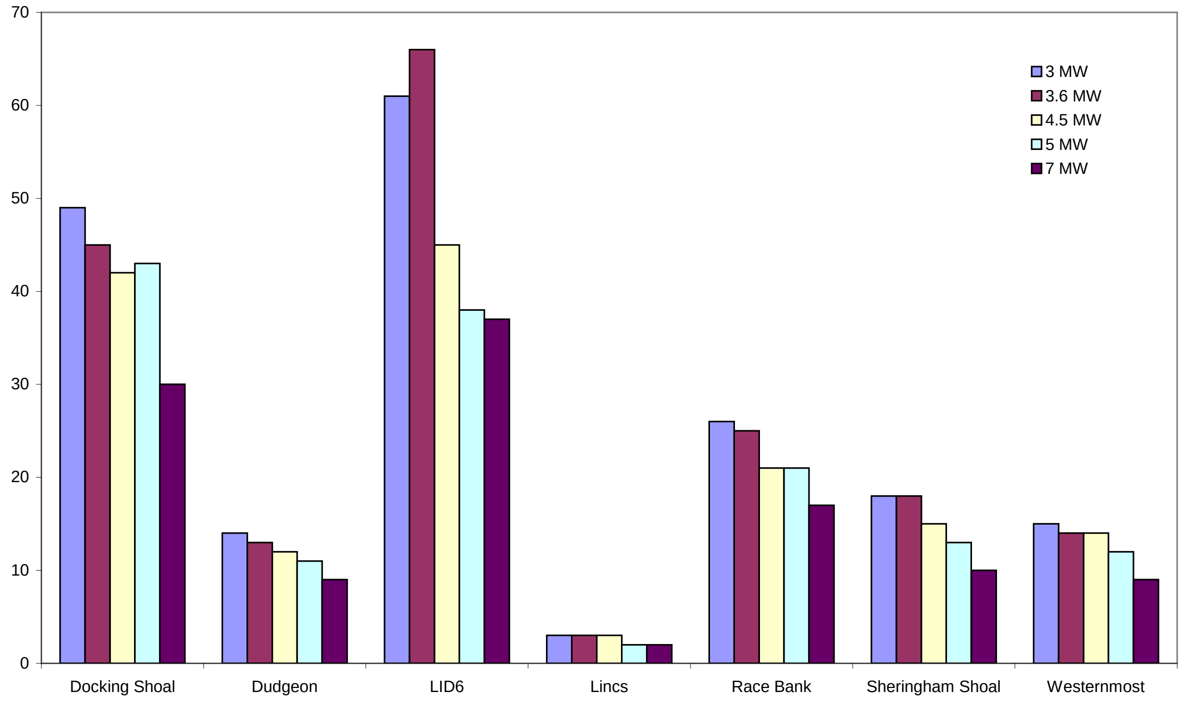

Figure 4.3.31 Common Guillemot mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

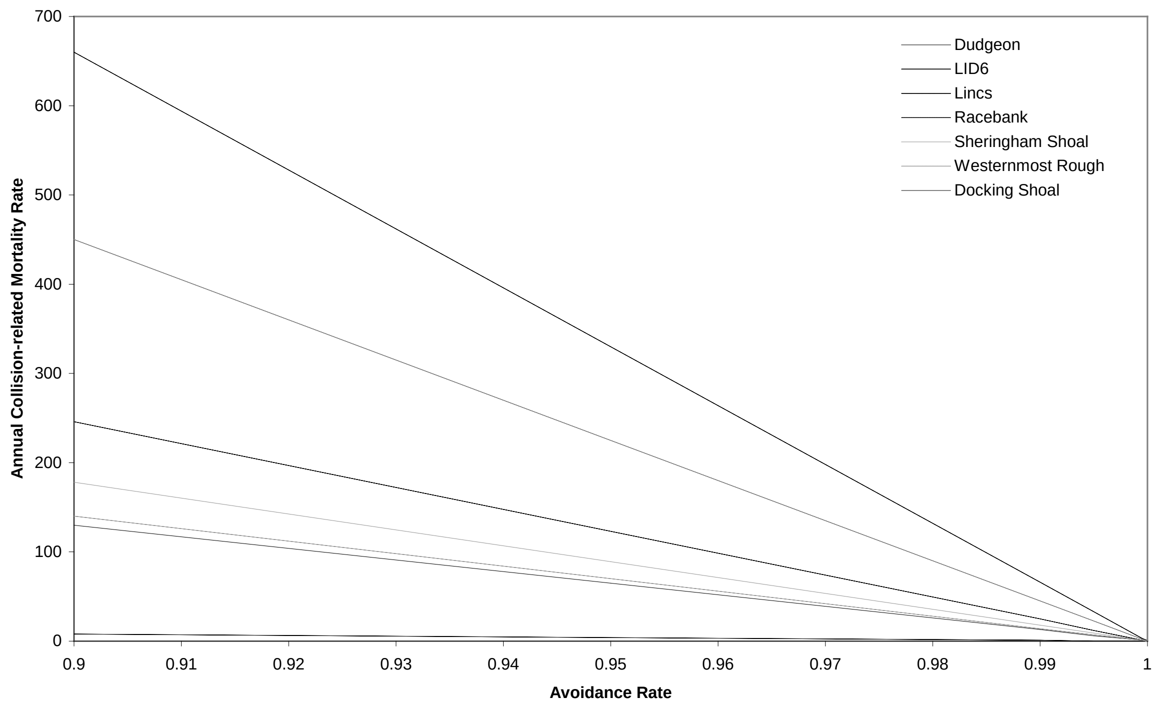

Figure 4.3.32 Modelled annual collision-related mortality rates for Common Guillemot within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

