

Inch Cape Offshore Wind Farm

New Energy for Scotland

Offshore Environmental Statement:
VOLUME 2F
**Appendix 15B: Population Viability
Analysis**



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15B.1 INTRODUCTION

15B.1.1 Purpose and Scope of the Report

This Appendix supports the population modelling which was carried out for the Ornithology Impact Assessment and Habitats Regulations Appraisal (HRA) for the Inch Cape Offshore Wind Farm.

Consultation with Marine Scotland and Scottish Natural Heritage (SNH) has been undertaken on the HRA Screening process. The HRA Screening Report submitted to Marine Scotland and SNH is attached as *Annex 15B.1*. SNH comments on this report are summarised in *Chapter 15, Section 15.2*.

A detailed quantitative population viability analysis (PVA) of the predicted effects of collision and displacement has been carried out for four key seabird species across their respective regional populations, which include a range of Special Protection Areas (SPA) colonies.

Species and SPA colonies were selected for PVA based on the list of key species from the HRA Screening Report screened in for Likely Significant Effect (LSE) from potential key impact sources. These include collision risk and displacement effects for kittiwake *Rissa tridactyla*, and displacement effects for guillemot *Uria aalge*, razorbill *Alca torda* and puffin *Fratercula arctica*. These, and all other impact sources are considered in *Chapter 15: Ornithology, Section 15.12 HRA Review*.

SPAs for which LSE was considered possible are Forth Islands, Fowlsheugh, St Abbs to Fast Castle and Buchan Ness to Collieston.

The report will therefore:

- Collate and consider all relevant demographic data for the four seabird species, if possible on a site-specific basis;
- Provide an overview of the key features used for each species-specific PVA model;
- Provide modelled population trends for the baseline situation based on the available demographic data; and
- Provide 'at risk' estimates of collision and displacement impacts for the worst case turbine and array dimensions, contextualising potential impacts in relation to known background populations at the regional level. Model predictions for the regional population will then be used for consideration in the HRA document.

Thus, all PVAs presented in this report are modelled on the regional population, with the findings applied to the individual SPA populations to aid the assessment of effects at the SPA level. Individual PVAs for each SPA population have not been produced because in almost all cases the available demographic data are applied generically across the region, with data specific to each individual SPA lacking. The one exception to this is breeding success data for kittiwake, which are available from each of the relevant SPAs.

The format of the remainder of this report is as follows:

- *Section 15B.2* provides an overview of the methodologies used to gather and analyse demographic data, the choice of key model features and assumptions about the impact of collision risk and displacement on seabird populations.
- *Section 15B.3* presents the modelling results for each of the species. Information is provided on predicted population trajectories, the probability of populations declining (or increasing) to different levels given estimated levels of additional mortality as well as – to provide context – the probability of population increase / decline occurring for a range of (theoretical) additional mortalities.

- *Annex 15B.2* presents predicted mean population sizes with standard deviations and minimum and maximum values for each year of the projections for the main PVA scenarios for each species.
- *Annex 15B.3* provides plots of predicted trends for the multiple collision risk and displacement scenarios assessed for kittiwake and razorbill.

15B.1.2 Definition of Terms

In the following sections the term 'Development Area' refers to The Crown Estate Lease Area , while the term 'Buffer Zone' refers to a buffer zone of 2-4 km around the Development Area. An overview of these areas can be found in Figure 15A.1.1 (*Appendix 15A*).

15B.2 METHODOLOGY

15B.2.1 Ornithological Considerations

15B.2.1.1 Seasonality

Table 15B.1 provides an overview of the definitions of seasonality used for the key species assessments in this document. The period of the core breeding season for each species is based upon recommendations from SNH, whilst other seasons are based upon the known ecology of the species (e.g. Coulson, 2011), factors such as the timing of when parents with chicks are out at sea and observed seasonal patterns in the study area during baseline data collection. More detailed information can be found in *Appendix 15A* (Table 15A.3).

Species	Breeding	Post-breeding	Non-breeding
Kittiwake	Apr-Aug	Sep-Oct	Nov-Mar
Guillemot	Apr-July	Aug- Oct	Nov-Mar
Razorbill	Apr-Jul	Aug- Oct	Nov-Mar
Puffin	Apr-Aug	Sep-Oct	Nov-Mar

Note: Core breeding seasons defined as per SNH recommendation; post-breeding and non-breeding season defined based on species' ecology and seasonal patterns in study area.

15B.2.1.2 Foraging Ranges

Spatial connectivity between the Development Area and seabird colonies was calculated by using the mean maximum foraging range plus one standard deviation (+ 1 SD) as per Thaxter *et al.* (2012). This is considered to be a robust indicator of connectivity for the key breeding seabird species involved. Table 15B.2 provides an overview of the foraging ranges used.

Colonies within each species-specific foraging range from the Development Area plus 4 km buffer were selected in ArcGIS 10.0. Distances to each colony were measured from the outer extent of the 4 km buffer zone. It is considered that if a bird can reach the buffer zone it can reach the Development Area as well.

Colonies which fell just outside a foraging range were considered for inclusion on a case by case basis. E.g. for kittiwake the Buchan Ness to Collieston (SPA) colonies fall just outside the foraging range by a few kilometres. However, given its location relative to the Development Area, with the potential of a direct line of flight and the species capacity to forage over reasonably long distances, connectivity with the study area was assumed.

Species	Foraging range (km)		
	Mean maximum	+1 SD	Total
Kittiwake	60	23.3	83.3
Guillemot	84.2	50.1	134.3
Razorbill	48.5	35.0	83.5
Puffin	105.4	46.0	151.4

15B.2.1.3 Regional Population and Colony Selection

Colony Counts and Trend Adjustment

For each colony within a species' foraging range the most recent count data were derived from the Seabird Monitoring Programme (SMP) database (JNCC, 2010). These counts were then added to provide a regional population total for each species. This approach was followed regardless of designated (SPA) status, i.e. recent counts were used as opposed to the population size at the time of citation. It is considered that for the purpose of exploring the relative importance of the Inch Cape study area it is more ecologically sound to do so in the

context of “real time” populations, more so in light of the declines many east coast colonies have undergone in recent years.

As data for many colonies originate from the last national census (Mitchell *et al.* 2004) which have not been monitored since, it is important to account for population trends, despite the possibility of inter-colony variation in actual trend. This was done by correcting - for each colony - Seabird 2000 and other count data collected before 2007 using the national (UK) 2000-2010 population trend (JNCC, 2012). Colony counts undertaken within the past five years (2007-2012) were considered sufficiently recent to reflect current population trends and were not adjusted for trend.

An overview of the regional population size for each species is provided in Table 15B.3. More detailed information is provided in *Appendix 15A (Section 15A.3.2)*.

TABLE 15B.3 SIZE OF REGIONAL BREEDING SEABIRD POPULATIONS	
Species	Breeding population - pairs (1)
	Region
Kittiwake	55,040
Guillemot	188,210
Razorbill	20,181
Puffin	114,642

1: guillemot and razorbill expressed as individuals – conversion to breeding pairs was done by using a correction factor of 0.67 to convert number of individuals in a colony to approximate number of pairs (Harris 1989).

15B.2.1.4 Apportioning On-site Populations to SPA Colonies

Critical to assessing impacts on the SPA species is the ability to estimate the proportion of the SPA population that is likely to be exposed to the impacts. It is likely that for most species a multitude of breeding colonies within foraging range contribute to the on-site population in the study area during the breeding season, and it is necessary to account for this. Logistical difficulties, together with the potentially variable nature of seabird foraging areas, mean that it is impractical to derive this information from direct monitoring of seabirds across the relevant SPAs. Therefore, the approach taken here to estimating the proportional contribution made by the different SPA populations to the on-site population of each SPA species is based upon adopting a logical approach that considers colony size, amount of potential foraging habitat (i.e. sea) between the colony and the site, and the distance to the site (all of which are likely to influence the extent to which birds from a particular colony use a site).

Therefore, for each species identified as having a potential for LSE in the HRA Screening Report (*Annex 15B.1, Table 10*), an ‘apportionment calculation’ was applied to all colonies within the specified foraging range (see *Appendix 15A, Table 15A.5*). There were several steps to this process, as follows:

- First, the colony size (corrected for population trend as described above) was extracted and, on the basis that the proportion of foraging trips from the colony to a range of sites will decline with distance to these sites (all else being equal), the number of birds foraging as far as the Development Area was estimated. This was achieved using a decay function that was based upon the ratio of the mean maximum foraging distance for the species to the distance from the colony to the site, and an assumption that 15% of all trips were at the mean maximum foraging distance for the species (15% approximating to one tail-end of values falling outside of 1 SD of the mean for a normal distribution). Distances were measured linearly for colonies with a direct line of flight to the study area, but for colonies in the Moray Firth, non-linear flight distances were approximately measured as directed by existing coast lines;
- Having estimated the number of birds from the colony that could access the site (the ‘effective colony size’), each colony within the mean maximum foraging range of the site was given a weighting, based upon the ‘effective colony size’ and the amount of available foraging habitat between the colony and site. The weighting was calculated by:

- (i) dividing the 'effective colony size' by the square of the distance from the colony to the site (the square of distance being used because of the linear to squared scaling involved); and,
 - (ii) for colonies located on mainland coasts (but not offshore islands), dividing the figure from (i) above by two (because they have approximately 50 % of the foraging habitat available as colonies on islands, for a given distance to the site).
- The calculated weights were then summed across colonies and the proportional contribution of the colony to the on-site population calculated as the colony weight expressed as a proportion of the summed weights.

By incorporating all known colonies within foraging range from the study area into the analysis, and with some assumptions about non-breeding birds, this method provides an approximate estimate of the contribution of each colony, including SPAs, to the on-site population. This approach has been implemented in the *Section 15.12 HRA Review of Chapter 15: Ornithology*.

15B.2.2 Population Models

15B.2.2.1 Demographic Parameters

To be of greatest potential value in predicting population-level impacts of additional mortality and/or reductions in reproductive success, population models require demographic parameters that are both contemporary and relevant to the geographical location of the population under study. As such, emphasis in the current work was placed on selecting demographic parameters from the same region as the Development Area, and derived from recent monitoring and research (with the latter of particular importance given the evidence of relatively recent changes in the fortunes of some Scottish seabird populations – Wanless & Harris 2012). In some cases this meant using demographic parameters derived from a small number of years of data (which will increase uncertainty in the estimates) but this disadvantage was considered to be offset by the value of using parameters that may be more relevant to the current time.

Following the production of initial population models for each species, the predicted population trend was compared against available data on population trends from the region to subjectively assess whether model predictions could be considered a reasonable representation of the known trends. The sources used for this comparison were Harris & Wanless (2011), which provided data on population trends of puffin on the Isle of May, and Lewis *et al.* (2012), which provided trend data (where available) from relevant SPAs within the region (see 2.1.3 above) for the remaining three species.

Details of the derivation of demographic parameters used (and estimation of variation about the estimates) are given below for each species, with the parameters given in Table 15B.4.

- **Kittiwake:**
 - *Breeding success: Annual estimates of the number of fledged chicks produced per nest were available from the Seabird Monitoring Programme (JNCC, 2011) for three of the four relevant SPAs (Fowlsheugh, St Abbs to Fast Castle, Buchan Ness to Collieston), and from the long-term monitoring undertaken on the Isle of May, which forms part of the Forth Islands SPA (http://www.ceh.ac.uk/sci_programmes/2012-seabird-breeding-IsleofMay.html). Data were used for the period 2007 – 2011 (the most recent period covered by the SMP data), taking an annual mean figure across the four sites. A mean value (with standard deviation, SD) was then calculated across years to provide the estimate of breeding success (Table 15B.4).*
 - *Annual survival rates: Studies by Harris et al. (2000) and Frederiksen et al. (2004a, 2004b) provide estimates of annual survival for kittiwakes on the Isle of May. The mean value of 0.88 (0.055 SD) for breeding adults for 1986 - 1997 (Harris et al. 2000) was used because a SD was provided, whilst it also appeared to be a reasonable reflection of annual estimates during the latter part of the 1986 – 2000 period, during which*

annual adult survival rates declined (Frederiksen *et al.* 2004a). Annual survival rates of immature birds were assumed to be equivalent to those of breeding adults (Coulson 2011), whilst a derived value of 0.4 was used for juvenile survival (Frederiksen *et al.* 2004a). No SD was available for the juvenile survival rate and so the value for adult survival was assumed.

- *Other parameters:* Age of first breeding was taken as 4 years (Coulson, 2011), and it was assumed that all birds of age 4+ attempted to breed in each year. Although this latter assumption is not always correct (Cam *et al.* 1998). The extent of non-breeding appears to be limited in most populations (Coulson, 2011).

- **Guillemot:**

- *Breeding success:* Annual estimates of the number of chicks produced per nest on the Isle of May were used for the period 2007 - 2012 (<http://www.ceh.ac.uk/sci-programmes/2012-seabird-breeding-IsleofMay.html>). The mean (and associated SD) was calculated for those years. No recent data were known to be available from other SPAs, or sites, within the region of interest.
- *Annual survival rates:* Reynolds *et al.* (2010) provide estimates of annual survival rates of guillemots from the Isle of May for 1983 – 2003, with the estimates for the different age classes (along with their SDs – Table 15B.4) being used to produce the initial population model for the present work. However, this initial model predicted an increasing population, which contrasted with available information on guillemot population trends at SPAs within the region (Lewis *et al.* 2012, see below). Juvenile survival rates appeared to have declined markedly between 1997 and 2003, and so the value for mean juvenile survival provided by Reynolds *et al.* (2010) was replaced with the mean of the values from 1999 - 2003, inclusive (as derived by reading off Figure 2 in Reynolds *et al.* 2010). The SD for the mean of these years was also used.
- *Other parameters:* Age of first breeding was taken as 5 years, and it was assumed that all birds of age 5+ attempted to breed in each year (Harris *et al.* 2007).

