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PBR for Flamborough Head and Filey Coast pSPA populations of Kittiwake and Gannet

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CONTENTS

EXECUTIVE SUMMARY

Estimated sustainable mortality thresholds for the Flamborough Head and Filey Coast pSPA populations of kittiwake and gannet calculated using the Potential Biological Removal (PBR) method are presented. The PBR method is discussed with reference to its intended purpose and the population modelling theory on which it is based.

Recent applications of PBR for these species are reviewed and consideration is given to the parameters used. The basis for the selection of parameter values for use in the current PBR are discussed, drawing on both the previous examples and available demographic data.

On the basis of this review, using parameters which lie within the precautionary ranges proposed for PBR, the annual mortality threshold estimated for the total population of kittiwake was calculated as 2,148 and the total population of gannet was 659. The breeding adult components of these estimates are 1,718 and 503 respectively.

1. INTRODUCTION

Potential Biological Removal (PBR) is a method for estimating the number of additional mortalities a population can sustain annually with no more than a 5% probability that the population will be reduced below its Maximum Net Productivity Level (MNPL). The approach was developed for marine mammals as a means to set limits on allowable by-catch by fisheries (Wade 1998) and has since been adopted for estimating sustainable levels of seabird mortality (Dillingham and Fletcher 2008).

This report provides the following:

- Introduction to the PBR model, recommendations from the source literature for parameter values and a summary of its theoretical basis;
- A review of recent applications of PBR, focussed on kittiwake and gannet (but including other seabird species for context as appropriate);
- A review of the responses from Statutory Nature Conservation Agencies (SNCAs) on PBRs used in support of offshore wind farm applications; and,
- Presentation of PBR for kittiwake and gannet, informed by the preceding reviews.

2. PBR Model

PBR was developed by Wade (1998) as a simple means to estimate levels of incidental harvest of marine mammals which would permit populations to be maintained at, or restored to, an optimum sustainable size, and which can be computed even in the absence of demographic data about the population in question (Cooke et al. 2012).
The PBR equation is:

$$PBR = N_{min} \times \frac{R_{max}}{2} \times F_R$$

[Eqn.1]

Where:

PBR = the number of additional animals which can be removed safely;
N_{min} = the minimum population estimate;
R_{max} = the maximum net recruitment rate; and
F_R = the recovery factor.

2.1 Estimating N_{min}

Counting populations is extremely challenging, hence population sizes are often only presented as a single value with no estimate of precision. To acknowledge this uncertainty in population estimates (and thus ensure the outputs are precautionary), during development of PBR, Wade (1998) conducted simulations on the sensitivity of results to the value of N_{min} used. This led to a recommendation that the lower 60th percentile (~ p = 0.2) of the assumed population distribution be used. This was further modified with an estimate of the coefficient of variation (Dillingham and Fletcher 2008):

$$N_{min} = \widehat{N} e^{(Z_p CV_{\widehat{N}})}$$

[Eqn.2]

Where:

$\hat{N}$ = population estimate;
Z_p = the *p*th standard normal variate; and,
$CV_{\hat{N}}$ = coefficient of variation for $\hat{N}$

The value for Z_p, at p = 0.2 is -0.842 and $CV_{\hat{N}}$ is typically set at 10%.

2.2 Estimating R_{max}

Maximum rates of population growth are predicted to occur at small population densities, and are rarely observable in nature. Using an allometric relationship, Niel and Lebreton (2005) derived a method to estimate the maximum population growth rate (λ_{max}) using only adult survival (s) and age at first reproduction (α):

$$\lambda_{max} = \frac{(s\alpha - s + \alpha + 1) + \sqrt{(s - s\alpha - \alpha - 1)^2 - 4s\alpha^2}}{2\alpha}$$

[Eqn.3]

R_{max} is then found as:

$$R_{max} = \lambda_{max} - 1$$

[Eqn.4]