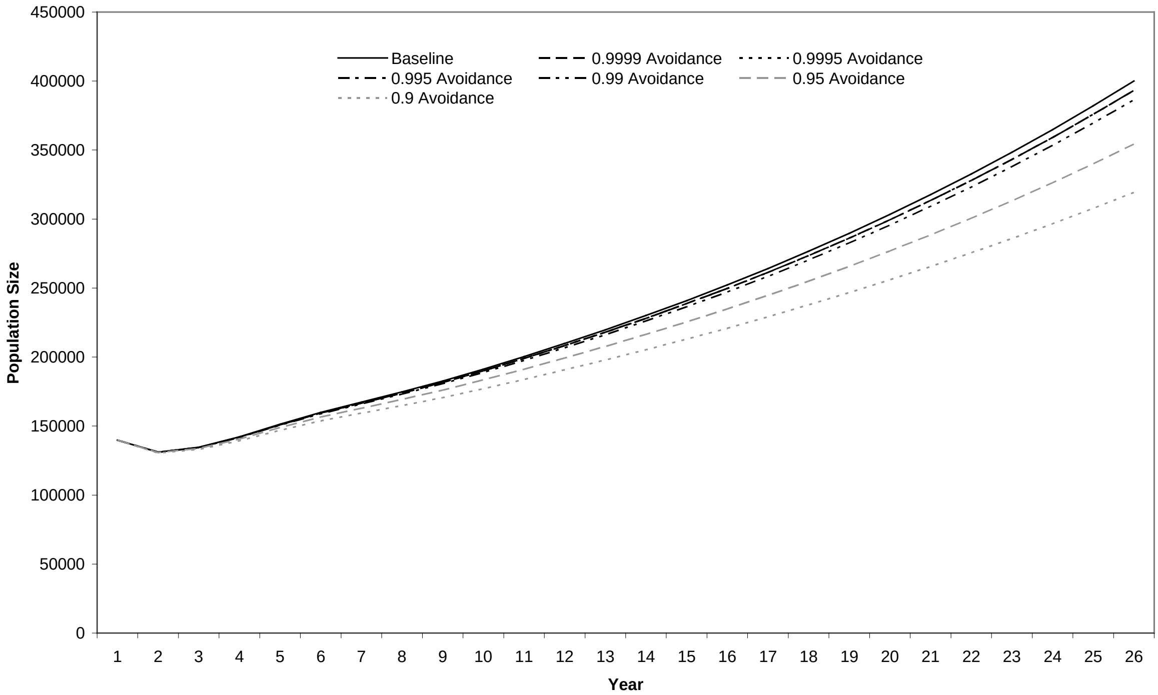

Figure 4.3.33 Impacts of collision-related mortality on the Common Guillemot breeding colony at Flamborough Head and Bempton Cliffs SPA assuming a range of avoidance rates assessed using Population Viability Analysis.

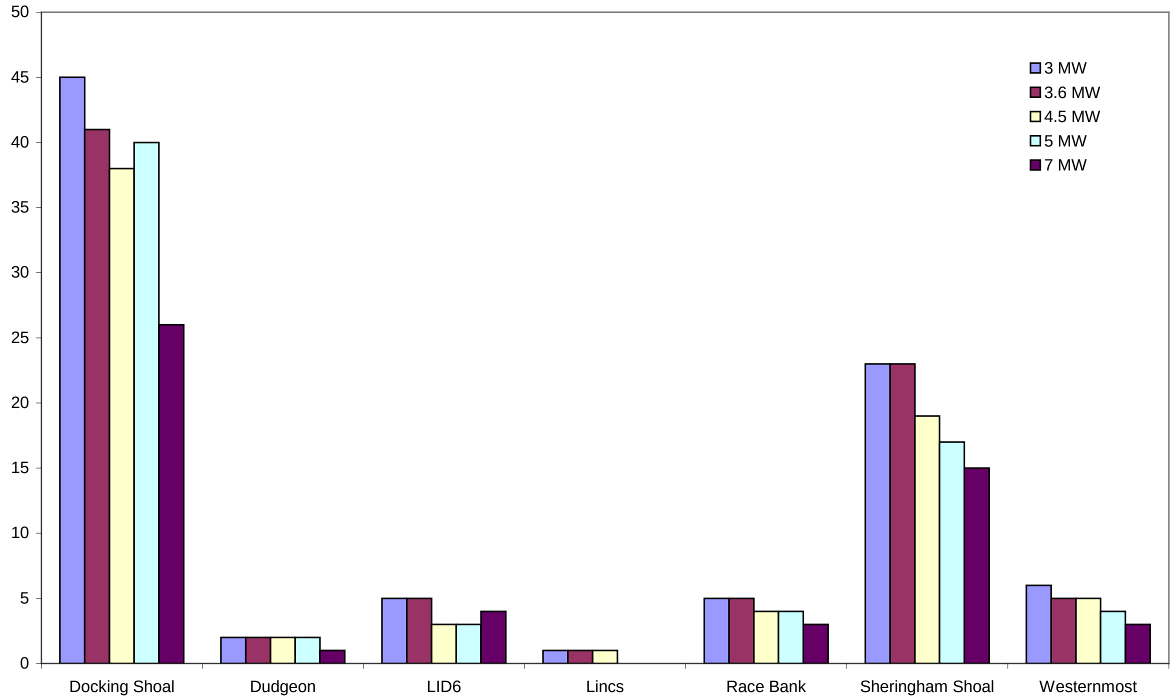

Figure 4.3.34 Razorbill mortality in response to different turbine sizes (i.e. generating capacities) within wind farms in the vicinity of the Greater Wash.