- **Razorbill:**

- *Breeding success:* Annual estimates of the number of chicks produced per nest on the Isle of May were used for the period 2007 - 2012 (<http://www.ceh.ac.uk/sci-programmes/2012-seabird-breeding-IsleofMay.html>). The mean (and associated SD) was calculated for those years. No recent data were known to be available from other SPAs, or sites, within the region of interest.
- *Annual survival rates:* Data on razorbill demography from the study region appear to be sparse, with no detailed studies (compared to the other species considered here) available. An estimate of the mean annual adult survival rate (with an associated SD) was available from the Isle of May for the period 1986 – 1997 (Harris *et al.* 2000). The survival rate (and SD) for the immature age classes was assumed to be the same as for breeding adults (on the basis that survival rates of immature birds are generally similar to those of breeding adults in other auks), whilst the juvenile survival rate (and SD) was taken to be equivalent to that given for guillemots by Reynolds *et al.* (2010), on the basis that guillemot is the species in this region with the most similar life-history strategy.
- *Other parameters:* Age at first breeding was taken to be 4 years, based on data from Canadian populations (Lavers *et al.* 2008). It was assumed that all birds of age 4+ attempted to breed in each year.

- **Puffin**

- *Breeding success*: Annual estimates of the number of chicks produced per nest on the Isle of May were used for the period 2007 - 2012 (http://www.ceh.ac.uk/sci_programmes/2012-seabird-breeding-IsleofMay.html). The mean (and associated SD) was calculated for those years. No recent data were known to be available from other SPAs, or sites, within the region of interest.
- *Annual survival rates*: Data on puffin demography are available from the long-term studies on the Isle of May (Harris & Wanless 2011). Annual survival rates of breeding adult birds in this population have shown a long-term decline since c.1970. Therefore, the mean annual adult survival rate over this whole period was not used in the current models, but instead the mean value (and associated SD) for the period 2000 – 2009 (inclusive) was calculated (deriving values by reading off Figure 11.1 in Harris & Wanless, 2011). This included a two year period in which survival rates showed a marked crash, relative to other years. Estimates of survival rates for the juvenile and immature age classes are available only as a composite figure but the Isle of May studies suggest that even amongst the juvenile age class survival may be almost as high as for breeding adults. Thus, between the mid 1970s and mid 1990s, the mean annual survival rate of birds between fledging and 5 years (at 93.1%) was slightly (but not statistically significantly) lower than that of breeding adults during this period, at 95.3% (Harris & Wanless, 2011). To provide an estimate of the mean annual survival rate of juvenile and immature birds, this was assumed to be in a ratio of 93.1:95.3 of the value used for annual adult survival (Table 15B.4). No SD was available for this value and so it was assumed to be equivalent to the SD for the mean annual adult survival rate.
- *Other parameters*: Age at first breeding was taken to be 5 years (Harris & Wanless 2011), and it was assumed that all birds of age 5+ attempted to breed in each year

TABLE 15B.4 DEMOGRAPHIC PARAMETERS USED FOR PVA MODELLING PRIOR TO INCORPORATING POTENTIAL WIND FARM EFFECTS

Species	Parameter	Baseline	Data source
		Mean (SD)	
Kittiwake	Adult survival	0.88 (0.055)	Harris <i>et al.</i> (2000), Frederiksen <i>et al.</i> (2004a), Coulson (2011)
	3rd year survival	0.88 (0.055)	
	2nd year survival	0.88 (0.055)	
	Juvenile survival	0.40 (0.055)	Frederiksen <i>et al.</i> (2004a)
	Breeding success (fledglings / adult)	0.339 (0.165)	SMP*/CEH*
	Age of first breeding (years)	4	Coulson 2011
Guillemot	Adult survival	0.910 (0.018)	Reynolds <i>et al.</i> (2010)
	4th year survival	0.930 (0.017)	Reynolds <i>et al.</i> (2010)
	1–3 year composite survival	0.760 (0.024)	Reynolds <i>et al.</i> (2010)
	Juvenile survival	0.360 (0.190)	Reynolds <i>et al.</i> (2010)
	Breeding success (fledglings / adult)	0.330 (0.098)	CEH*
	Age of first breeding (years)	5	Harris <i>et al.</i> (2007)
Razorbill	Adult survival	0.905 (0.070)	Harris <i>et al.</i> (2000)
	1-3 year composite survival	0.819 (0.070)	Assumed (see text)
	Juvenile survival	0.540 (0.013)	Assumed (see text)
	Breeding success (fledglings / adult)	0.298 (0.028)	CEH*
	Age of first breeding (years)	4	Lavers <i>et al.</i> (2008)
Puffin	Adult survival	0.876 (0.105)	Harris & Wanless (2011)
	1-4 year composite survival	0.627 (0.105)	Harris & Wanless (2011), but see text
	Juvenile survival	0.856 (0.105)	Harris & Wanless (2011), but see text
	Breeding success (fledglings / adult)	0.299 (0.095)	CEH*
	Age of first breeding (years)	5	Harris & Wanless (2011)

Note: All birds of breeding age are assumed to breed in each year of the model projection.

*SMP – data from Seabird Monitoring Programme (JNCC, 2011)

*CEH – data from http://www.ceh.ac.uk/sci_programmes/2012-seabird-breeding-IsleofMay.html

15B.2.2.2 Key Model Features

The 'Rramas' package available in R software for statistical computing (R Development Core Team, 2012) was used for the PVA modelling. The population model is matrix-based, and allows the inclusion of stochasticity. Models were run in R version 2.14.1. Key model features are presented in Table 15B.5.

Model components	Choice of approach
Age structure	Matrix-based
Stable age distribution	Matrix-based
Census	Post-breeding
Sex ratio	50:50
Initial abundance	Based on regional / colony population estimate and stable age distribution
Density dependence	None, exponential increase or decrease allowed
Environmental stochasticity	Based on standard deviation of vital rates
Demographic stochasticity	Yes, assumes binomial distribution for survival and Poisson distribution for fecundity
Emigration / immigration	None incorporated, populations considered 'closed'
Replications	1,000
Duration	25 years
Calculation of decline or explosion probabilities	1,000 bootstrap samples taken for each model to compute probability that population size declines below or exceeds abundance thresholds during projection period
Collision risk	Affects survival rates across all age classes
Displacement	Affects breeding success (number of fledged birds per individual breeding bird)

Age-Structure

The 'Rramas' package simulates the growth of each population with a matrix-based age-structured model, generally called a transition matrix, which is commonly used in population modelling (e.g. Caswell, 1989). Age-structured models attempt to account for the fact that organisms of different ages have different characteristics, which are reflected in their vital rates (e.g. survival rates). A matrix of standard deviations for each estimated survival (or fecundity) value is also used to enable the incorporation of environmental stochasticity within the modelling framework.

Stable Age Distribution

The age distribution of a given population is defined as the proportion of the population belonging to each age class at a given moment in time. If the vital rates of that population are more or less constant for a sufficiently long period of time it will reach a stage at which the proportion of individuals in each age class remains the same – the stable age distribution.

Based on the available vital rates (see Table 15B.4) the stable age distribution was calculated automatically in 'Rramas'. Table 15B.6 provides an overview of the calculated proportions for each age class for each of the four species.

Species	Age class proportion					
	Juveniles	1st years	2nd years	3rd years	4th years	Breeding adults
Kittiwake	0.186	0.077	0.069	0.063	N/A	0.606
Guillemot	0.202		0.074*		0.057	0.667
Razorbill	0.188		0.100*		N/A	0.712
Puffin	0.175		0.148*			0.677

* represents proportion for a composite age class spanning > 1 year (see Table 15B.4)

Census

The model is based on a post-breeding census, i.e. the model considers a population census immediately after the annual reproduction, followed by a one year period of survival after which surviving adults breed.

Sex Ratio

Sex ratio was assumed to be 50:50 in all models – i.e. the proportion of females in a population or age class was considered equal to the proportion of males. As such reproduction (breeding success) was implemented in terms of “number of fledged birds per individual breeding bird”.

Initial Abundance

The initial abundance of populations (i.e. population size at $t=0$, Table 15B.7) was calculated by using the known size of a breeding bird population or colony (Table 15B.3), calculating the size of all other age classes using the stable age distribution (Table 15B.6), and then summing across all age classes.

For kittiwake and puffin estimating the breeding population was straightforward as published population sizes of breeding birds tend to be expressed in pairs. Population size for guillemot and razorbill is generally expressed in individuals rather than breeding pairs as it is usually not possible to count apparently occupied sites or nests (AOS or AON). As counts of individuals may include off-duty adults away from a nest, non-breeders and immature birds, as well as breeding birds, a correction factor of 0.67 is applied to estimate the number of AON or breeding pairs (based on studies where counts of AON have been made, Harris 1989, Mitchell *et al.* 2004).

TABLE 15B.7 REGIONAL POPULATION ESTIMATES USED TO PROVIDE INITIAL ABUNDANCE FOR THE PVA MODELS

Species	Regional population size (number of individuals)
Kittiwake	181,832
Guillemot	378,113
Razorbill	37,980
Puffin	338,677

Density Dependence

All models were set to be density independent as there is no evidence to suggest that restrictive population control through density-dependence is particularly realistic for these species, and the choice of level at which to set density dependence is likely to control the predictions obtained.

While density independent simulations are also based on an unrealistic premise - that of potentially unlimited growth, this is a more reasonable assumption within typical prediction time frames than simply assuming that density dependent regulation occurs and so must be included, even if this requires fabrication of the mechanism and model strength to satisfy this assumption.

Stochasticity

Two types of stochasticity were included in the PVA models: environmental and demographic stochasticity. The difference between the two can be thought of as follows: environmental stochasticity generates random values for the probability of survival from one time step to the next based on available vital rate values (mean and standard deviation); whereas demographic stochasticity generates random numbers of individuals which survive from one time step to the next for any given survival probability. Thus, the former models variable environments (e.g. weather effects) while the latter models chance effects due to the population size. Demographic stochasticity is of particular importance for small populations, as unpredictable events can push a population close to extinction.

Standard deviations were used to model environmental stochasticity at each time step, effectively describing temporal variation in vital rates. Survival and reproduction rates were randomly drawn from a binomial and log-normal distribution respectively. Demographic stochasticity on survival is modelled using a binomial (or Poisson for fecundity) distribution, whereby the number of individuals surviving from one time step to the next is estimated using the number of individuals available after the previous time step and a randomly generated survival rate.

Emigration/Immigration

The modelling has been based on a 'closed' population, i.e. one where it is assumed that there is no immigration or emigration to and from any of the colonies. This is considered a reasonably realistic approach as most seabird species do have a tendency to be colony-faithful once settled. For most species, inter-colony movements are probably more prevalent in the pre-breeding age (Harris and Wanless, 2011).

Estimating Population Trends and Probabilities of Decline or Increase

Population models were set to simulate population trends over a duration of 25 years, with each time step defined as one year. A 25 year projection period was used to maintain consistency with certain of the existing PVAs within the industry (WWT Consulting 2012), and in recognition of the fact that uncertainty in model predictions increases with the length of the projection period. Each model was replicated 1,000 times, calculating the mean population size and SD for each year of the projection. For populations showing a declining trend the probability of the population falling below particular abundance thresholds was calculated as the ratio between the number of times these thresholds were attained and the number of replications, with 1,000 bootstrap samples taken of the abundances in each year (in all replications) to produce a 95% confidence interval about this probability. In the same way probabilities of exceeding particular abundance thresholds were calculated for populations showing increasing trends.

15B.2.2.3 Collision Risk – Additional Mortality

Collision risk modelling (CRM) was undertaken to quantify the possible extent of additional mortality due to collisions with turbines for key seabird species. The Band (2012) model, recently developed as part of the Crown Estate's Strategic Ornithological Support Services work output, was used for collision risk estimation. A detailed overview of the CRM calculations is provided in *Section 15A.2.5.2 (Appendix 15A)*, with estimates of collision mortality presented for both 98% and 99% avoidance rates. Of the four species for which PVAs were carried out, collision risk impacts were modelled for kittiwakes only because none of the auk species were recorded flying at potential collision risk height during the two year baseline monitoring programme (*Appendix 15A*).

Collision estimates for kittiwake were incorporated in the PVA models on the basis that a 100% mortality rate occurs from collisions, giving a total of 547 additional deaths under the 98% avoidance rate and 273 deaths with 99% avoidance (Table 15B.8). However, it is highly unlikely that all of these collisions would involve birds from the regional breeding population because of post-breeding movements away from the region. Thus, studies undertaken during 2007/08 and 2009/10 demonstrated that a high proportion of breeding kittiwakes from the Isle of May winter in the East, Central and West Atlantic (Bogdanova *et al.* 2011a, Frederiksen *et al.* 2012). During these studies, at least 20 of 31 kittiwakes tracked in 2007/08 had moved out of the North Sea region (within which the Inch Cape regional breeding population occurs) by the start of September (coinciding with the post-breeding season used in this assessment – Table 15B.1), with only one of these 31 birds still located within the area of the breeding colony by that date (Bogdanova *et al.* 2011b). Furthermore, the median distance from the breeding colony of 16 kittiwakes tracked in 2009/10 was almost 3000 km by the start of October (Frederiksen *et al.* 2012). Many of the kittiwakes recorded within the Development Area during the post-breeding and wintering periods are likely to derive from arctic and sub-arctic breeding colonies, such as those on Bear Island and Spitsbergen (Frederiksen *et al.* 2012).