2.3 Estimating F_R

The final parameter used to calculate PBR is F_R, the recovery factor, which can (theoretically) take any value between 0.1 and 1 (or higher). This parameter was included to add an extra level of precaution to PBR and to acknowledge variations among species' conservation status (Dillingham and Fletcher 2008). In the original description of PBR there is discussion regarding the inclusion of F_R (to allow for potential and 'other' uncertainties; so-called *unknown unknowns*). Suggested values to use were 0.5 for healthy populations, while 0.1 was reportedly used for marine mammal species in the U.S. classed as endangered (Wade 1998). Dillingham and Fletcher (2008) proposed using PBR for birds and made the connection between IUCN (International Union for the Conservation of Nature and Natural Resources) criteria; 'least concern', 'near threatened', 'vulnerable', 'endangered' or 'critically endangered'. They suggested that it 'may be reasonable to set':

- F_R = 1.0 for populations of 'least concern' species that are known to be increasing or stable;
- F_R = 0.5 for populations of 'least concern' species that are declining or of uncertain trend;
- F_R = 0.3 for populations of 'near threatened' species; and,
- F_R = 0.1 for populations of 'vulnerable' and 'endangered' species.

The rationale for an F_R of 0.1 for vulnerable and endangered species is that PBR estimates are set at levels which ensure that the time for population recovery to MNPL is not increased by more than 10% (Cooke et al. 2012).

3. Review of recent examples of kittiwake PBR parameters used for offshore wind farm assessments

PBRs have been reviewed for several recent offshore wind farm assessments. Kittiwake parameters are provided in Table 1.

Table 1. Kittiwake PBR parameters reported in relation to offshore wind farm assessments.

Wind Farm	Proposer	Colony	Colony size (AON)	N_{min} percentile / CV used	N_{min}	Adult survival	Age 1st breeding	F_R	PBR
Triton Knoll	RWE	FHBC	37,617	NA	75,234	0.941	4	0.1	381
Triton Knoll	NE	FHBC	37,617	0.2 / 0.5	49,383	0.941	4	0.1	250
EA One	NE	FHBC	37,617	0.2 / 0.1	69,159	0.941	4	0.1	350
Hornsea	Smart Wind	FHFC	44,520	0.2 / 0.1	81,849	0.9	4	0.2	1023
Atlantic Array	RWE	Lundy	302	0.2 / 0.1	555	0.809	3	0.1	5.5

3.1 N_{min}

Previous values

For the east coast wind farms in Table 1 (Triton Knoll, EA One and Hornsea) the kittiwake population assessed in each case was the Flamborough Head and Bempton Cliffs (FHBC) SPA. For Triton Knoll, RWE simply doubled the number of breeding pairs and used this (N_{min} = 75,234; Triton Knoll 2012). In their response, Natural England applied the correction proposed by Wade (1998) and detailed in 2.1 above, however a precautionary CV of 0.5 was used (N_{min} = 49,3873; Natural England 2012). This precaution was later revised by Natural England for the EA One response (Natural England 2013), when a CV of 0.1 was employed (N_{min} = 69,159). In all other cases the same N_{min} adjustment was applied. However, for the Hornsea wind farm, Smart Wind were advised by Natural England to undertake their assessment against the proposed extension: Flamborough Head and Filey Coast (FHFC) pSPA, and therefore to use a slightly higher AON estimate of 44,520 which included the colonies within the proposed SPA extension (N_{min} = 81,849; Smart Wind 2013a).

Value proposed for current assessment

The first complete census of kittiwake breeding colonies in Britain and Ireland was conducted in 1969-70 and recorded 30,800 pairs at the Flamborough Head and Bempton Cliffs colonies. By 1979 the colony had increased to 83,000 pairs (an average increase of 11.6% per year) and remained around this level at the time of the next complete census in 1985-87 (85,095 pairs). By the time of the next complete census in 2000 the colony had declined to 41,971, and the most recent count in 2008 indicates the population has remained around this level at 37,617 pairs (http://jncc.defra.gov.uk/pdf/UKSPA/UKSPA-A6-87.pdf accessed 27/11/2013). The recently proposed extension to the SPA (Flamborough Head and Filey Coast pSPA) includes some additional colonies which bring the estimated number of pairs to 44,520 (Natural England recommended this figure to Forewind and Smart Wind for their assessments).