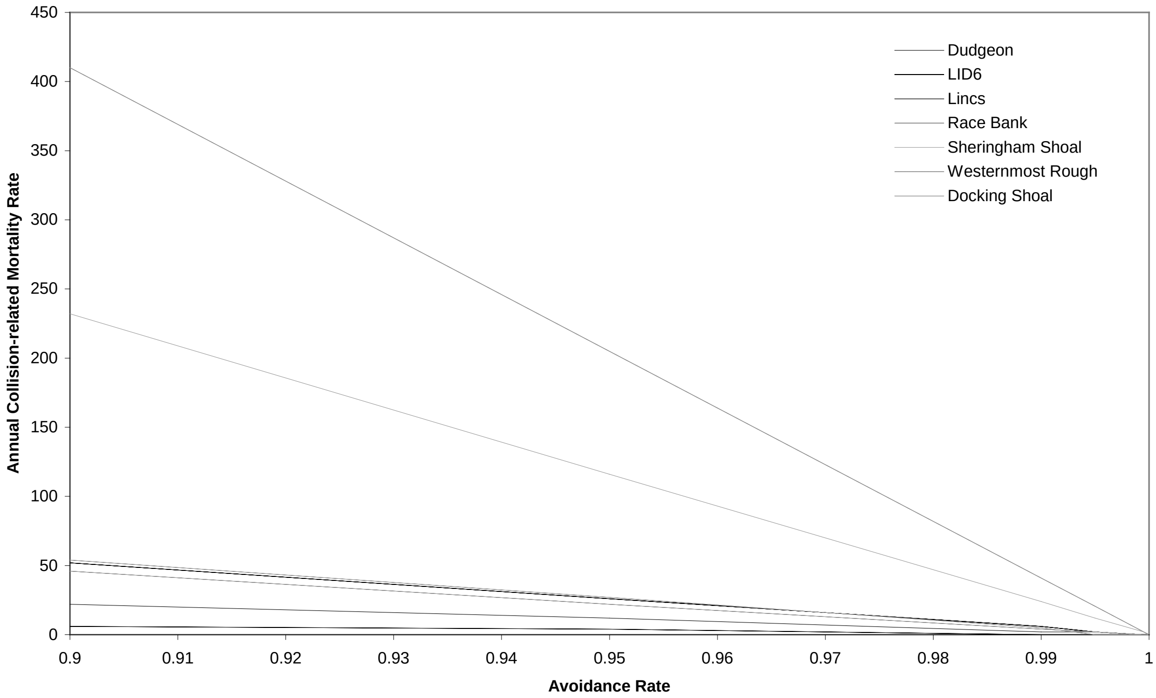

Figure 4.3.35 Modelled annual collision-related mortality rates for Razorbill within wind farms in the vicinity of the Greater Wash in response to different avoidance rates.