Therefore, two different scenarios were considered for the proportion of birds (and hence predicted collisions) that were associated with the regional breeding population. First, a highly precautionary scenario was used, in which all birds from all seasons (and hence all collisions) were assumed to be from the regional breeding population. The second scenario assumed that 100%, 50% and 25% of birds recorded during the breeding, post-breeding and winter seasons respectively, belonged to the regional breeding population, with a concomitant adjustment made to the number of collisions associated with the regional breeding population in each of these seasons (see *Section 15A.2.5.2* in *Appendix 15A* for the details of the seasonal breakdown in predicted collision risk). Each of these scenarios was applied to the collision estimates derived using the two avoidance rates, giving four different estimates of additional mortality predicted to arise from collisions (Table 15B.8).

TABLE 15B.8 LEVELS OF ADDITIONAL MORTALITY INCORPORATED INTO THE KITTIWAKE PVA FROM COLLISION ESTIMATES UNDER DIFFERENT AVOIDANCE RATES AND SCENARIOS FOR THE REGIONAL BREEDING POPULATION

Associated avoidance rate	Estimated annual collisions (no. of birds) (1)	Turbine scenario (2)	Assumed seasonal occurrence of regional breeding population (3)	Additional mortality incorporated into PVA (no. of birds)
98%	547	Large	All birds in all seasons	547
			All birds in breeding period, 50% in post-breeding period and 25% in winter period	246
99%	273	Large	All birds in all seasons	273
			All birds in breeding period, 50% in post-breeding period and 25% in winter period	123

1: average no. of collisions each year, regardless of age class (see *Appendix 15A, Section 15A.4.3*), if the wind farm were operational

2: the Large turbine scenario results in the largest collision estimate for kittiwake and is considered to represent the 'worst case' for PVA modelling purposes

3: seasonal periods used are defined in Table 15B.1

To incorporate additional mortality into the PVA, the value for additional annual mortality through collisions as defined at the outset of a simulation was used to calculate the proportional mortality for the sub-adult and adult age classes – in turn based on the stable age distribution. For example, if the additional mortality is set at 100 individuals, the estimated sub-adult and adult proportions of the initial population that this number represents are calculated. In this manner, additional mortality is converted into a proportion, which is then applied across all years of the simulation. Thus, additional mortality remains proportional to the population size throughout the simulation. Because collision mortality was estimated on a seasonal basis (Table 15B.1), the apportioning of mortality to age classes was carried out separately for the breeding season when the juvenile component of the population was omitted (as they would be restricted to the nest-site and not exposed to collision risk). Thus, during the breeding season 74.4% of the kittiwakes recorded during the surveys were classed as breeding adults, as opposed to 60.6% at other times. The revised annual survival rates resulting from the incorporation of additional mortality are provided in Table 15B.9 for each of the four different estimates of additional mortality arising from predicted collisions. These survival rates were used to model effects of estimated collision mortality within the PVA (retaining the SD associated with the mean value from the 'no collision' scenario in each case – Table 15B.4). Breeding success was assumed to be unaffected by collision mortality, which was reasonable given the small number of collisions estimated to occur during the breeding season.

TABLE 15B.9 EFFECTS OF ADDITIONAL MORTALITY FROM ESTIMATED COLLISIONS ON THE ANNUAL SURVIVAL RATES USED IN THE KITTIWAKE PVA			
Estimated collision risk	Assumed seasonal occurrence of regional breeding population	Juvenile annual survival rate	Annual survival rate of 2nd/3rd year and adult age classes
No collisions	-	0.40	0.88
Collisions at 98% avoidance	All birds from all seasons	0.397	0.877
	Post-breeding/winter adjustment*	0.399	0.879
Collisions at 99% avoidance	All birds from all seasons	0.399	0.878
	Post-breeding/winter adjustment*	0.399	0.879

*adjusted percentage of birds from regional breeding population given in Table 15B.8

In addition to modelling the effects of the predicted number of collisions on the kittiwake population, a range of potential additional mortalities, with starting point ranging from 200 to 1,000 birds, were also modelled to indicate how impacts varied across a wider range of additional mortality levels. The procedure for modelling these additional mortalities followed that described above for the predicted collision mortality.

15B.2.2.4 Displacement – Reduction in Breeding Success

Following recommendations from Marine Scotland, SNH and the JNCC a simple displacement rate approach was used for analysis (*Section 15A.2.5.4, Appendix 15A*). This approach was based on the proportion of birds which may be displaced from the Development Area and a 2 km buffer around it, based on estimated bird densities for a given season. Peak mean densities were used for this analysis to more accurately represent the populations utilising the study area across an entire breeding or non-breeding season. The peak mean density was derived through calculating the average density for each season in Year 1 and Year 2 and then selecting the highest seasonal value. A full overview of density and population estimates thus derived can be found in *Appendix 15A*.

For each of the four modelled species, the number of breeding adults exposed to potential displacement at the outset of the simulation was calculated by applying the stable age distribution from the relevant PVA to estimate the proportion of breeding adults amongst the breeding season peak mean population within the Development Area and 2 km buffer. As for collision mortality during the breeding season, the juvenile age class was omitted from consideration in calculating this, because birds from that age class were restricted to nest-sites at this time. Thus, 74.4% of kittiwakes, 83.6% of guillemots, 87.7% of razorbills and 82.1% of puffins recorded during the breeding season surveys were classed as breeding adults, as opposed to 60.6%, 66.7%, 71.2% and 67.7%, respectively.

For kittiwake it was assumed that 30% of the breeding adults exposed to potential displacement were actually displaced, whilst for the three auk species 50% of the potentially exposed birds were assumed to be displaced. The rationale for these values can be found in the *Chapter 15, Section 15.6.2*.

Initial modelling was undertaken by assuming that for each adult bird displaced the breeding attempt failed - i.e. a loss of fledglings equivalent to the mean fledging success per breeding pair, as opposed to the mean fledging success per breeding adult. This equated to a 100% reduction in the breeding success of the birds that were assumed to be displaced, and was considered to be a precautionary estimate of the potential effects on breeding success (being the maximum possible impact on breeding success resulting from the displacement of these birds). Therefore, for species where the assumed 100% failure rate was considered to produce more than a minor effect on the predicted population trend, effects of 75% and 50% breeding failure were also investigated. For any given failure rate, the figure for the reduced mean breeding success per pair was then calculated by removing the number of chicks lost due to displacement at the outset of the simulation (i.e. mean fledging success per pair * number of displaced adults) from the total breeding output of the population at the outset of the simulation.

Thus, the reduction in breeding success resulting from displacement was proportional to the population size at each time step. The reduced levels of breeding success resulting from these displacement levels are given in Table 15B.10. The revised figures for the mean number of fledglings produced per adult were used to model the effects of displacement within the PVAs (retaining the associated SD for the breeding success estimate for 'no displacement' scenario in each case – Table 15B.4).

As for collision mortality, impacts from a range of displacement values were also examined for each species (by varying the percentage of exposed birds that were assumed to be displaced).

TABLE 15B.10 DISPLACEMENT ESTIMATES AND EFFECTS ON BREEDING SUCCESS RATES USED IN PVA MODELLING

Species	Displacement estimate (1)	Associated displacement rate	Assumed reduction in breeding success of displaced birds	Mean no. of fledglings per adult	
				With no displacement	With displacement
Kittiwake	1,671	30%	100%	0.339	0.336
Guillemot	3,654	50%	100%	0.330	0.320
Razorbill	1,434	50%	100%	0.298	0.283
			75%		0.286
			50%		0.290
Puffin	2,953	50%	100%	0.299	0.295

1: estimated number of breeding adults potentially exposed to displacement

15B.3 RESULTS AND DISCUSSION

15B.3.1 Overview of Section

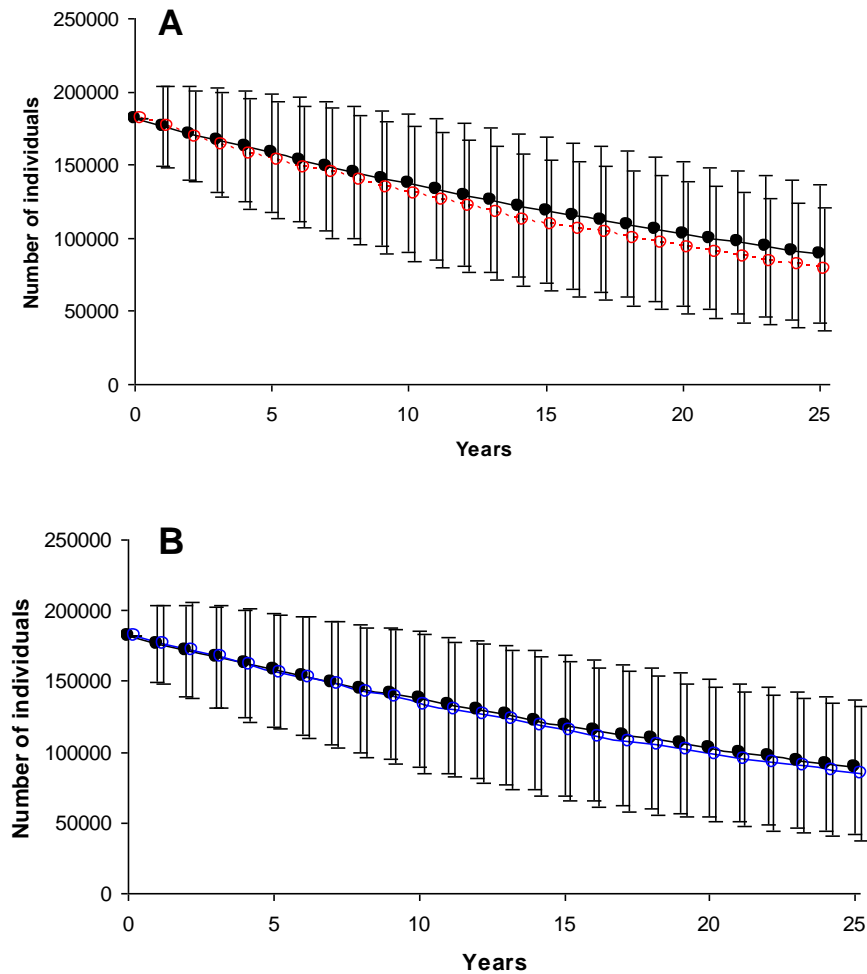
Outputs from the PVAs are presented in this section on a species by species basis, along with brief interpretation and discussion. Interpretation and discussion focus on aspects of how well model predictions fit with known trends in the regional population of these species, and on the sensitivity of the model predictions to variation in the level of impacts, and (in some cases) to the assumptions concerning the impacts. Discussion of the magnitude and significance of the impacts is not considered here, as details of this are presented in Chapter 15, *Section 15.6*.

15B.3.2 Kittiwake

15B.3.2.1 Predicted Trend

The baseline population model for kittiwake predicted a decline of c.50% over the 25 year period, from a starting population of 181,832 birds to one of 89,020 (Figure 15B.1, Table 15B.11). This equated to a mean annual growth rate of 0.972. The predicted trend fits with the known widespread declines in kittiwake numbers across Scotland (Wanless & Harris, 2012), and with the evidence of declines in their numbers at three of the four relevant SPAs within the region (Lewis *et al.* 2012). Thus, declines have been detected for the Forth Islands, Fowlsheugh and St Abbs to Fast Castle SPAs, with the confidence in the reliability of the trend being very high, low and moderate for each of these SPAs, respectively (Lewis *et al.* 2012). Trends at Buchan Ness to Collieston (the fourth SPA of relevance) have been assessed with moderate confidence as stable.

Figure 15B.1. Projected trends for the regional kittiwake population in the absence of any collision mortality (A and B – solid black symbols) and with the estimated collision mortality at the 98% avoidance rate (A – open red symbols and dashed line) and 99% avoidance rate (B – open blue symbols and dashed line) incorporated. In both A and B, the predicted trends with estimated collision mortality incorporated adopt the precautionary scenario of assuming all birds from all seasons belong to the regional breeding population. Mean population sizes ± 1 SD are shown. (Plotted lines are staggered to aid presentation).



15B.3.2.2 Effects of Collision Mortality

Of the four scenarios considered for estimating the additional mortality resulting from collisions, the most precautionary assumed that all of predicted collisions affected birds from the regional breeding population, whilst the avoidance rate was 98%. Incorporating the predicted level of collision mortality under this scenario into the population model for kittiwake reduces the mean annual growth rate of the population from 0.972 to 0.967, giving a population size at the end of the projection period of 78,717 – i.e. a reduction of c.10,000 birds relative to the ‘no-impact’ scenario (Figure 15B.3.1, Table 15B.11). However, as detailed above (Section 15B.2.2.3), this scenario is unlikely to be realistic. Less precautionary assumptions for the proportion of the estimated collisions affecting birds from the regional breeding population during the post-breeding and winter period (i.e. reducing this to 50% and 25%, respectively), give a mean annual population growth rate of 0.970 and a population size of 84,531 at the end of the projection period – i.e. a reduction of c.4,500 birds compared to the ‘no-impact’ scenario (Table 15B.11). Scenarios that assumed a 99% avoidance rate for collisions produced similar effects on

the predicted population trend, with little difference according to whether or not all collisions were assumed to affect birds from the regional breeding population (Table 15B.11).