Estimated numbers of collisions with offshore wind turbines are based on observations of birds of all age classes, not just breeding adults. Hence, to ensure the collision estimate and the PBR derived mortality threshold are compatible, it is necessary for both to be based on the same demographic groups. This was undertaken here by calculating the total population size associated with the number of breeding pairs. Two adjustments were applied, accounting for the presence of immature (pre-breeding age) birds and breeding adults taking a 'sabbatical' year respectively. Dillingham and Fletcher (2011) presented a modification to the PBR method to accomplish this adjustment for species with minimal data. However, in the current instance there are sufficient demographic data available to permit a more straightforward correction of population size.

The only estimate of the proportion of adults which breed in any given year which was found in the published literature was for a colony in north-west France. At this colony, the proportion of breeding adults was more or less constant over a 12 year period at approximately 0.93, during which time the population was more or less stable in size (Cam et al. 1998). Therefore, in the absence of alternative estimates, and on the grounds that the FHFC population has also been more or less stable during the last decade, this value was used to estimate the total number of additional breeding age adults at risk of collision. It should also be noted that this is a comparatively low rate of non-breeding compared with those estimated for other gull species (c. 30-40%; Calladine and Harris 1996; Kadlec and Drury 1968; Pugesek and Diem 1990; Samuels and Ladino 1984) and hence is likely to be quite conservative.

A population model of the FHFC kittiwake population generated estimates of the proportion of breeding adults (birds 4 years old and older) in the population of between 0.6 and 0.68 (Smart Wind 2013b), giving an average of 0.64. While this implies that 0.36 of the population are immature birds, not all of these individuals will be present in the area and are therefore at risk of collision. Wernham et al. (2002) reported that some young birds probably remain on the other side of the Atlantic for two years or more, but from the age of three a significant proportion return to their natal colonies. Therefore, it has been assumed that 50% of immature birds are present in the colony area, giving an immature proportion of 0.18. This value has been used to account for their presence in the population for the purposes of setting a PBR value.

The calculation of total population size was thus:

$$\begin{aligned} Total\ N = &\ (2 \times AON) + \left(2 \times AON \times\ (1 - breeding\ proportion)\right) \\ &+ \left(2 \times AON \times (1 - breeding\ adult\ proportion)\right) \\ Total\ N = &\ (2 \times 44520) + \left(2 \times 44520 \times\ (1 - 0.93)\right) + (2 \times 44520 \times 0.18) \\ Total\ N = &\ 111{,}300 \end{aligned}$$

[Eqn.6]

As per PBR methods, the lower 60th percentile of Total N, with a CV of 10%, was calculated, **giving an N_{min} of 102,312 for use in the PBR for the FHFC pSPA population**.

In addition the PBR based on just the number of breeding pairs (44,520) has been calculated, again using equation 2 to calculate N_{min}. This second PBR is applicable to just the breeding adult component of the population.

3.2 Adult survival

Previous values

Adult survival for Triton Knoll and EA One was quoted as 0.941, which was the rate provided on the BTO Bird Facts webpage (http://blx1.bto.org/birdfacts/results/bob6020.htm, accessed 26/11/2013). However, this figure has been used in error on the above website, and in fact refers to a rate which was estimated to be theoretical survival rate that would be required in order to balance a population model (Frederiksen et al. 2004). As such it is higher than any published estimate (Frederiksen et al. 2005; NB: this error on the web page was brought to the attention of the BTO and the figure has been revised to 0.882 as of 16/12/2013). For Hornsea, a rate of 0.9 was used, taken from estimates calculated for use in the FHFC population model (Smart Wind 2013b), while Atlantic Array used a rate from a study on Skomer of 0.81.

Value proposed for current assessment

As can be seen, a wide range of adult survival values have been used. Frederiksen et al. (2005) provide a review of published adult survival rates from studies of nine kittiwake colonies, with values ranging from 0.801 to 0.933. Rather than pick any single study from these, it was considered that the most robust approach would be to take the average across these studies (0.865). **Thus, a rate of 0.865 is suggested to be the most robust estimate to use in PBR for the FHFC pSPA population.** This value is also consistent with data from the two closest populations where kittiwake adult survival has been monitored: North Shields, and the Isle of May (Coulson and Wooller 1976; Coulson 2011; Frederiksen et al. 2005).