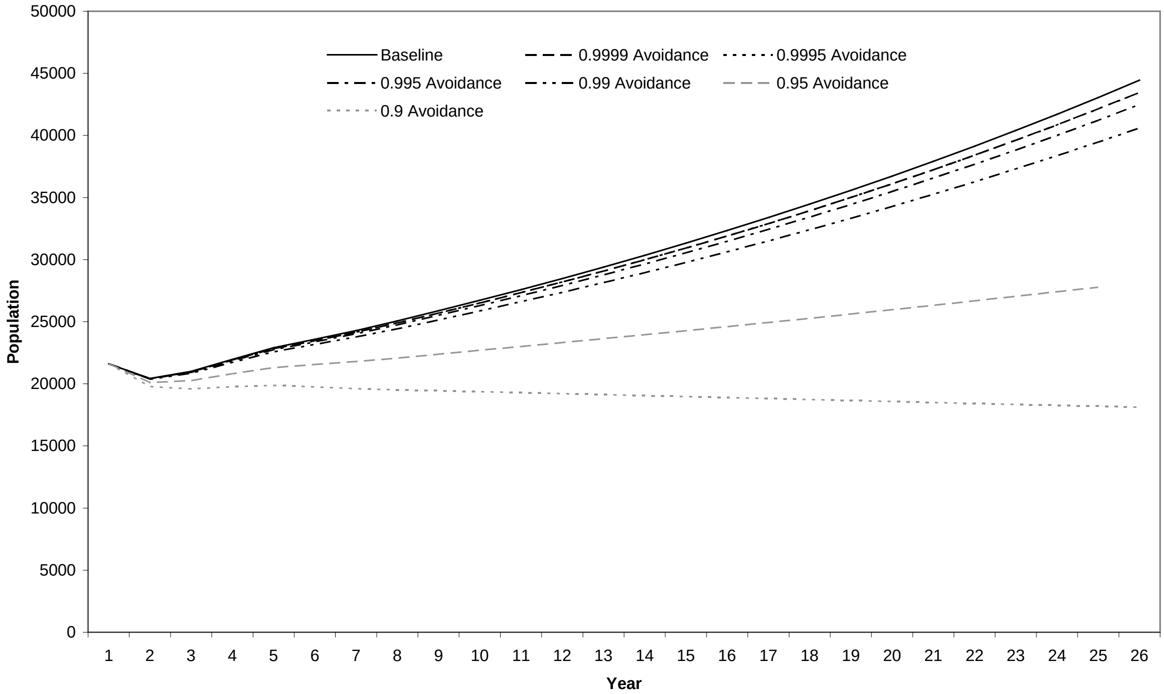

Figure 4.3.36 Impacts of collision-related mortality on the Razorbill breeding colony at Flamborough Head and Bempton Cliffs SPA assuming a range of avoidance rates assessed using Population Viability Analysis.

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Appendix 1. Literature Review

The list below provides a bibliography of all references sourced (the full literature review is provided separately in Excel format)

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Appendix 2. Interview Questions

Personal details:

Name: ……………………………………………………………………………………………………
Organisation: …………………………………………………………………………………….
Role: …………………………………………………………………………………………………..

Q1. What are your general views about mitigation methods to reduce avian collision? Do we need mitigation methods to reduce avian collision with offshore wind turbines?
……
……
………

Q2. What techniques and technologies are you aware of to reduce bird collisions (and what is their status e.g. theoretical, early stage R&D, pilot testing, full-scale trials, operational). List:

Option:	Status:	Do you employ / recommend?

For each technique please provide as much detail as possible:

<u>Technique 1 (repeated for 2-6)</u>:	
Description:	
Main advantages:	
Main disadvantages:	
Where is it used:	
Reason for use:	
Operational Timescales (if deployed/proposed):	Start date: End date:
Cost:	
Has or will the technology be monitored?	
Is there any data currently available?	
Any reference material (website links, contacts etc.)	

Q3. Do you have, or are you aware of, any existing monitoring data on avian collisions with wind turbines? Are you aware of any ongoing or planned research / monitoring?
………
………
………
……

Appendix 3. Met Office Report – “Mitigating avian collision with wind turbines using information from weather radars”

“Mitigating avian collision with wind turbines using information from weather radars”

Katie Norman, Met Office, FitzRoy Road, Exeter, EX1 3PB, UK

1. Introduction to radar and its use to detect birds.

Radio detection and ranging (RADAR) is used for many applications including the surveillance of ships and aircraft and monitoring of the weather. Radars transmit electromagnetic waves, which propagate through the atmosphere where they interact with the atmosphere itself, man-made and biological targets, which back-scatter the electromagnetic waves. These backscattered waves can be detected and measured at a receiver.

Radar has been used in ornithological studies for many years, after it appeared early in radar’s development, that birds were being detected, often appearing as ring like echoes (“ring angels”). These ring angels grew larger as birds dispersed from their roost to their feeding areas (Eastwood 1967).

Due to the many applications of radar, radar systems have evolved many specifications with varying suitability for detecting birds. But, this also applies in the wider sense, as all methods for observing birds have their strengths and weaknesses. The primary reason radar has been used so frequently for ornithological studies is its functionality at times of low visibility for human or other visual observations, for example in fog or at night. This is especially relevant for studying nocturnal species or nocturnal migrations. Secondly, the area of coverage of radar is much greater than the visual range of a human observer; for example, weather radars usually operate out to a range of approximately 250 km, though at this range the beam is approximately 4 km high and samples a large volume.

2. The UK weather radar network

The Met Office operates 16 C-band (5.3 cm wavelength, 1°

Figure A1: Map of the UK weather radar network, blue circles indicate, 50, 100 and 250 km range from each radar.