Estimated collision risk	Assumed seasonal occurrence of regional breeding population	Predicted mean no. of birds (\pm 1SD) at 25 years	Mean probability (95% CI) of decline of:				
			> 0%	\geq 10%	\geq 25%	\geq 50%	\geq 75%
No collisions	-	89020 (\pm 47398)	0.996 (0.994-0.998)	0.987 (0.984-0.990)	0.951 (0.945-0.957)	0.735 (0.722-0.748)	0.195 (0.183-0.206)
Collisions at 98% avoidance	All birds from all seasons	78717 (\pm 41774)	0.997 (0.993-1.000)	0.992 (0.986-0.997)	0.968 (0.957-0.979)	0.808 (0.783-0.832)	0.278 (0.249-0.305)
	Post-breeding/winter adjustment*	84531 (\pm 45421)	0.996 (0.992-0.999)	0.990 (0.984-0.996)	0.953 (0.940-0.966)	0.768 (0.742-0.794)	0.219 (0.193-0.244)
Collisions at 99% avoidance	All birds from all seasons	84945 (\pm 47245)	0.997 (0.993-1.000)	0.986 (0.978-0.993)	0.961 (0.949-0.972)	0.772 (0.746-0.798)	0.215 (0.188-0.240)
	Post-breeding/winter adjustment*	84320 (\pm 46427)	0.996 (0.992-0.999)	0.987 (0.980-0.993)	0.957 (0.944-0.970)	0.772 (0.744-0.797)	0.239 (0.214-0.268)

***adjusted percentage of birds from regional breeding population given in Table 15B.8**

As would be expected, the probability that the population will experience declines of varying magnitudes increases with the addition of collision mortality, particularly under the most precautionary scenario (Table 15B.11, Figure 15B.2). This difference is most marked for declines in the range of 50 – 75%, which have a moderate to high likelihood of occurrence (Figures 15B.2, 15B.3).

Over a range of additional annual mortalities (proportional to the population size at each step), it is apparent that their impact on the likelihood of declines of up to 25% is small, because the population has such a high likelihood of experiencing such declines, irrespective of additional mortality (Figure 15B.3). For more substantial declines (e.g. of 50% and 75%), there is a greater effect of the additional mortality on the likelihood of the population experiencing such declines, although this is strongly influenced by the level of additional mortality. Thus, additional mortalities equivalent to removing c.100 - 400 birds from the starting population increase the likelihood of such declines by c.2 - 4%, with no apparent increase in this risk over this range of additional mortality (Figure 15B.3). This range encompasses three of the four scenarios considered for the additional mortality resulting from the estimated collisions (i.e. all but the most precautionary scenario). Higher levels of additional mortality produce a greater increase in the likelihood of the population experiencing declines of up to 50% and 75%, with the most precautionary collision mortality scenario producing an increase of c.7 - 8% in the likelihood of such declines (Figure 15B.3).

Figure 15B.2. The probability of the kittiwake population declining to different levels in the absence of the estimated collision mortality (black line) and with additional collision mortality incorporated (red line), based upon the most precautionary scenario considered (i.e. 98% avoidance and assuming all birds from all seasons belong to the regional breeding population). In both cases, 95% CIs shown by thin lines.

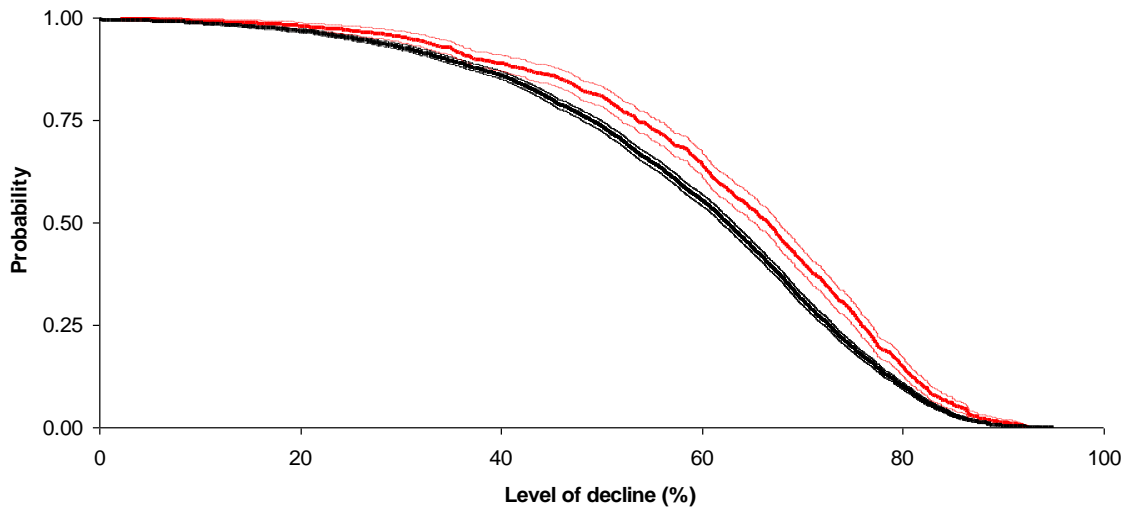
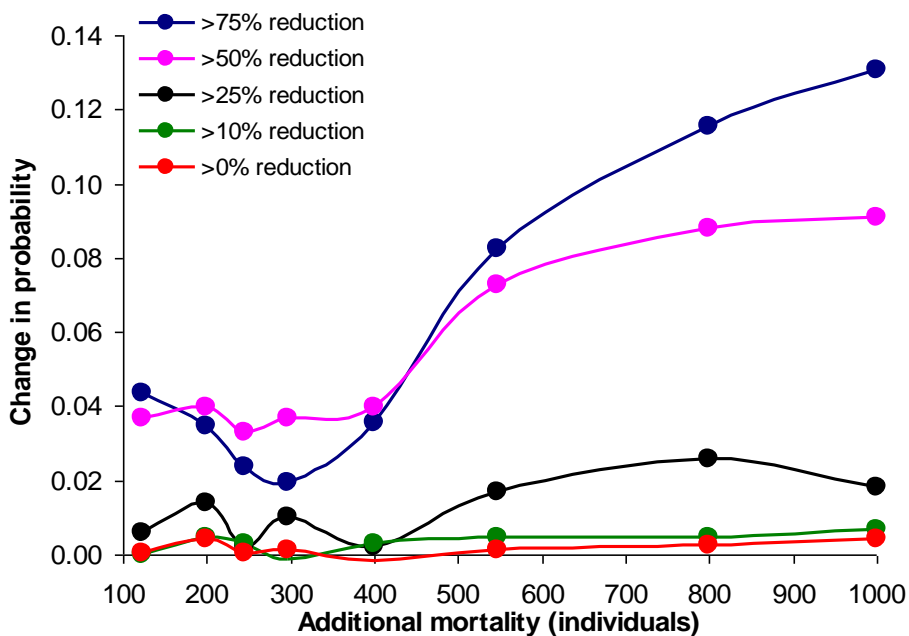


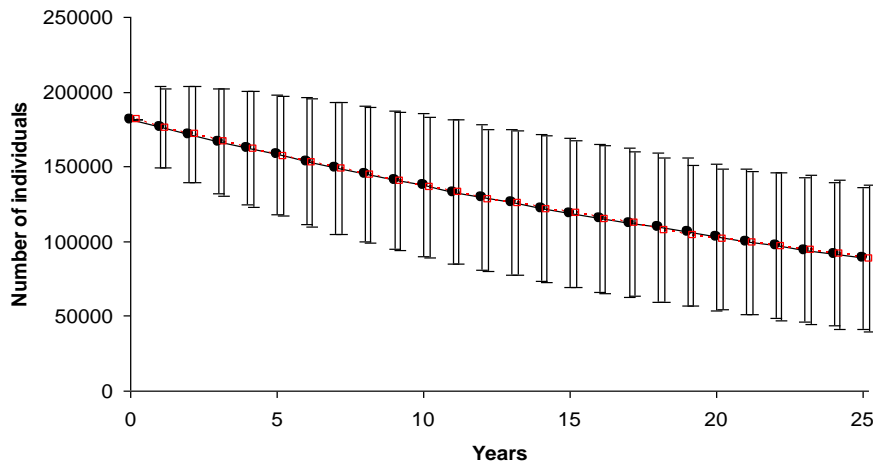
Figure 15B.3. Changes in the probability of the kittiwake population declining to different thresholds for a range of additional mortalities, relative to that predicted in the absence of additional mortality. The four scenarios for estimated additional mortality resulting from collisions are included – i.e. 98% and 99% avoidance, with all birds from all seasons included (equivalent to additional mortalities of 547 and 273 birds, respectively, from the starting population), and 98% and 99% avoidance, with a reduced proportion of the post-breeding and winter bird numbers included (equivalent to additional mortalities of 246 and 123 birds, respectively, from the starting population).



15B.3.2.3 Effects of Displacement

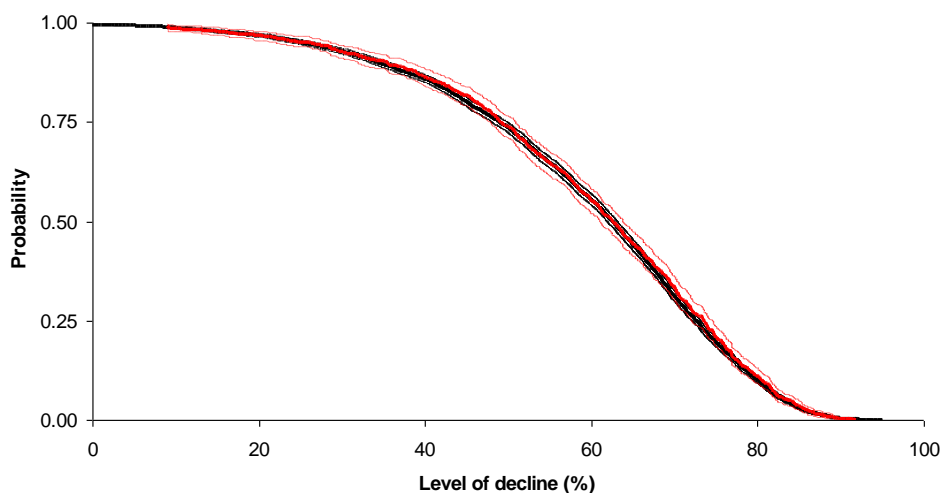
Incorporating the effects of displacement (at the assumed 30% level) into the kittiwake population model reduces the mean annual growth rate to 0.9716 (from 0.9718), giving a population size at the end of the projection period of 88,608 ($\pm 48,912$ SD) – i.e. a reduction of c.400 birds relative to the ‘no-impact’ scenario (Figure 15B.4). The difference in the final population sizes predicted under the two scenarios is not statistically significant.

Figure 15B.4. Projected trends for the regional kittiwake population. Solid black symbols represent trend with no wind farm displacement (and no collisions). Open red symbols and dashed line represent trend with estimated displacement (at 30%) from the wind farm incorporated. Mean population sizes ± 1 SD are shown. (Plotted lines are staggered to aid presentation).



The probability that the population will experience declines of varying magnitudes increases with the addition of displacement, but the increase is marginal, with the 95% CIs for the two scenarios overlapping considerably (Figure 15B.5). Doubling the displacement effect (so that 60% of birds are displaced) increases the impacts (as would be expected) but they remain relatively minor. Thus, with a displacement rate of 60%, the population size at 25 years is predicted to be 84,198 ($\pm 46,231$ SD), whilst increases in the likelihood of decline are at most 5% for reductions in population size of > 0, 10, 25, 50 and 75%.

Figure 15B.5. The probability of the kittiwake population declining to different levels for the modelled population in the absence of displacement effects (black line) and with the assumed reduction in breeding success resulting from 30% displacement (red line). In both cases, 95% CIs shown by thin lines.

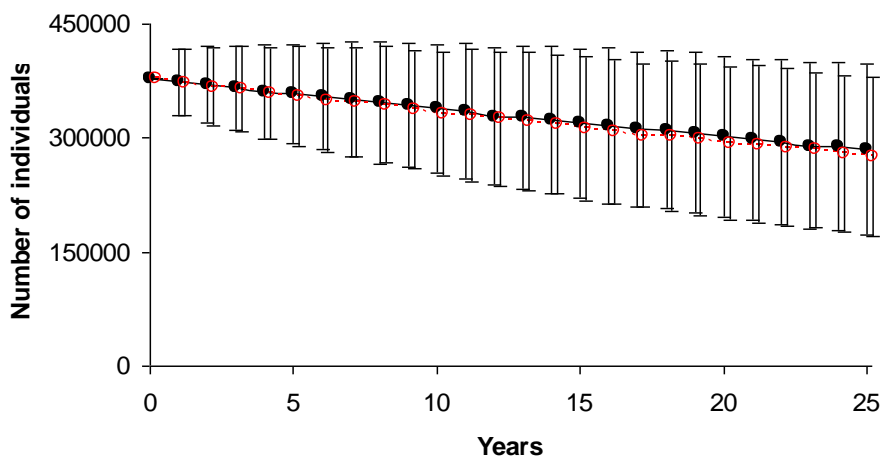


15B.3.3 Guillemot

15B.3.3.1 Predicted Trend

The baseline population model for guillemot predicted a decline of c.25% over the 25 year period, from a starting population of 378,113 birds to one of 284,950 (Figure 15B.6). This equated to a mean annual growth rate of 0.989. The predicted trend fits with the fact that declines have been reported for all of the four relevant SPAs, although for three of these the confidence in the reliability of the trend is low, with only that from the Forth Islands being considered to be of very high confidence (Lewis *et al.* 2012).