3.3 Age at first breeding

Previous values

Age at first breeding was defined as 4 in all examples with the exception of Atlantic Array, where a value of 3 was used, from a study on Skomer.

Value proposed for current assessment

A value of 4 is considered appropriate to use for the PBR of the FHFC pSPA population, consistent with data from the nearby colony at North Shields (Wooller and Coulson 1977; Coulson 2011).

3.4 Recovery rate F_R

Previous values

The recovery rate (F_R) used in all cases in Table 1 was 0.1, with the exception of Hornsea where a value of 0.2 was used.

Value proposed for current assessment

In relation to F_R, the basis of all advice on the choice of appropriate values to use for seabirds is cited as Dillingham and Fletcher (2008), where it is stated that (emphasis added):

> *The recovery factor f is selected based on a species' population status, with a value of 0.1 suggested for threatened or endangered species (Wade, 1998; Taylor et al., 2000; Niel and Lebreton, 2005). BirdLife International maintains the International Union for the Conservation of Nature and Natural Resources (IUCN) population status for birds. Birds are classified according to IUCN criteria (IUCN, 2001) as 'least concern', 'near threatened', or 'threatened'. 'Threatened' species are further classified as 'vulnerable', 'endangered', or 'critically endangered'. Without further information, <u>it may be reasonable to set f = 0.5 for 'least concern' species, f = 0.3 for 'near threatened', and f = 0.1 for all threatened species. A value of f = 1.0 may be appropriate for 'least concern' species known to be increasing or stable.</u>*

The IUCN 'threatened' category is further sub-divided into 'vulnerable', 'endangered' and 'critically endangered' categories. These three classes of threatened status extend from species facing a high risk of extinction in the medium term (vulnerable) to those facing an extremely high risk of extinction in the immediate future (critically endangered). In the above PBR proposal it is notable that an F_R value of 0.1 is proposed for all species classed as threatened, despite the fact that this value needs to cover species with very different conservation classifications. If 0.1 is suitable for critically endangered species it is surely too low for vulnerable ones, or if it is suitable for vulnerable ones it must be putting critically endangered ones at an unnecessary risk of further declines.

All British seabird species are classed as being of 'least concern' in the IUCN classification, which is used for widespread and abundant species. In order to determine appropriate F_R values for SPA populations, Natural England provided the following response:

> *One parameter within the model is termed F; this is a „recovery" factor, and is designed to reflect the level of concern about the population. Where F is small, the safe threshold estimated by PBR is lower; thus, it is appropriate to use smaller F values for depleted populations. Natural England advised a precautionary F value of 0.1 within PBR modelling, which allows the population to grow to a level close to that achieved in a „no harvest" scenario, and with minimal delay. <u>This is appropriate for a depleted protected population, such as in this case (Dillingham & Fletcher 2008)</u> and was used by the Applicant (Triton Knoll).*

[Natural England 2012, underlining added].

By advocating a value of 0.1, Natural England are equating the kittiwake population of FHFC pSPA to a 'threatened' species as per IUCN definitions, the lowest category of which is 'vulnerable', defined by the IUCN as:

> *likely to become Endangered unless the circumstances threatening its survival and reproduction improve*

and,

> *is facing a high risk of extinction in the wild in the medium-term future*

In order to be classed as vulnerable by the IUCN a species needs to meet one of the following criteria:

1. Population reduction (20% over the last 10 years or 3 generations);
2. Predicted population reduction (20% within the next 10 years or 3 generations);
3. Spatially restricted (extent of occurrence less than 20,000km^2)
4. Population less than 10,000 mature individuals; or,
5. Predicted probability of extinction is at least 10% within 100 years.