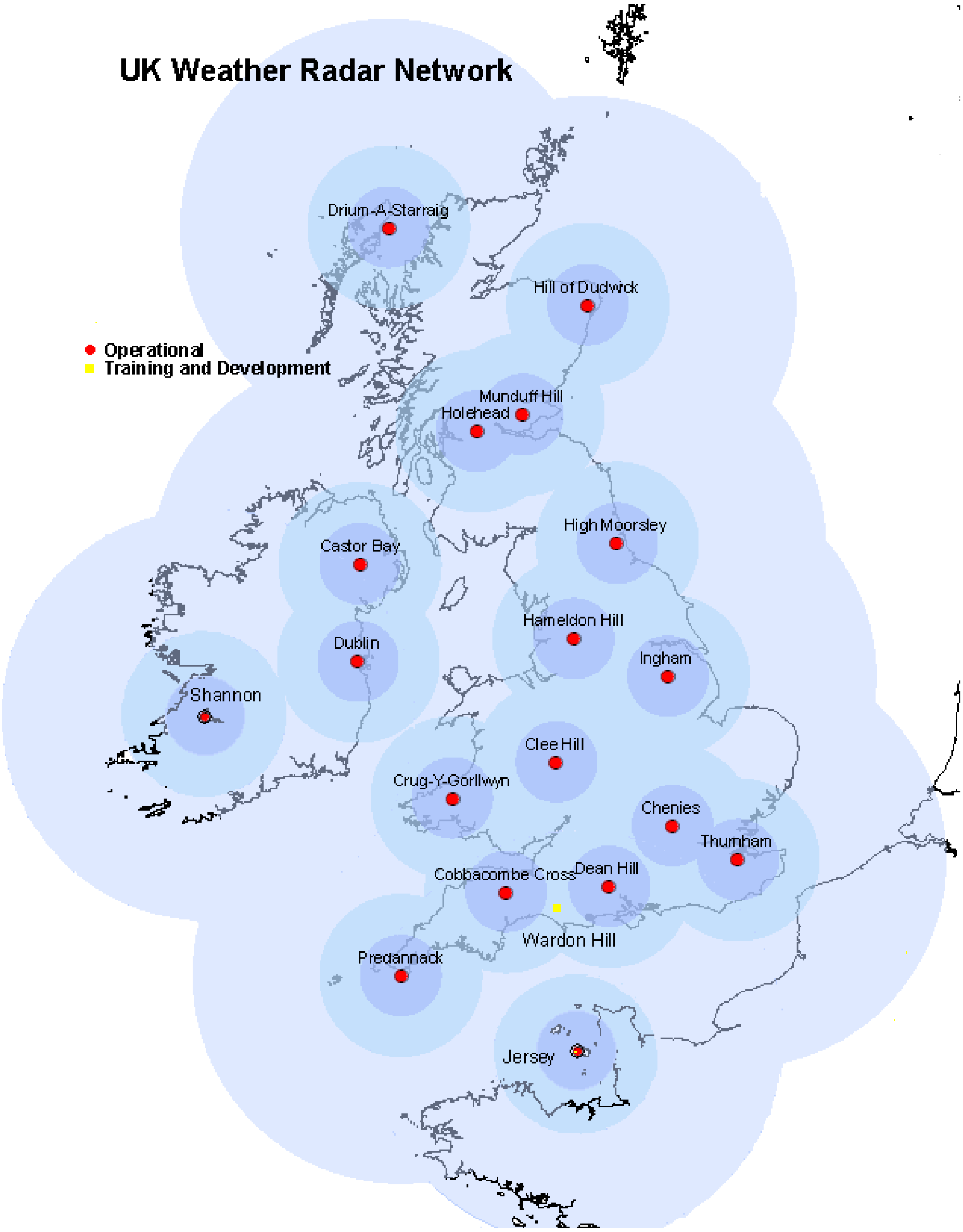
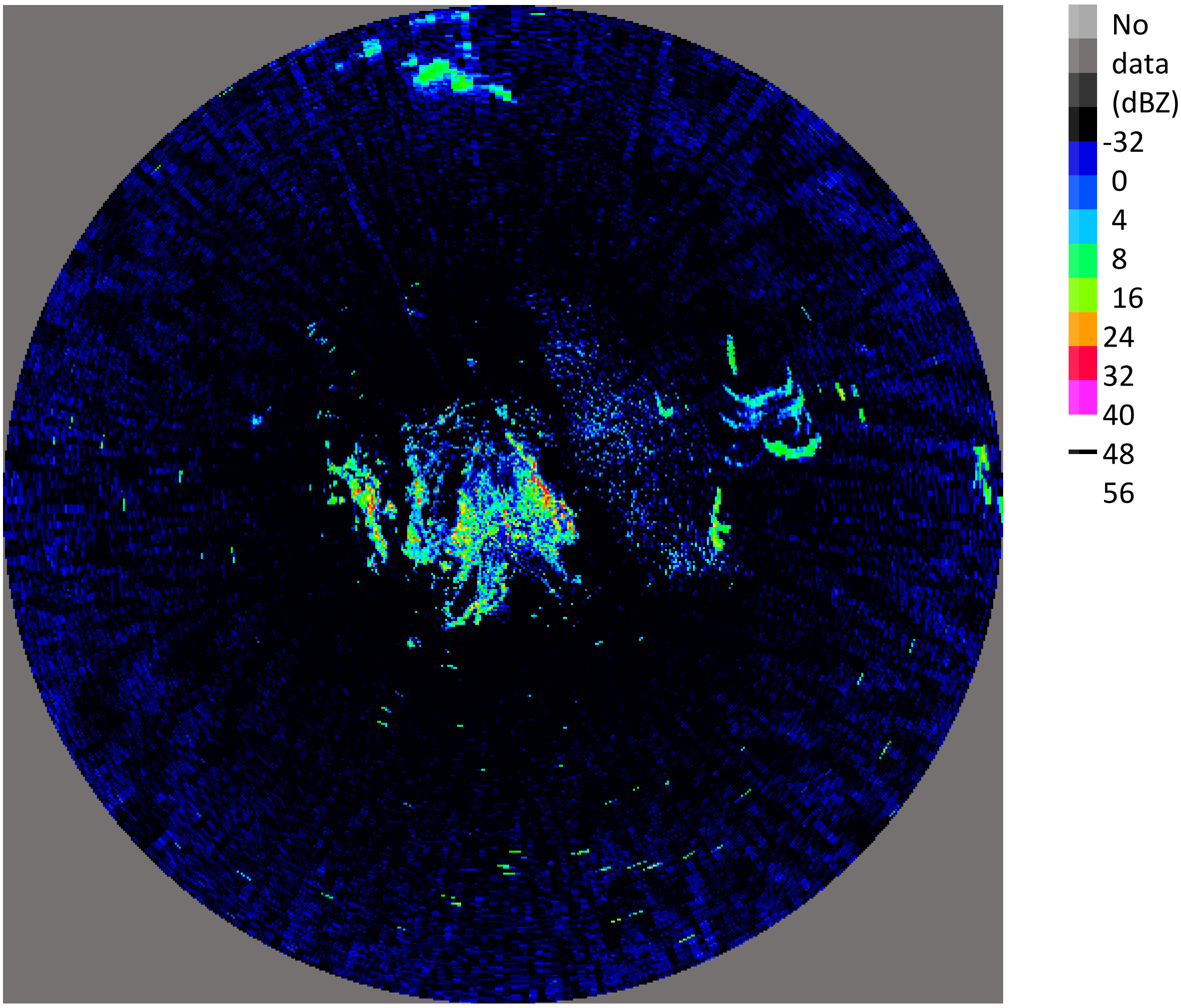