Figure 15B.6. Projected trends for the regional guillemot population. Solid black symbols represent trend with no wind farm displacement. Open red symbols and dashed line represent trend with estimated displacement (at 50%) from the wind farm incorporated. Mean population sizes \pm 1SD are shown. (Plotted lines are staggered to aid presentation).



15B.3.3.2 Effects of Displacement

Incorporating the effects of displacement (at the assumed 50% level) into the guillemot population model reduces the mean annual growth rate to 0.987, giving a population size at the end of the projection period of 275,690 (\pm 104,356 SD) – i.e. a reduction of 9,260 birds relative to the ‘no-impact’ scenario (Figure 15B.6).

The probability that the population will experience declines of varying magnitudes increases with the addition of displacement, but the increase is small, with the 95% CIs for the two scenarios overlapping considerably (Figure 15B.7). Displacement effects have small effects (\leq c.1%) on increasing the likelihood of population reductions of up to c.10% and of large reductions of \geq 75%, even with a displacement level of 100% (i.e. double the assumed level). For population reductions of 25 or 50%, the effect of the assumed 50% displacement level is to increase the likelihood of such declines by 2-3% (Figure 15B.8).

Figure 15B.7. The probability of the guillemot population declining to different levels for the modelled population in the absence of displacement effects (black line) and with the assumed reduction in breeding success resulting from 30% displacement (red line). In both cases, 95% CIs shown by thin lines.

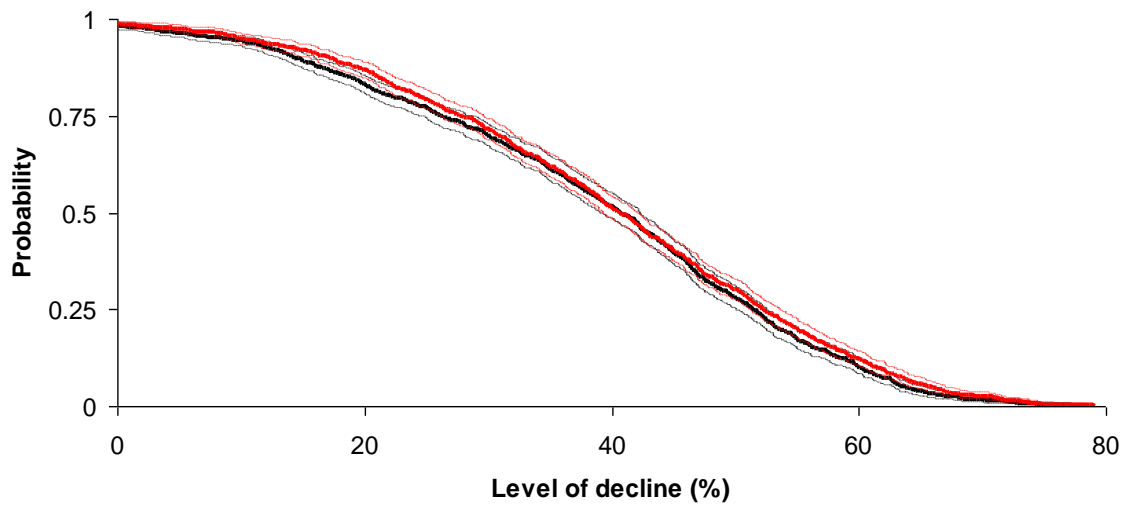
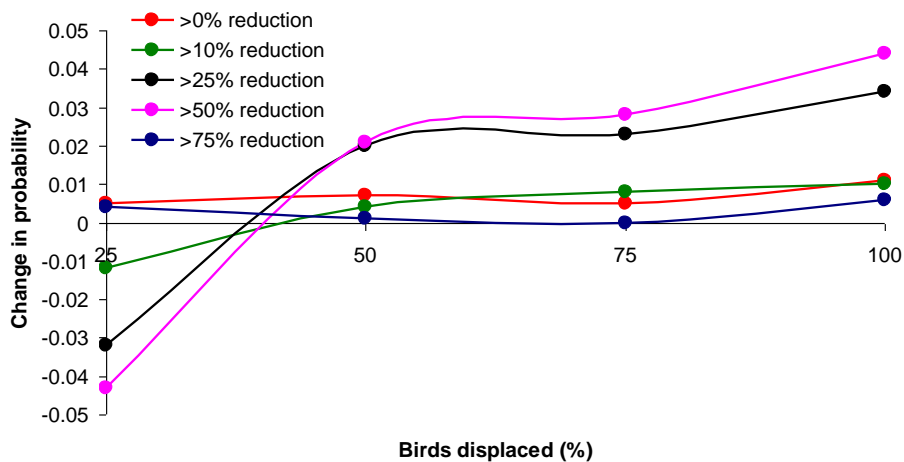


Figure 15B.8. Changes in the probability of the guillemot population declining to different thresholds for a range of potential displacement levels, relative to that predicted in the absence of displacement.

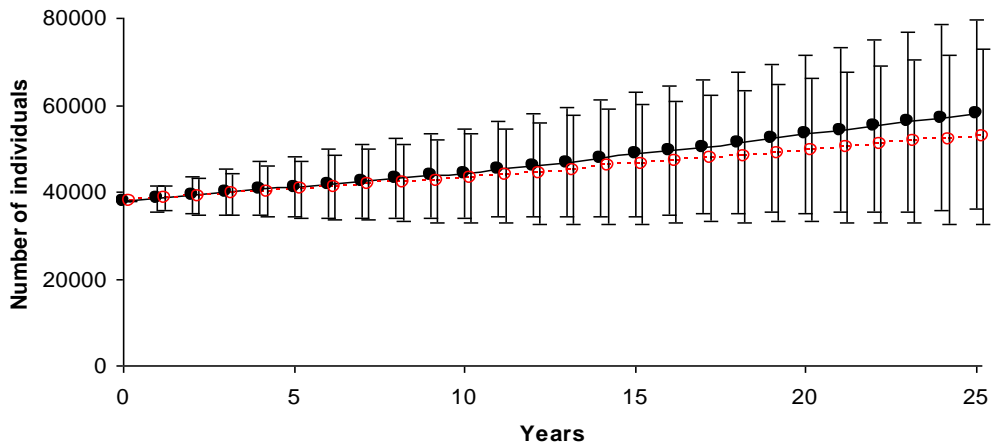


15B.3.4 Razorbill

15B.3.4.1 Predicted Trend

The population model for razorbill predicted an increase of c.50% over the 25 year period, from a starting population of 37,980 birds to one of 58,013 (Figure 15B.9). This equated to a mean annual growth rate of 1.017. The extent to which this matches the actual trend from the region is unclear, with razorbill numbers considered stable on the Isle of May (with high confidence), but as having unclear and declining trends at the Fowlsheugh and St Abbs to Fast Castle SPAs, respectively (Lewis *et al.* 2012). Therefore, although the available data do not provide strong support for the modelled trends for this species, the actual overall population trend within the region is unclear, and there is insufficient evidence to conclude that the modelled trends are a poor representation of the real population trend.

Figure 15B.9. Projected trends for the regional razorbill population. Solid black symbols represent trend with no wind farm displacement. Open red symbols and dashed line represent trend with estimated displacement (at 50%) from the wind farm incorporated. Mean population sizes \pm 1SD are shown. (Plotted lines are staggered to aid presentation).



15B.3.4.2 Effects of Displacement

Incorporating the effects of displacement (at the assumed 50% level, and with an assumed 100% breeding failure amongst displaced birds) into the razorbill population model reduces the mean annual growth rate to 1.013, giving a population size at the end of the projection period of 52,718 – i.e. a reduction of 5,295 birds compared to the ‘no-impact’ scenario (Figure 15B.9, Table 15B.12). Reducing the assumed level of breeding failure amongst displaced birds to 75% and 50% gives mean population sizes by the end of the projection period that represent reductions of 5,096 and 2,925 birds, respectively, compared to the ‘no-impact’ scenario (Table 15B.12).

TABLE 15B.12 EFFECTS OF DISPLACEMENT ON THE PREDICTED RAZORBILL POPULATION FOR A RANGE OF DISPLACEMENT AND BREEDING FAILURE RATES

Estimated displacement rate	Assumed reduction in breeding success of displaced birds	Predicted mean no. of birds (\pm 1SD) at 25 years	Mean probability (95% CI) of increase of:				
			> 0%	\geq 10%	\geq 25%	\geq 50%	\geq 75%
0%	-	58013 (\pm 21745)	0.977 (0.968-0.986)	0.914 (0.897-0.931)	0.793 (0.767-0.818)	0.573 (0.541-0.603)	0.354 (0.326-0.383)
50%	100%	52718 (\pm 20142)	0.958 (0.946-0.969)	0.874 (0.853-0.893)	0.719 (0.693-0.745)	0.479 (0.448-0.508)	0.295 (0.268-0.323)
	75%	52917 (\pm 20209)	0.955 (0.942-0.968)	0.872 (0.851-0.893)	0.724 (0.697-0.751)	0.487 (0.456-0.519)	0.297 (0.269-0.327)
	50%	55088 (\pm 20635)	0.966 (0.955-0.977)	0.891 (0.873-0.910)	0.769 (0.744-0.796)	0.522 (0.492-0.552)	0.311 (0.285-0.340)
25%	100%	55216 (\pm 20676)	0.966 (0.955-0.976)	0.910 (0.892-0.927)	0.764 (0.739-0.791)	0.538 (0.509-0.568)	0.318 (0.290-0.350)
	75%	56290 (\pm 20258)	0.972 (0.961-0.981)	0.921 (0.903-0.938)	0.779 (0.753-0.804)	0.546 (0.515-0.577)	0.348 (0.319-0.380)
	50%	57512 (\pm 20735)	0.971 (0.961-0.981)	0.915 (0.898-0.931)	0.792 (0.767-0.816)	0.568 (0.537-0.597)	0.363 (0.332-0.391)

Given that the model predicted an increasing razorbill population, displacement effects are considered in terms of limiting population growth as opposed to causing, or exacerbating,

declines. The assumed displacement has a relatively marked effect compared to effects of displacement on the other species considered in this report. Thus, under the assumption of 100% breeding failure amongst the displaced birds, the reduced probabilities of achieving increases of varying magnitudes are often sufficient to produce non-overlapping 95% CIs with the 'no-impact' scenario (Figure 15B.10). The extent to which the assumed 50% level of displacement may limit population growth is predicted to be greatest for situations of relatively high growth – e.g. for increases of 25-75% displacement decreases the likelihood of achieving such increases by c.6-10% when 100% breeding failure is assumed for the displaced birds (Figure 15B.11). Assuming a 75% breeding failure rate amongst the displaced birds produces a marginal difference only to these predicted effects, although with an assumed 50% breeding failure rate the likelihood of achieving increases of 25-75% decreases by a maximum of 5% (Table 15B.12). Increases of 25-50% in population size are predicted to be likely events under the 'no-impact' scenario (Figure 15B.10).

Effects of displacement in limiting the predicted population growth are sensitive to the displacement level that is assumed, becoming considerably more marked under scenarios of higher potential levels of displacement but being substantially reduced (to 3-4%) under the 25% displacement rate scenario (Figure 15B.11). Displacement is predicted to have small effects only (frequently <1% reductions) on the likelihood of the population achieving moderate to high growth rates when it is assumed that 25% of birds are displaced and 50-75% of these birds fail to breed (Table 15B.12).

Figure 15B.10. The probability of the razorbill population increasing to different levels for the modelled population in the absence of displacement effects (black line) and with the assumed reduction in breeding success resulting from 50% displacement and 100% breeding failure amongst displaced birds (red line). In both cases, 95% CIs shown by thin lines.