Thus, in stating that British seabird SPA populations in general, and kittiwake in particular, should be assigned an F_R of 0.1 for estimating PBR, Natural England are suggesting that kittiwake are effectively a threatened species and that as such at least one of the above (points 1 to 5) applies. While it could be argued that the FHBC population is spatially restricted (point 3 above) this requires that the SPA population is treated as completely isolated, and ignores the fact that this is a very widespread and migratory species which shows high rates of immigration between colonies (Coulson 2011) so represents a large meta-population rather than a small isolated population. The colony peaked at approx. 80,000 pairs in the mid-1980s, having increased from around 30,000 pairs in 1970 and decreased again to around 40,000 pairs by 2000. However the colony has since remained around this level, and has not experienced a 20% decline in the last 10-12 years. Furthermore, kittiwake is not listed on Annex 1 of the Birds Directive. Thus, SPA designation is not on the basis of conservation concern, but rather due to their migratory nature. As such, application of a much higher level of IUCN conservation status (as inferred from an F_R value of 0.1) than the species warrants is an extremely precautionary approach.

In light of the above, and the recent use of an F_R value of 0.3 for another SPA gull species (great black-backed gull at East Caithness Cliffs SPA), it is considered that, at most, the FHBC kittiwake population could be considered to be 'near threatened' and therefore a more appropriate value for F_R is 0.3 (Dillingham and Fletcher 2008). Thus, while still retaining a high level of precaution, **an F_R value of 0.3 may be considered appropriate as a highly precautionary value for the FHFC pSPA kittiwake population**. However, for illustration purposes other values are also presented in the results.

Following the original argument presented by Dillingham and Fletcher (2008) would result in an F_R value of 0.5 being considered appropriate if the kittiwake colony is considered to be in decline, or 1.0 if it is considered to be stable or increasing. Natural England's consideration of kittiwake as equivalent to an 'endangered species' so meriting an F_R value of 0.1 is clearly inappropriate and contradicts the clear recommendations in Dillingham and Fletcher (2008).

4. PBR for the FHFC pSPA Kittiwake population

The PBR parameters for kittiwake, estimated as detailed in the preceding sections, were entered into equations 1 to 4 to calculate the PBR for kittiwake (Table 2).

Table 2. Kittiwake PBR estimates for the total population and the breeding adult component. The most appropriate estimate for this population is highlighted.

Age class	Estimated population	N_{min}	Adult survival	Age at 1st breeding	R_{max}	F_R	PBR
All age classes	111,300	102,312	0.865	4	0.140	0.1	716
						0.2	1,432
						0.3	**2,148**
						0.4	2,863
						0.5	3,579
Breeding adults only	44,520	81,850				0.1	573
						0.2	1,145
						0.3	**1,718**
						0.4	2,291
						0.5	2,863

Two sets of PBR estimates are provided in Table 2. The first uses a value for N_{min} estimated for the complete population, including all age classes and non-breeding adults and are thus appropriate for consideration of collision mortality across all age classes. The second uses just the number of breeding adults to generate an estimate appropriate to just this age class.

Using an F_R of 0.3, which remains precautionary (as discussed above), it is calculated that the total FHBC kittiwake population could sustain an additional level of mortality of 2,148 individuals per year (distributed across all age classes in proportion to their presence in the population). Of this, the breeding adult threshold is 1,718.

5. Review of recent examples of gannet PBR parameters used for offshore wind farm assessments

PBRs have been reviewed for several recent offshore wind farm assessments. Gannet parameters are provided in Table 3.

Table 3. Gannet PBR parameters reported in relation to offshore wind farm assessments.

Wind Farm	Proposer	Colony	Colony size (AON)	N_{min} percentile / CV used	N_{min}	Adult survival	Age 1st breeding	F_R	PBR
Triton Knoll	RWE	FHBC	7,859	0.2 / 0.1	14,449	0.919	5	0.4	286
Triton Knoll	NE	FHBC	7,859	0.2 / 0.25	12,734	0.919	5	0.3	189
EA One	NE	FHBC	7,859	0.2 / 0.1	14,449	0.919	5	0.4	286
Hornsea	Smart Wind	FHFC	9,947	0.2 / 0.1	18,287	0.919	5	0.5	452