Figure A2: Un-corrected reflectivity data from Ingham radar on 17th October 2008 at 08:50 (dimensions: 510 by 510 km). Speckled low reflectivity areas (4-8 dBZ) east of the radar are likely to be birds. Higher reflectivities close to the centre of the image are echoes from the ground close to the radar.



3. Using radar to study birds

Radar has been considered in many published ornithological studies. Here, we consider those published after 2000, which number 65 on ISI web of knowledge, including 8 studies on the affect of man-made obstacles on bird behaviour. Excluding purely ornithological studies there are a further 63 publications on the detection of birds with radar.

In many cases, users of radar data want to exclude data from biological targets, so much effort has been focussed on the identification and removal of biological information from radar data. For example, birds often have a negative impact on the quality of wind profile measurements made by radar. 11 studies have been published on the contamination of wind profiles by birds. 17 studies look at the detection, identification or quantification of birds in radar data. There are 5 publications on the design of dedicated bird radar and 4 on the associated signal processing. 3 publications discuss the use of radar for the monitoring of birds in the context of flight safety systems, which are discussed in the next section.

a) Studies to reduce risk to aircraft

Much of the research done using weather radar to detect birds has been towards providing flight safety products to reduce the risk of bird strike on aircraft, which will reduce both the risk to life of crews and passengers, and also the costs of damaged aircraft. These are described below by way of the FlySafe scheme in Europe and AHAS in the USA.

i FlySafe

FlySafe is a European Space Agency project, which has produced a bird avoidance model (BAM) in order to mitigate the impacts that birds have on military flight training at low levels. According to their website (European Space Agency 2010) "FlySafe aims at improving and harmonising national bird-warning systems into an extended and standardized System of Systems (SoS) to improve flight safety in northwest Europe for military Air Force operations." Weather radar was used as one of these systems to gather information on bird migration in real time, including the velocity, density and location. Military air surveillance radars were the primary source of real time bird information, however it was found that the weather radars were useful for providing 3-dimensional information (instead of 2-dimensional information from the military radars used).

The success of the weather radar for detecting birds was quantified as 87 % of bird densities measured by the weather radars were within a factor of 3 of the measurements made by the Superfledermaus radar (a purpose-built bird detection radar). The executive summary for the FlySafe project (Shamoun-Baranes and Bouten 2009) also points out the opportunity for expansion posed by the European weather radar network organised by OPERA (Huuskonen, 2006). Continental scale migration information from weather radars can already be derived from the network of WSR88D radars in the USA as achieved by Gauthreaux *et al.* (2003).

A pre-operational service uses measured bird density by military radars and forecasting models to produce a BirdTAM intensity (between 0 and 8) over time periods of several hours for use by the Belgian and Dutch Air Forces.

ii Avian Hazard Advisory System (AHAS)

In the USA, weather radar, weather forecasts and known bird distribution data are inputted to a model which forecasts bird activity for the next 24 hours. A small subset of species, deemed to be most hazardous to aircraft, is modelled. This is used to inform military aircraft of the level of risk posed to bird migration at a given time (Kelly *et al.* 1999). This was expanded to civilian airfields to form a terminal area bird detection and monitoring system (Troxel 2002)

b) Studies to quantify bird migration

Various studies have been done to quantify the relationship between reflectivity measured by weather radar and actual bird counts in order to use weather radar more independently from other observing methods. For example in Canada (Gagnon *et al.* 2010), and to explore Polarimetric identifiers for birds in Japan (Minda *et al.* 2008), USA (Zrnic and Ryzhkov 1998), and Finland (Koistinen *et al.* 2009). Several studies have used co-located measurements from a dedicated bird detection radar and weather radar, for example Van Gasteren *et al.* (2008), Dokter *et al.* (2010) and Budgey *et al.* (2006) to find the reflectivity measured by weather radar correlates with the measurements of the bird-radar.

Many of the studies mentioned above have used a multi-sensor approach to address the problem of quantifying bird migration. O'Neal *et al.* (2010) looked at the quantification of the migration of different species of bird using weather radar in the USA. Ground-truthing and existing knowledge of bird movements were used to test whether weather radar could be used to study the movements of specific bird species. The FlySafe project is another example of a multi-sensor approach (Shamoun-Baranes and Bouten 2009), using several types of radar. Gagnon *et al.* (2010) used radar and aural counts during nocturnal migration. Other instruments such as thermal imaging cameras (Gauthreaux and Livingston 2006) and ceilometers (Williams *et al.* 2001) have also been used in conjunction with radar technology for ornithological studies.