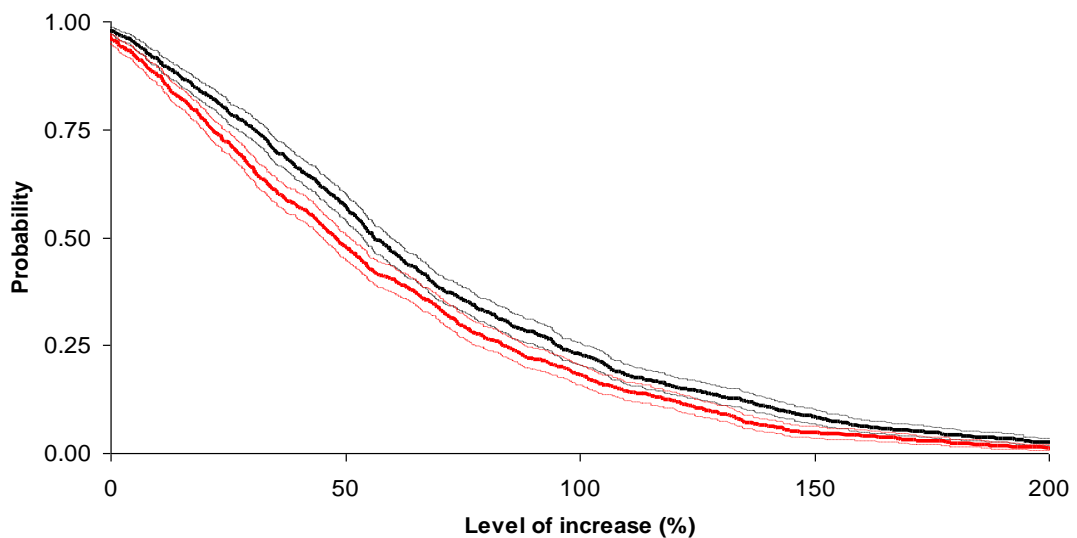
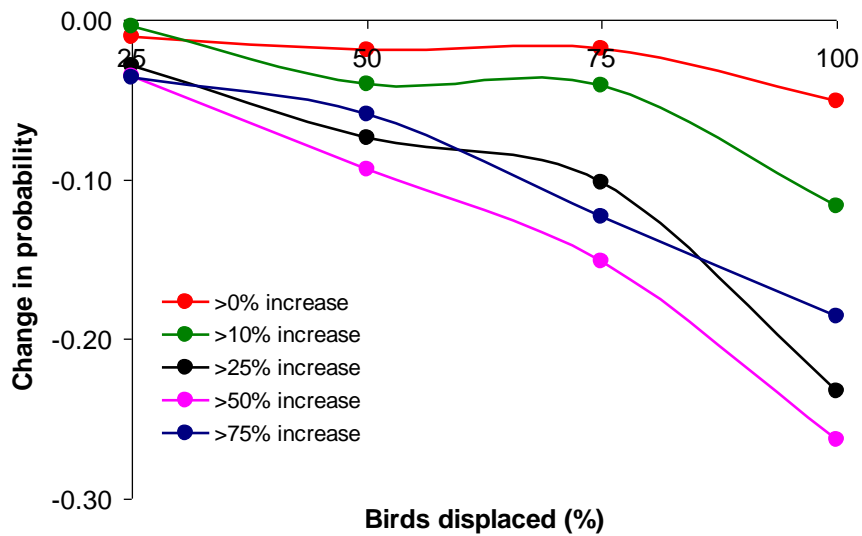


Figure 15B.11. Changes in the probability of the razorbill population increasing to different thresholds for a range of potential displacement levels, relative to that predicted in the absence of displacement. For all displacement levels, 100% breeding failure is assumed amongst displaced birds.

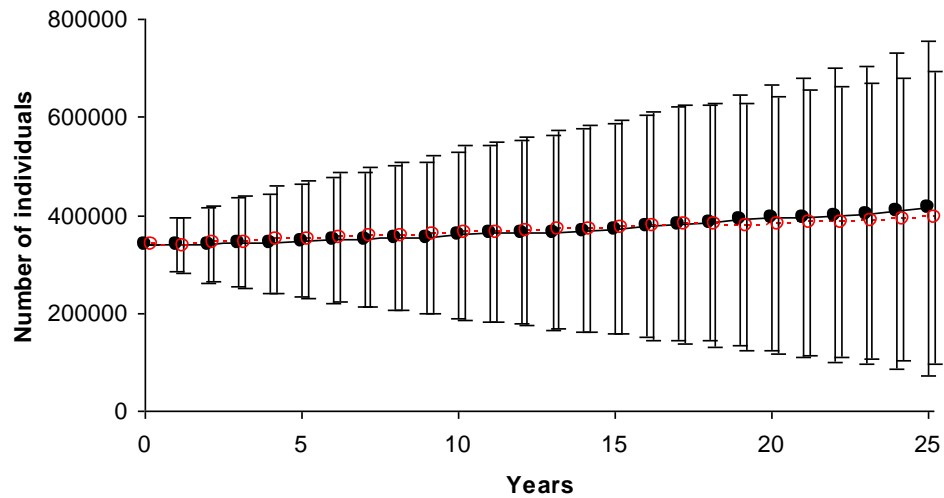


15B.3.5 Puffin

15B.3.5.1 Predicted Trend

The population model for puffin predicted an increase of c.20% over the 25 year period, from a starting population of 338,677 birds to one of 414,670 (Figure 15B.12). This equated to a mean annual growth rate of 1.008. However, there was considerable variability about the mean values for population size, indicating a high degree of uncertainty in these predictions. Data on population trends for puffin in the region come from the Isle of May, where the main puffin colonies within this region occur (Harris & Wanless, 2011). Numbers of puffin on the Isle of May have undergone a long-term increase since the 1950s but with a relatively abrupt and steep decline of c.30% in recent years. This recent decline appears to have been associated with two consecutive winters (2006/07 and 2007/08) of aberrant low adult survival, with adult survival rates returning to more typical levels in the past two years (Harris & Wanless, 2011). Therefore, it is difficult to ascertain whether the recent population declines will be of a short or long-term nature, and hence whether the modelled trend provides a reasonable representation of the actual trend.

Figure 15B.12. Projected trends for the regional puffin population. Solid black symbols represent trend with no wind farm displacement. Open red symbols and dashed line represent trend with estimated displacement (at 50%) from the wind farm incorporated. Mean population sizes \pm 1SD are shown. (Plotted lines are staggered to aid presentation).



15B.3.5.2 Effects of Displacement

Incorporating the effects of displacement (at the assumed 50% level) into the puffin population model reduces the mean annual growth rate to 1.006, giving a population size at the end of the 25 year period of 395,103 (\pm 298,086 SD) – i.e. a reduction of 19,567 birds compared to the ‘no-impact’ scenario (Figure 15B.13).

As with razorbill, displacement effects for puffin are considered in terms of the potential to limit population growth rather than to cause, or exacerbate, declines. The predicted effects of displacement are small, with considerable overlap in the 95% CIs for the probability of attaining varying levels of population increase under the scenarios of 50% displacement and ‘no impact’ (Figure 15B.14). The 50% displacement level has minimal, or no detectable, effects on limiting population growth, at most levels of increase, being greatest (at c.1% reduction in likelihood) for increases of \geq 50% (Figure 15B.14). Impacts on the likelihood of population growth increase under higher displacement levels but remain relatively small, even at assumed displacement of 100%.

Figure 15B.13. The probability of the puffin population increasing to different levels for the modelled population in the absence of displacement effects (black line) and with the assumed reduction in breeding success resulting from 50% displacement (red line). In both cases, 95% CIs shown by thin lines.

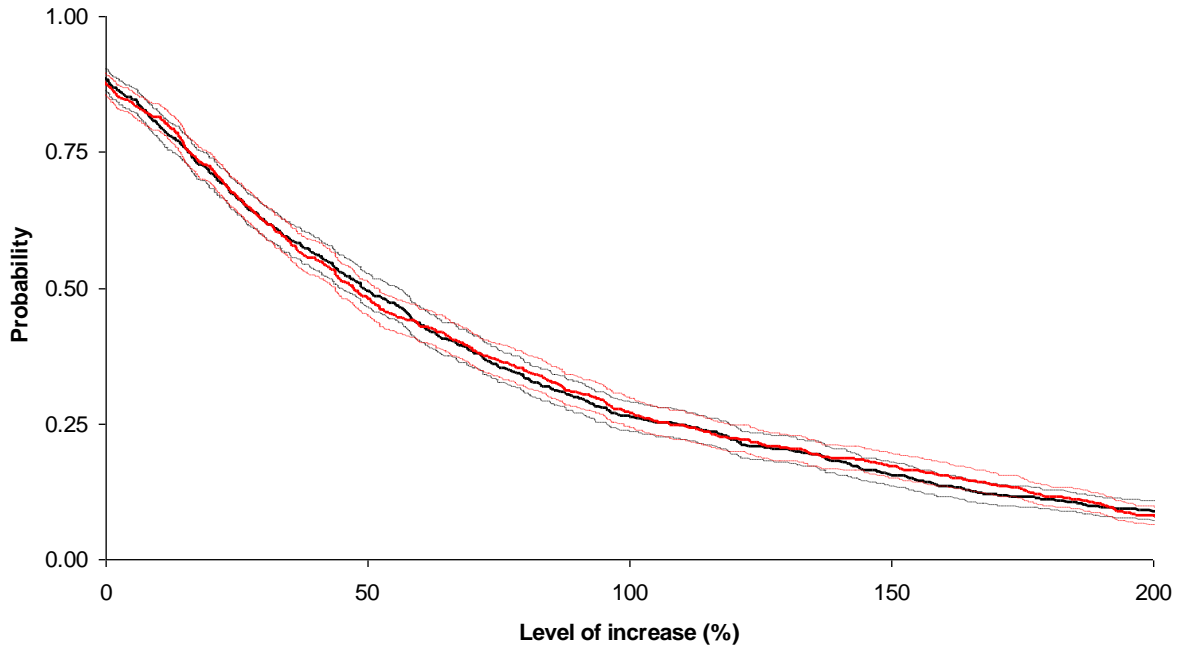
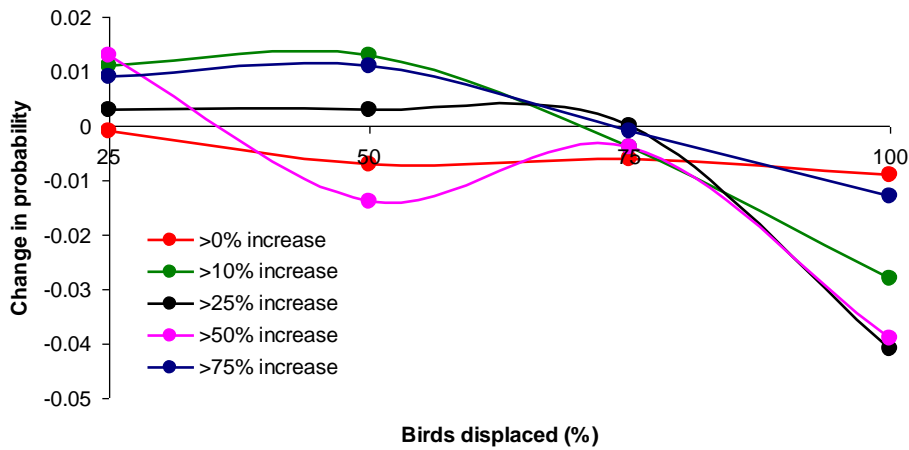


Figure 15B.14. Changes in the probability of the puffin population increasing to different thresholds for a range of potential displacement levels, relative to that predicted in the absence of displacement



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ANNEX 15B.1 – HRA SCREENING REPORT

ANNEX 15B.2 – PREDICTED MEAN POPULATION SIZES WITH STANDARD DEVIATIONS AND MINIMUM AND MAXIMUM VALUES FOR EACH YEAR OF THE 25-YEAR PROJECTIONS FOR THE MAIN PVA SCENARIOS FOR EACH SPECIES

Kittiwake:

Model With no Additional Mortality or Displacement

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	101537	149334.18	176671.8	204009.4	268381
3	75526	131615.3	167011	202406.8	323724
4	66254	124857.18	162783.8	200710.5	330560
5	55743	118145.01	158118.8	198092.5	333308
6	55257	111500.6	153786.4	196072.1	320484
7	47440	105130.55	148996.5	192862.4	364975
8	43358	100042.37	145276.6	190510.7	365963
9	44205	94545.12	141006.5	187467.9	359625
10	37517	89829.85	137592.1	185354.4	432872
11	34405	84959.13	133188.7	181418.2	403116
12	34442	80994.77	129717.8	178440.8	450037
13	27686	77168	126181.1	175194.2	437553
14	25456	73219.15	122346	171472.9	409180
15	25732	68905.44	118924.8	168944.2	434538
16	27380	65599.67	115409.9	165220.1	522778
17	19794	62776.51	112539.4	162302.3	413431
18	20513	59462.37	109551.2	159640	449826
19	17715	56575.2	106221	155866.7	500606
20	14634	53963.27	102949.9	151936.5	490688
21	15011	51143.94	99849.11	148554.3	451194
22	14417	48568.26	97194.84	145821.4	532724
23	13048	46318.9	94446.15	142573.4	427854
24	11144	43921.44	91698.79	139476.1	541630
25	9168	41623.18	89019.85	136416.5	570591

Model With Estimated Collision Mortality Incorporated at 98% Avoidance and All Collisions Assumed to be of Birds from the Regional Breeding Population

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	107352	148355.6	176242.1	204128.6	263019
2	88190	138661.9	169545.5	200429.1	282771
3	74828	127662.2	163555.9	199449.7	301257
4	68142	119781.9	157833.8	195885.7	338044
5	60825	113587.1	153431.3	193275.4	308883
6	51786	107127	148448.6	189770.2	323137
7	49802	100225.5	144723.5	189221.5	323490

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
8	45847	95502.13	139799.4	184096.8	313035
9	44518	89741.67	134926.6	180111.6	311369
10	41926	83575.57	129888.6	176201.7	409880
11	37003	80028.44	126198.7	172368.9	347265
12	37284	76329.87	121836.6	167343.3	324226
13	36935	71567.46	117185.7	162804	315864
14	29249	67242.85	112506.8	157770.7	338476
15	29242	64042.5	108864	153685.4	368830
16	29351	59940.53	106183.9	152427.2	433677
17	25170	57497.49	103525.2	149552.9	332878
18	25906	53903.33	100112.8	146322.3	329315
19	19375	50980.3	97024.88	143069.5	370538
20	20038	48205.82	93534.57	138863.3	368168
21	17764	44986.5	90182.22	135378	306435
22	13512	42348.29	87027.26	131706.2	321337
23	13571	40529.73	83960.8	127391.9	311022
24	16634	38765.38	81588.74	124412.1	310102
25	14618	36942.93	78717.31	120491.7	288597

Model With Estimated Collision Mortality Incorporated at 99% Avoidance and All Collisions Assumed to be of Birds from the Regional Breeding Population