5.1 N_{min}

Previous values

For Triton Knoll and EA One the gannet population assessed in each case was the Flamborough Head and Bempton Cliffs (FHBC) SPA. For Hornsea the extended pSPA (FHFC) was used. For Triton Knoll, RWE presented N_{min} values with and without allowance for a 10% measurement error (only the latter are presented in Table 3), thus N_{min} values of 15,718 and 14,449 were used (Triton Knoll 2012). In their response, Natural England applied the correction proposed by Wade (1998) and detailed in 2.1 above, however a precautionary CV of 0.25 was used (N_{min} = 12,374; Natural England 2012). This precaution was later revised by Natural England for the EA One response, when a CV of 0.1 was employed (N_{min} = 14,449; Natural England 2013). In all other cases the same N_{min} adjustment was applied. However, for the Hornsea offshore wind farm Smart Wind used a slightly higher AON estimate of 9,947 derived from a single count in 2011 and attributed to an unpublished Natural England report, on the basis of which an N_{min} of 18,287 was used (Smart Wind 2013a).

Value proposed for current assessment

The British gannet population has increased steadily at all colonies since the first census in 1902 and recent counts indicate this trend is continuing (WWT 2012). The colony at Bempton was counted in 2012 by the RSPB, when 11,061 pairs were recorded (http://www.rspb.org.uk/news/326575-shining-a-light-on-gannet-numbers-at-rspb-bempton-cliffs).

Estimated numbers of collisions with offshore wind turbines are based on observations of birds of all age classes, not just breeding adults. Hence, to ensure the collision estimate and the PBR derived mortality threshold are compatible, it is necessary for both to be based on the same demographic groups. This was undertaken here by calculating the total population size associated with the number of breeding pairs. Unlike many seabirds, breeding age gannets appear to breed in all years

(WWT 2012), therefore it was only necessary to account for the presence of immature (pre-breeding age) birds.

A population model of the British and Irish gannet population (WWT 2012) reported that the proportions of breeding adults and immature birds observed in surveys of wind farm sites averaged 0.69 and 0.31 respectively across the year (the proportions varied across months, but during the breeding months when more than 75% of observations were made the proportions were very similar at 0.67:0.33). The adult proportion was used here to estimate the additional pre-breeding age birds present in the FHBC population at risk of collisions and which therefore need to be included in the estimate of N_{min}. The calculation of total population size was thus:

$$Total\ N = (2 \times AON) + \left(2 \times AON \times (1 - breeding\ adult\ proportion)\right)$$
$$Total\ N = (2 \times 11061) + \left(2 \times 11061 \times (1 - 0.69)\right)$$
$$Total\ N = 28{,}980$$

[Eqn.7]

As per PBR methods, the lower 60th percentile of Total N, with a CV of 10%, was calculated, **giving an N_{min} of 26,640 for use in the PBR for the FHFC pSPA population**.

In addition the PBR based on just the number of breeding pairs (11,061) has been calculated, again using equation 2 to calculate N_{min}. This second PBR is applicable to just the breeding adult component of the population.

5.2 Adult survival

Previous values

Adult survival used in all previous PBR was 0.919, presented originally in Wanless et al. (2006).

Value proposed for current assessment

A value of 0.919 is considered appropriate to use for the PBR of the FHFC pSPA population.

5.3 Age at first breeding

Previous values

Age at first breeding was defined as 5 in all previous PBR examples.

Value proposed for current assessment

A value of 5 is considered appropriate to use for the PBR of the FHFC pSPA population.

5.4 Recovery rate F_R

Previous values

The recovery rate (F_R) used in previous PBR for the FHBC SPA gannet population has varied between 0.3 (Natural England for Triton Knoll), 0.4 (RWE for Triton Knoll, Natural England for EA One) and 0.5 (Hornsea).

Value proposed for current assessment

As detailed in the discussion of appropriate values for F_R in relation to kittiwake, the key recommendation in Dillingham and Fletcher (2008) is:

> *Without further information, it may be reasonable to set f = 0.5 for 'least concern' species, f = 0.3 for 'near threatened', and f = 0.1 for all threatened species. A value of f = 1.0 may be appropriate for 'least concern' species known to be increasing or stable.*

In their initial advice, Natural England advocated use of an F_R of 0.3, which would be suitable for a 'near threatened' population. Subsequently they revised this up to 0.4. However, the British gannet population is increasing and is classified by the IUCN as of 'least concern'. Therefore, as a 'least concern' species, a minimum F_R of 0.5 is appropriate, and since the population is increasing, there is a strong case for setting F_R to 1.0.