4. Conclusions

Radar can be used in two ways to mitigate avian collision with wind turbines:

i. Real time observations of birds from radar can be used to mitigate the risk to birds at wind farm sites. This is similar to the real time use of weather radar in the mitigation of bird strike to aircraft as described previously.
ii. Detailed analysis of historical radar observations of birds within a multi-sensor framework can be used to study their behaviour and to model how wind farm development at specific sites may impact populations.

As more wind farms are constructed offshore, the observation of birds offshore also needs to be considered. This poses the additional challenges of observing birds in the marine environment, which is difficult in inclement weather conditions and at night. This is where remote sensing could take a leading role: Kelly *et al.* (2009) look at the challenges facing the use of remote sensing to study birds offshore, and propose several solutions.

It is clear from the studies mentioned above that radar is a very useful tool for detecting birds, providing coverage, when or where conventional visual bird observations are difficult. Weather radar has been primarily used for mitigating the risk of bird strike to military aircraft; studies for ecological purposes require more detailed information, which is why a multi-sensor approach has been widely used.

Appendix 4. Summary of key features of non-selected options

Table 1: Increasing visibility – marking of ground wires or power lines

	Increasing visibility – marking of ground wires or power lines
Description	A number of studies have been carried out to test the effectiveness of ground wire or power line markers/deflectors to reduce collisions with power lines.
Benefits / impacts	Collision victims tend to be 'poor' fliers. Electrocution victims are birds of prey, ravens and thermal soarers (Janss, 2000). Raptors, herons, storks and allies are most affected by power-line mortality. Passerines and allies occur less frequently (Rubolini *et al.*, 2005).
Drawbacks / risks	-
Effectiveness / status	Shown to be effective for reducing collision with power lines. One study (Janss *et al.*, 1998) investigated the efficacy of various power line markers on bird collision rates. It showed overall reduction in mortality for both the spiral and the crossed bands (types of power line markers) was more than 75%. Markers or deflectors on ground wires have been shown to reduce collisions, flight intensity and collision frequency decreased by around 60% at marked spans (Alonso and Alonso1999). Marking of ground wires or conductors found an average reduction in bird mortality of 45% (Beaulaurier, 1981). A third study (Alonso *et al.* 1994), where red-coloured PVC spirals (rolled around ground wires at 10 m intervals were installed, showed that flight intensity and collision frequency decreased respectively by 61% and 60% at marked spans compared to the same spans prior to marking, while there was no significant change in collision frequency at spans left unmarked. Yellow plastic spirals installed on a circuit have been proved to reduce mortality of birds as shown by fewer birds reacting close to the line, fewer birds flying at the height of the conductors and lower collision rates with the marked line (De La Zerda and Munoz-Pulido 1994).
Application	Not easily applicable to offshore wind turbines.
Other comments	-

Table 2: Wind farm siting, design and layout

	Wind farm siting, design and layout
Description	This mitigation measure is concerned with the proper siting of wind farms, away from sensitive areas, migratory corridors, etc., as well as with the design and layout of the wind farm itself, in order to minimise any adverse impacts.
Benefits / impacts	Suitable siting is generally considered the most important factor in minimising collision impacts. Avoidance of sensitive species can contribute to reducing impacts of avian collision at a population level. It will also minimise the overall development footprint.
Drawbacks / risks	-
Effectiveness / status	Considered most important factor in minimising collision impacts.

Application	There should be a precautionary avoidance of locating wind farms in statutorily designated or qualifying international or national sites for nature conservation, or other areas with large concentrations of birds, such as migration crossing points, or species identified as being of conservation concern (Langston and Pullan, 2003). The following elements in site selection and turbine layout and in developing infrastructure for the facility should be considered (Edkins, 2008): • Minimise fragmentation and habitat disturbance. • Establish buffer zones to minimize collision hazards (for example, avoiding placement of turbines within 100 meters of a riparian area). • Reduce impacts with appropriate turbine design and layout. • Reduce artificial habitat for prey at turbine base area. • Avoid lighting that attracts birds and bats. • Minimize power line impacts by placing lines underground whenever possible. • Avoid using structures with guy wires. • Decommission non-operational turbines.
Other comments	The costs of this measure are dependent on the financial variables for different siting options.

Table 3: Structural modifications

	Structural modifications
Description	This mitigation option involves carrying out structural modifications within the wind farm to minimise avian collision. For example: Updating older model turbines towers from a lattice framework to a tubular construction. Stringing mesh wire around lattice towers. Replacing older, smaller turbines with fewer larger ones.
Benefits / impacts	<u>Lattice or tubular construction / stringing mesh around lattice towers</u> In some studies, updating older model turbines towers from a lattice framework to a tubular construction has been shown to be effective in reducing collisions (Osborn *et al.*, 2000; Barrios and Rodriguez 2004). Other studies contradict this view (Percival, 2001; Marsh, 2009) Stringing mesh wire around lattice towers has helped to reduce collisions (Smallwood and Thelander 2004). <u>Size / number of turbines</u> While replacing older, smaller turbines with fewer larger ones may reduce bird fatalities per megawatt, it could result in increased numbers of bat fatalities (Barclay *et al.* 2007). The same study also showed that neither turbine tower height nor rotor diameter had any effect on birds.
Drawbacks / risks	-
Effectiveness / status	The literature on use of lattice or tubular structures is inconclusive with regard to its effectiveness.
Application	-
Other comments	-