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	110512	147930.2	175959.3	203988.5	254872
2	91387	138325	171934.6	205544.3	284567
3	84016	130682.1	167328.6	203975.2	311067
4	64580	120822	161240	201657.9	356564
5	60011	115988.4	156618.8	197249.2	324502
6	58538	109180.5	152201	195221.5	333014
7	55659	103454.2	148150.6	192847	351944
8	45464	96698.76	142023	187347.2	372058
9	50974	91132.61	138932.3	186732	402152
10	32891	84278.91	133577.5	182876.2	451665
11	32540	82122.98	129688.5	177254	395074
12	28531	77795.32	126912	176028.8	434689
13	29113	73767.18	123130.5	172493.7	436415
14	27155	69168.18	118361.9	167555.5	419462
15	20000	65542.54	114986.1	164429.7	448835
16	19775	61170.41	110619.1	160067.7	436840
17	22920	58103.37	107668.5	157233.6	413389
18	23578	55466.75	104670	153873.3	469507
19	17580	54066.15	101351	148635.7	355474
20	21149	50441.18	98064.78	145688.4	377633
21	18183	47486.62	95236.74	142986.9	354092
22	13291	44579.36	92383.75	140188.1	382991
23	12786	42507.2	90166.35	137825.5	377715
24	12853	40170.44	87653.99	135137.5	418744
25	10631	37699.92	84945.07	132190.2	459889

Model With Estimated Collision Mortality Incorporated at 98% Avoidance and 100%, 50% and 25% of Collisions During the Breeding, Post-breeding and Winter Seasons Assumed to be of Birds from the Regional Breeding Population

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	117440	148686.6	175726.1	202765.5	251649
2	88079	140471.7	171131	201790.2	282891
3	71863	132847.8	166165.3	199482.9	270236
4	73356	124573.1	160937.2	197301.4	292020
5	63609	117105.8	156046.7	194987.6	295682
6	57166	111873.8	152499.2	193124.5	302379
7	51199	105118.4	147695.8	190273.1	304959
8	45021	99103.65	143413.6	187723.5	308426
9	35441	93154.49	138065.7	182976.9	320382
10	41805	88762.84	133833.8	178904.7	293866
11	40936	84667.85	130278.2	175888.6	315978
12	32600	78978.87	125212.2	171445.4	341561
13	30241	76292.1	122165.7	168039.3	322042
14	28388	71810.86	118638.9	165466.9	322168
15	24284	68685.3	114175.2	159665.1	321643
16	25956	64428.35	111411.1	158393.8	318513
17	23888	60618.47	107894.5	155170.5	322917
18	19810	57797.56	103782.7	149767.9	295049
19	21853	54190.51	100024.5	145858.5	296391
20	25183	52013.95	97365.67	142717.4	352332
21	21932	48712.61	95318.33	141924	326049
22	16396	46566.87	91786.85	137006.8	367253
23	17882	44094.52	89213.24	134332	311809
24	15325	41512.56	87402.27	133292	356823
25	11952	39109.84	84530.83	129951.8	374135

Model With Estimated Collision Mortality Incorporated at 99% Avoidance and 100%, 50% and 25% of Collisions During the Breeding, Post-breeding and Winter Seasons Assumed to be of Birds from the Regional Breeding Population

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	110083	149011.4	177182.7	205354	261214
2	87827	138195.5	171255.5	204315.6	291213
3	77301	129547.4	165448	201348.6	339871
4	72212	121324.9	159584.8	197844.7	336928
5	64155	114694	155335.6	195977.2	307538
6	49811	108512.9	150997.2	193481.4	312680
7	43872	102275.1	145439.7	188604.4	341232
8	51601	97657.1	143040.1	188423.1	318866
9	44243	90336.62	137463	184589.5	361255
10	33852	85192.53	133464.2	181735.8	387265
11	39776	80403.46	128781.9	177160.3	397502
12	31095	76947.67	124522.3	172096.9	344951
13	29345	72474.27	122041.4	171608.5	376262
14	23318	68674.95	118355.5	168036	353661
15	23471	64867.3	113906	162944.6	358150
16	21696	60979.95	111090.9	161201.9	325295

17	17058	58469.44	107526.9	156584.3	337123
18	17886	56795.39	103787.7	150780.1	311818
19	19612	52248.69	99938.57	147628.5	329647
20	22125	49974.37	97109.94	144245.5	334255
21	16659	47642.45	93761.93	139881.4	322467
22	16710	44682.39	91867.91	139053.4	347767
23	12876	43645.07	89255.26	134865.5	331988
24	12606	40565.1	86391.11	132217.1	350036
25	12576	37892.45	84319.93	130747.4	315917

Model With Displacement at 30% Level Incorporated

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	181832	181832	181832	181832	181832
1	105229	149141.8	175634.9	202128	280268
2	91017	139681.6	171704.9	203728.3	271965
3	74187	130268.9	166392.4	202515.9	287307
4	70568	122646.5	161745	200843.4	309790
5	50849	116778.1	157105.7	197433.2	299629
6	49235	109953.8	152574.3	195194.9	323823
7	44906	104430.6	148855.7	193280.7	343868
8	46958	99167.42	144283.5	189399.6	320504
9	39104	93744.96	139973.2	186201.5	328704
10	37219	89401.64	136202.8	183003.9	334972
11	28880	84587.03	132877.6	181168.1	358604
12	27781	80005.36	127586.7	175168.1	327358
13	26252	77701.01	125740.6	173780.2	334534
14	20842	72410.69	121577	170743.2	353531
15	24411	69398.99	118583.7	167768.4	329520
16	19116	65470.62	114798.7	164126.8	369921
17	19580	63853.69	112047	160240.3	346708
18	14838	59365.03	107596.4	155827.8	346423
19	21863	57018.39	104099.9	151181.4	329210
20	18604	54084	101295.7	148507.4	311805
21	18384	51101.11	98889.89	146678.7	335076
22	18713	46996.74	96423.09	145849.4	364134
23	18101	44240.47	94185.52	144130.6	353490
24	17067	41493.9	91348.99	141204.1	391361
25	16042	39695.98	88607.97	137520	409584

Guillemot:

Model With No Displacement

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	378112.6	378112.6	378112.6	378112.6	378112.6
1	254868	330681.2	373934.7	417188.3	533282
2	230556	320299.6	370592.3	420884.9	573187
3	232659	309670.3	365747.3	421824.2	595535
4	204632	298206.9	360180	422153	697647
5	217373	293636	358181.1	422726.3	584434
6	195561	285182.7	354585.3	423988	629145
7	174931	275962.1	351345.8	426729.6	681103

8	174005	266694.2	346499.6	426304.9	726864
9	162387	261560.4	342915.1	424269.8	662885
10	145394	253972.7	338797.1	423621.5	730871
11	126866	246767.4	335700.3	424633.2	755067
12	144841	237923.7	328042.6	418161.5	813540
13	136259	233642.1	327606.7	421571.4	814207
14	132422	227748.3	323873.2	419998	751683
15	116022	221831.7	319887.5	417943.2	796250
16	119824	213617.4	315846.1	418074.9	870406
17	97302	209963.2	311574.1	413185	955747
18	119663	206786.7	310529.7	414272.8	849820
19	105503	201204.6	307131.1	413057.6	905248
20	100127	196340.7	302120.7	407900.8	885172
21	94807	191418.9	297916.2	404413.5	952664
22	96535	186667	294942.9	403218.8	919393
23	89504	181099.4	289860.5	398621.5	868047
24	89913	178091.2	288495.9	398900.6	855909
25	83174	172570.2	284950	397329.7	906731

Model With Displacement at 50% Level Incorporated

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	378112.6	378112.6	378112.6	378112.6	378112.6
1	249458	328961.7	373220.4	417479.2	525638
2	229162	315717.1	366876.8	418036.4	540461
3	210011	307839.9	364014.3	420188.8	604374
4	213075	299104.9	358883.5	418662.2	589894
5	156317	289299.8	354630.3	419960.8	701225
6	186333	280672.2	350023.6	419375	732025
7	150370	275895	347054.9	418214.8	768043
8	162136	267302.7	343952.8	420603	797149
9	169055	260076.5	337945.9	415815.3	880447
10	162100	250980.2	331960.9	412941.7	910072
11	142282	241890.7	329471	417051.3	1064081
12	138836	237296.2	324922.1	412547.9	1001919
13	132721	230944.9	321916.2	412887.4	856991
14	119271	226792.1	317689.5	408586.9	974835
15	120995	217564.5	312274	406983.5	975213
16	118854	212821	308151.7	403482.3	791376
17	114567	209116.6	303530.2	397943.8	820910
18	109267	203131.5	301946.7	400761.8	1004771
19	110518	198341.4	298195.3	398049.2	1100008
20	99064	192885.4	293703.2	394521.1	918435
21	97529	187233.6	291234.6	395235.6	886237
22	96508	183796.3	287942.5	392088.6	852815
23	80822	182142.5	284425.9	386709.3	902304
24	78958	177010.9	280032.8	383054.7	929550
25	80373	171334.6	275690.3	380046	918770

Razorbill:

Model With No Displacement

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	28667	35570.57	38548.58	41526.59	45129
2	27021	35160.03	39294.95	43429.87	50530
3	23142	34727.94	39959.65	45191.36	56118
4	22673	34578.84	40752.42	46926.01	59667
5	20157	34250.02	41205.17	48160.32	66146
6	22082	34006.73	41880.15	49753.57	72037
7	23682	33923	42463.07	51003.13	76530
8	22158	33901.21	43095.57	52289.92	74923
9	20245	34055.77	43825.88	53595.99	79735
10	20916	34011.1	44340.31	54669.52	88427
11	20353	34296.76	45267.91	56239.06	99901
12	19248	34254.41	46145.77	58037.13	112018
13	19642	34220.9	46843.24	59465.58	118555
14	18409	34425.21	47817.22	61209.23	137086
15	18288	34449.33	48703.56	62957.79	145351
16	18140	34593.03	49446.23	64299.44	140299
17	18212	34898.03	50409.33	65920.64	161255
18	16911	35179.44	51389.55	67599.67	180118
19	17583	35331.2	52269.64	69208.07	182245
20	14735	35217.22	53322.56	71427.89	207730
21	15690	35374.08	54248.51	73122.94	202998
22	15949	35290.4	55115.37	74940.34	229804
23	17641	35274.26	56113.29	76952.33	253760
24	17546	35631.76	57112.13	78592.49	245326
25	16488	36268.19	58013.04	79757.89	232672

Model With Displacement at 50% Level Incorporated and 100% Breeding Failure of Displaced Birds Assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	30342	35581.5	38439.02	41296.55	44223
2	26167	34845.14	38979.37	43113.61	50239
3	25000	34540.94	39470.64	44400.35	54074
4	22949	34167.23	40107.15	46047.07	61241
5	23889	34119.97	40667.95	47215.93	60691
6	19712	33707.23	41102.86	48498.48	63439
7	20823	33483.68	41621.03	49758.38	66207
8	19803	33222.33	42072.18	50922.03	74356
9	19881	32833.36	42388.56	51943.76	76160
10	19689	32744.92	43014.45	53283.98	81689
11	19357	32831.67	43752.04	54672.42	94231
12	16838	32730.2	44387.13	56044.05	89543
13	16081	32693.93	45108.8	57523.67	92296
14	15084	32672.75	45848.88	59025.01	99778
15	15009	32637.58	46441	60244.43	101764
16	14760	33019.13	46923.55	60827.96	107598
17	15684	33178.35	47686.99	62195.64	105198

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
18	17641	33058.12	48234.81	63411.5	111385
19	18777	33190.54	48969.39	64748.25	111227
20	17018	33114.4	49715.77	66317.14	116972
21	16974	32988.65	50276.39	67564.13	118627
22	17179	32885.23	50970.72	69056.2	135413
23	16285	32811.81	51567.88	70323.95	121309
24	15992	32660.51	52152.29	71644.08	127273
25	14667	32575.69	52717.64	72859.59	127741

Model With Displacement at 50% Level Incorporated and 75% Breeding Dailure of Displaced Birds Assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	27776	35638.47	38536.34	41434.21	44452
2	27141	35034	39192.13	43350.26	50098
3	20857	34686.7	39752.76	44818.82	54780
4	22262	34269.2	40205.59	46141.98	58756
5	19699	34068.42	40851.96	47635.49	64459
6	16134	33609.49	41217.81	48826.13	70035
7	14955	33326.3	41764.18	50202.06	76466
8	14391	33153.98	42394.41	51634.85	77916
9	12527	32945.63	43030.77	53115.9	80906
10	13071	32965.43	43664.56	54363.68	88714
11	12800	32734.62	44083.09	55431.56	99402
12	12772	32630.69	44730.08	56829.48	105238
13	13783	32312.99	45240.07	58167.16	117542
14	14491	32339.57	45898.23	59456.89	109218
15	14115	32693.46	46743.72	60793.97	117118
16	14860	32963.84	47263.94	61564.05	109859
17	13895	32813.82	47714.54	62615.26	126826
18	13385	32712.35	48302.53	63892.71	122550
19	11492	32487.25	48936.95	65386.65	130121
20	12014	32620.43	49716.11	66811.78	129132
21	11758	32655.89	50224.72	67793.56	134847
22	10666	32717.3	50859.63	69001.96	127875
23	10169	32631.75	51720.58	70809.41	143313
24	10466	32715.01	52334.22	71953.43	142770
25	10261	32707.83	52916.73	73125.62	142185

Model with Displacement at 50% Level Incorporated and 50% Breeding Failure of Displaced Birds assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	25650	35553.19	38478.6	41404.01	44426
2	25493	34953.31	39026.68	43100.06	51055
3	22195	34824.21	39738.64	44653.07	55620
4	21633	34526.43	40414.61	46302.8	62368
5	18465	34354.84	41001.94	47649.04	69153
6	21413	34354.36	41855.48	49356.6	74182
7	20211	34179.38	42353.85	50528.33	71265
8	19842	34161.66	42947.07	51732.47	76550

9	18236	34157.57	43557.01	52956.45	78977
10	16817	34049.51	44058.45	54067.39	83293
11	17280	33981.37	44633.24	55285.1	86623
12	17089	33963.91	45224.17	56484.42	92202
13	18075	33884.64	45951.21	58017.78	100551
14	18315	33691.06	46682.33	59673.59	114039
15	14981	33472.27	47255.65	61039.04	127445
16	16080	33426.32	47953.4	62480.48	132595
17	14789	33432.49	48618.61	63804.74	147705
18	14953	33395.82	49515.98	65636.14	162808
19	11741	33237.54	50294	67350.46	173877
20	12230	33659.46	51162.59	68665.73	171010
21	12692	33805.4	51835.94	69866.47	181315
22	12382	33996.9	52617.98	71239.07	160569
23	13235	33986.93	53500.37	73013.8	183800
24	12316	34217.98	54278	74338.03	165388
25	12420	34453.38	55088.29	75723.2	159795

Model with Displacement at 25% level Incorporated and 100% Breeding Failure of Displaced Birds Assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	28873	35835.9	38619.88	41403.85	44951
2	26923	35028.75	39102.97	43177.18	49621
3	25182	34547.25	39720.73	44894.2	54782
4	23970	34393.81	40287.3	46180.78	59986
5	21984	34351.13	41075.41	47799.68	62955
6	21435	34234.17	41734.69	49235.21	65723
7	21318	34157.55	42437.83	50718.1	73825
8	19874	34234.16	43097.78	51961.39	72315
9	21143	34187.53	43797.63	53407.73	76981
10	20543	33974.16	44554.53	55134.9	84961
11	20496	33995.06	45230.14	56465.22	89823
12	21623	34104.25	45789.75	57475.24	96907
13	18658	34138.13	46459.11	58780.09	96972
14	18252	33831.93	47029.24	60226.55	104008
15	17449	33869.4	47599	61328.61	109440
16	17824	33935.22	48327.89	62720.55	108873
17	17318	33991.51	49217.02	64442.54	119961
18	16610	33852.86	49958.51	66064.15	131836
19	15682	33706.31	50361.17	67016.04	124229
20	14726	33912.69	51201.77	68490.86	129783
21	15206	34221.35	52137.41	70053.47	129343
22	14138	34377.33	52901.29	71425.25	135728
23	15802	34560.18	53746.72	72933.25	147503
24	14813	34473.26	54469.06	74464.85	146780
25	13584	34540.57	55216.15	75891.72	147164

Model With Displacement at 25% Level Incorporated and 75% Breeding Failure of Displaced Birds assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	28925	35621.18	38491.66	41362.14	44142
2	24588	35024.41	39097.36	43170.31	49299
3	24343	34888.39	39774.25	44660.12	54027
4	21398	34467.17	40281.28	46095.4	58849
5	22088	34393.96	40924.5	47455.04	65820
6	20202	34464.22	41721.62	48979.03	67936
7	20720	34447.54	42457.69	50467.85	75923
8	22158	34501.22	43079.9	51658.58	72225
9	22452	34622.62	43905.51	53188.4	78943
10	21152	34371.27	44387.79	54404.3	82568
11	19243	34450.72	45100.76	55750.8	90516
12	19508	34420.06	45847.93	57275.79	90844
13	16615	34278.13	46397.75	58517.38	94930
14	17982	34519.02	47232.47	59945.92	103033
15	17755	34633.19	48194.81	61756.43	101338
16	17699	34683.52	48865.1	63046.69	104144
17	18012	34805.68	49493.51	64181.34	113392
18	17267	35063.21	50335.74	65608.26	107697
19	16057	35250.92	51183.1	67115.27	118136
20	16047	35280.36	51787.03	68293.7	133389
21	16267	35272.87	52606.71	69940.56	131234
22	17609	35588.55	53416.06	71243.58	128899
23	18097	35843.33	54499.23	73155.12	140281
24	17040	35814.93	55374.47	74934.02	148868
25	15498	36031.93	56290.1	76548.28	157781

Model With Displacement at 25% Level Incorporated and 50% Breeding Failure of Displaced Birds Assumed

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	37980.33	37980.33	37980.33	37980.33	37980.33
1	27898	35506.24	38470.4	41434.55	44768
2	26628	35104.4	39312.99	43521.59	49882
3	25124	35040.21	40028.03	45015.86	54108
4	25032	34811.53	40633.46	46455.38	59865
5	23420	34564.17	41108.34	47652.51	67533
6	22535	34422	41951.45	49480.9	71183
7	21188	34408.63	42531.34	50654.04	75652
8	18769	34385.29	43124.9	51864.52	75163
9	20584	34511.39	43926.21	53341.02	78836
10	20271	34469.56	44561.6	54653.64	83556
11	21213	34777.16	45441.83	56106.5	91082
12	20277	35118.72	46240.75	57362.77	90779
13	20822	35073.61	47095.61	59117.61	93558
14	19589	35245.79	47933.89	60622	96217
15	17951	35207.57	48799.61	62391.65	101186
16	18398	35501.05	49660.74	63820.42	106321
17	17958	35441.72	50414.86	65388	115274

18	18233	35624.17	51318.06	67011.96	120885
19	18506	35828.14	51912.96	67997.77	120302
20	18286	35919.61	52857.11	69794.61	125965
21	16204	36022.51	53808.18	71593.85	120560
22	18591	36214.88	54690.67	73166.45	130501
23	18330	36342.1	55529.58	74717.06	139769
24	14067	36511.05	56494.17	76477.29	141620
25	14869	36777.22	57512.16	78247.09	155866

Puffin:

Model With No Displacement

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	338676.5	338676.5	338676.5	338676.5	338676.5
1	166578	283400.2	338506.8	393613.3	458544
2	152876	262066.5	338528.7	414990.8	555941
3	125207	252581.1	343937.8	435294.5	659971
4	110239	241331.4	342673.6	444015.8	783847
5	93544	232527.2	347744.3	462961.5	786260
6	65142	221417.4	348825.8	476234.2	855925
7	73480	213006.6	350741.4	488476.2	877807
8	51751	207546.4	353704.5	499862.6	966736
9	61082	199465.6	354159.7	508853.8	1063122
10	54116	189414.9	358835.3	528255.7	1264328
11	41358	183157.7	362710.2	542262.7	1286850
12	27746	176965.4	365388.2	553811	1541108
13	37557	166504.2	364595.5	562686.9	1508853
14	42566	160037.8	368499.8	576961.8	1638154
15	40590	157068.4	372519.7	587971	1622022
16	32598	150027.3	377080.7	604134.2	1641636
17	34526	143353.4	381657.1	619960.8	1798565
18	25953	142799.4	382993.7	623188	1926934
19	25900	134955.8	389849.6	644743.5	2036694
20	22142	124645.7	394532.6	664419.5	2230666
21	20557	110599	395647.8	680696.6	2731327
22	18704	100205.4	399677.6	699149.8	3129150
23	19251	97653.26	400271.9	702890.6	2810047
24	16846	84882.87	407635.7	730388.5	3438886
25	19012	73329.25	414670.1	756010.9	3999250

Model With Displacement at 50% Level Incorporated

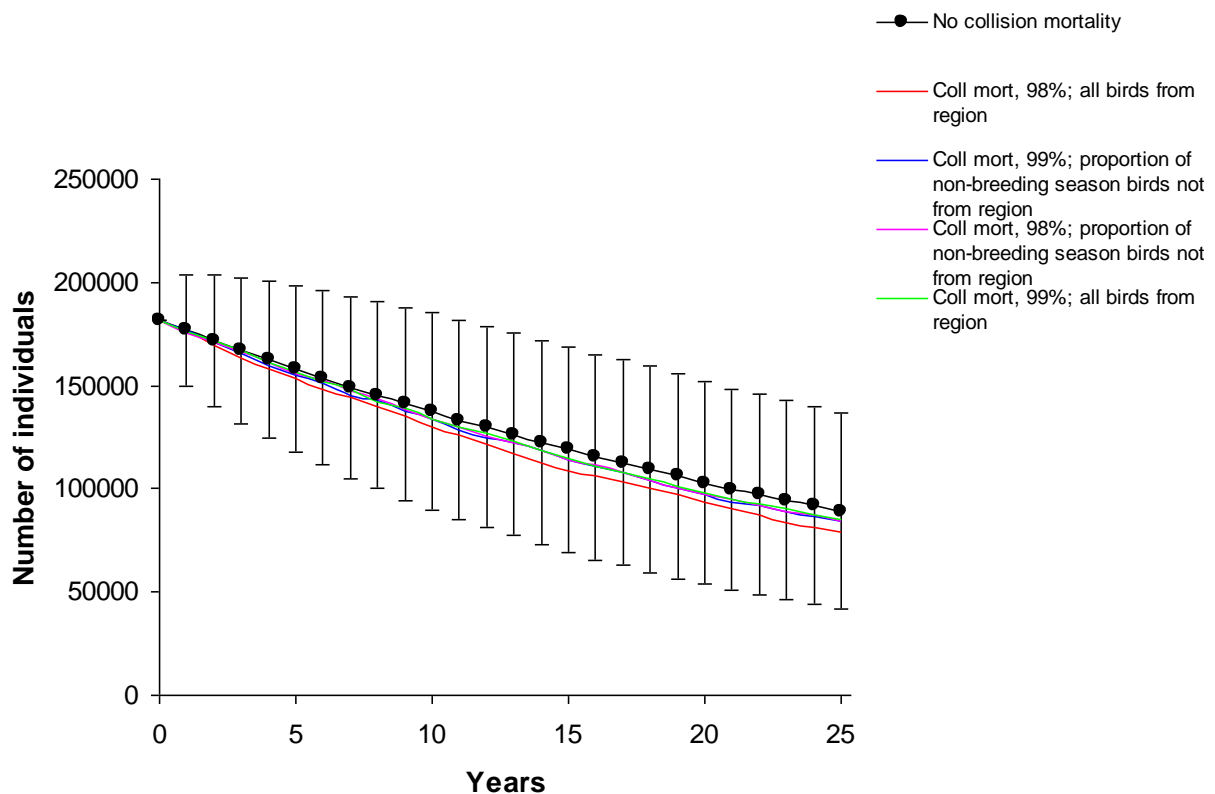
Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
0	338676.5	338676.5	338676.5	338676.5	338676.5
1	171303	281048.2	337104.6	393161	455324
2	116838	264106.9	342277.1	420447.3	567192
3	110371	249393.2	343930.7	438468.3	631398
4	86375	240846.5	349650.6	458454.8	756085
5	86713	229918.4	350996	472073.7	917092
6	83610	223572.1	354740.5	485908.9	989787
7	69507	214465.6	355857.7	497249.9	1032754
8	52018	205745.7	357071.7	508397.7	1042973

Time	Minimum	-1 S.D.	Average	+1 S.D.	Maximum
9	62070	198545.5	360497.6	522449.6	1080829
10	73465	186821.1	363910.1	540999.2	1209711
11	56777	181654.4	365493.3	549332.2	1358459
12	60379	175759.3	368112.8	560466.3	1805039
13	52677	168748.2	371730.8	574713.4	1461415
14	55271	161007.9	372467.4	583926.8	1550058
15	43551	156250.1	375539.4	594828.6	1441716
16	43932	145886.6	378533.1	611179.5	1564624
17	44439	138506.4	380997.1	623487.8	1506422
18	43218	129386.1	379528.2	629670.2	1863124
19	37794	124560.4	377136.9	629713.4	1578395
20	40950	116460.8	380057.4	643654.1	1720780
21	35776	113483.8	383995.1	654506.4	1748431
22	32611	108323.6	385814.3	663305.1	1980690
23	28454	106304.7	387946.5	669588.4	1806290
24	24319	103459.4	391153.5	678847.7	2082065
25	25466	97017.08	395102.6	693188.2	2049953

ANNEX 15B.3 – PLOTS OF PREDICTED TRENDS FOR THE MULTIPLE COLLISION RISK AND DISPLACEMENT SCENARIOS ASSESSED FOR KITTIWAKE AND RAZORBILL

Kittiwake – PVAs Assessing Predicted Collision Risk Mortality

Figure 15B.3.1. Projected trends for the regional kittiwake population in the absence of any wind farm impacts and with predicted mortality from four different collision risk scenarios incorporated (i.e. collision risk mortality estimated for 98% and 99% avoidance, assuming (i) either all birds from all seasons are from the regional breeding population or (ii) 100%, 50% and 25% of birds recorded during the breeding, post-breeding and winter seasons, respectively, are from the regional breeding population; see 15B.3.2.2). Mean population sizes at each year with associated SDs are shown for the 'no-impact' scenario but only the trend lines are shown for each of the collision mortality scenarios.



Razorbill – PVAs Assessing a Range of Displacement Scenarios

Figure 15B.3.2. Projected trends for the regional razorbill population in the absence of any wind farm impacts and with the predicted reduction in breeding success resulting from six different displacement scenarios incorporated (i.e. 50% and 25% displacement assuming 100%, 75% and 50% breeding failure amongst the displaced birds for each displacement level - see 15B.3.4.2). Mean population sizes at each year with associated SDs are shown for the 'no-impact' scenario but only the trend lines are shown for the displacement scenarios.