Table 4. Awareness, research and monitoring

	Awareness, research and monitoring
Description	This mitigation option involved carrying out additional research and monitoring on bird behaviours, effectiveness of mitigation measures, etc. It also is about awareness around this type of information and the best practices for the siting, design and mitigation options.
Benefits / impacts	Further research is considered critical for a number of reasons: Don't understand specifically how light attracts birds to communication towers, tall buildings, wind turbines, transmission towers and other lit structures. Need to learn if deterrents such as low frequency sound, coloured markers, or structural modifications reduce avian collisions. Don't understand specifically how birds select stopover areas during spring and fall migrations. Don't fully understand the cumulative impacts of collisions on bird populations Without research, cannot effectively manage habitats and recommend against building new structures in critical bird use areas. One study noted that new wind installations must be preceded by detailed behavioural observation of soaring birds as well as careful mapping of migration routes (Barrios and Rodriguez 2004).
Drawbacks / risks	
Effectiveness / status	
Application	One study (Langston and Pullan, 2003) noted that a map of potential and high sensitivity locations for wind energy development on the basis of nature conservation concerns, for example avoidance of focal points for migration crossings, would be beneficial. That study led to subsequent sensitivity mapping projects for Scotland (Bright *et al.*, 2008) and England (Bright *et al.*, 2009). High sensitivity locations encompass those requiring the strictest tests of compatibility with sustainable development. Similar mapping approaches have been or are being developed in other countries across Europe and further afield, e.g. South Africa. Data gaps are an important constraint on such maps, but they are a useful tool for site selection and scoping. Langston and Pullan (2003) also noted that there is a need for best practice guidance on standard study methods, to inform the EIA process.
Other comments	-

Table 5: Timing of construction and maintenance

	Timing of construction and maintenance
Description	This mitigation measure is one where any construction and maintenance will be timed in order to avoid sensitive time periods; e.g. breeding seasons.
Benefits / impacts	-
Drawbacks / risks	-
Effectiveness / status	-
Application	Could be considered in good practice guidelines
Other comments	-

Appendix 5. Likely focal species for risk assessment in potential Round 3 development zones (after Langston 2010).

CE zone	Location	Nearest distance to mainland (km)[1]	Species
1	Moray Firth	20	Northern Fulmar Northern Gannet Arctic Skua Great Skua Great Black-backed Gull Black-legged Kittiwake Whooper Swan Pink-footed Goose Barnacle Goose (Svalbard)
2	Firth of Forth	20	Northern Gannet Black-legged Kittiwake Arctic Skua Herring Gull Little Gull terns Sandwich Tern Arctic Tern Migrating waterbirds
3	Dogger Bank	120	Northern Fulmar Northern Gannet gulls Black-legged Kittiwake Migrating waterbirds
4	Hornsea	19[2]	Northern Gannet Little Gull Black-legged Kittiwake Migrating waterbirds
5	East of Norfolk & Suffolk	55.5[2]	Lesser Black-backed Gull Little Gull Migrating waterbirds
6	Hastings	6	Mediterranean Gull Little Gull terns Migrating waterbirds
7	West Isle of Wight	7	Mediterranean Gull Sandwich Tern Common Tern Migrating waterbirds
8	Bristol Channel	9	Northern Gannet Lesser Black-backed Gull Herring Gull
9	Irish Sea	17	Little Gull terns

[1] Shortest distance from mainland to wind farm;
[2] Distance obtained from http://www.thecrownestate.co.uk/interactive_map_round3_table

Appendix 6. Likely focal species for risk assessment in Scottish Territorial Waters (after Langston 2010).

Location	Species
Tiree & Coll	Arctic Skua Black-legged Kittiwake Arctic Tern Common Tern Whooper Swan Greenland White-fronted Goose Barnacle Goose (Nearctic) Brent Goose (light-bellied, E Canada) Corncrake Migrating waterbirds
West of Islay	Herring Gull Common Tern Whooper Swan Greenland White-fronted Goose Barnacle Goose (Nearctic) Corncrake Migrating waterbirds
West of Kintyre	Northern Gannet Herring Gull Black-legged Kittiwake Whooper Swan Greenland White-fronted Goose Barnacle Goose (Nearctic) Migrating waterbirds
Wigtown Bay	Northern Gannet Whooper Swan Pink-footed Goose Migrating waterbirds
Solway	Herring Gull Whooper Swan Pink-footed Goose Barnacle Goose (Svalbard) Migrating waterbirds

Appendix 7. Likely focal species for risk assessment in extension areas to Rounds 1 and 2 sites (after Langston 2010).

Round 2 strategic area	Species
Liverpool Bay	Lesser Black-backed Gull Herring Gull Little Gull Arctic Tern Whooper Swan Pink-footed Goose Migrating waterbirds
Greater Wash	Sandwich Tern Common Tern Pink-footed Goose Migrating waterbirds
Greater Thames	Northern Gannet Lesser Black-backed Gull Common Tern Migrating waterbirds