Thus, while still retaining a high level of precaution, **an F_R value for the FHFC pSPA gannet population of 0.5 is used here**. However, for illustration purposes other values are also presented in the results.

6. PBR for the FHFC pSPA Gannet population

The PBR parameters for gannet, estimated as detailed in the preceding sections, were entered into equations 1 to 4 to calculate the PBR for gannet (Table 4).

Table 4. Gannet PBR estimates for the total population and the breeding adult component. The most appropriate estimate for this population is highlighted.

Age class	Estimated population	N_{min}	Adult survival	Age at 1st breeding	R_{max}	F_R	PBR
All age classes	28,980	26,640	0.919	5	0.099	0.3	395
						0.4	527
						0.5	**659**
						1.0	1,318
Breeding adults only	22,122	20,336				0.3	302
						0.4	402
						0.5	**503**
						1.0	1,006

Two sets of PBR estimates are provided in Table 4. The first uses a value for N_{min} estimated for the complete population, including all age classes and non-breeding adults and are thus appropriate for consideration of collision mortality across all age classes. The second uses just the number of breeding adults to generate an estimate appropriate to just this age class.

Using an F_R of 0.5, which remains precautionary (as discussed above), it is calculated that the total FHBC gannet population could sustain an additional level of mortality of 659 individuals per year (distributed across all age classes in proportion to their presence in the population). Of this, the breeding adult threshold is 503.

7. Discussion

Theoretical basis of PBR

The target of PBR is to ensure the population remains at the optimum sustainable population (OSP) size, which is defined as a range between the carrying capacity and the population size at which the MNPL is reached. The population dynamics theory on which PBR is based is the generalised logistic population growth model:

$$N_{t+1} = N_t + N_t R_{max} \left[1 - \left(\frac{Nt}{K} \right)^{\theta} \right]$$

[Eqn.5]

Where:

N_t = population size at time t
R_{max} = the maximum population growth rate
K = the carrying capacity, and
θ = the density dependent shape parameter.

When θ equals 1 the model generates a classic sigmoid growth curve (Figure 1), with the rate of population increase fastest at 0.5K (half the carrying capacity) which is also equivalent to the MNPL. At higher values of θ the MNPL is shifted upward towards the carrying capacity, thereby reducing the OSP range.

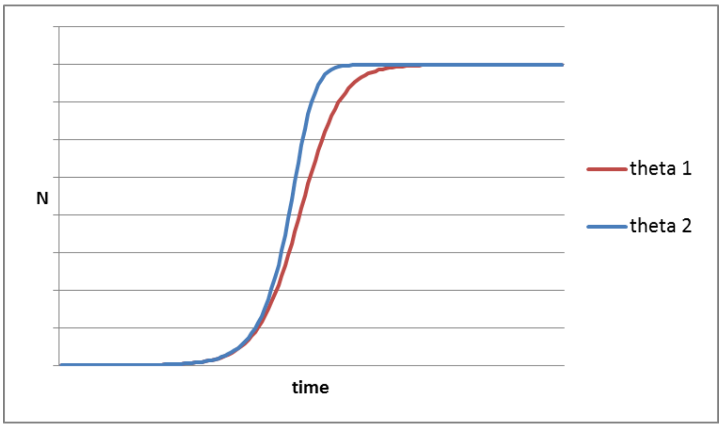

Figure 1. Illustration of population size (N) against time under the theta-logistic model of population growth. When theta = 1 (red line) the maximum growth rate occurs at half the carrying capacity. At higher values of theta the maximum growth rate occurs at higher population levels (e.g. when theta = 2, max growth rate occurs at 0.7K, blue line).

Seabird population growth typically asymptotes to a carrying capacity in a manner consistent with a value of θ greater than 1 (e.g. more like the blue line than the red line in Figure 1). The basis of PBR assumes that θ equals 1 as this generates precautionary estimates.

When PBR was originally developed (Wade 1998) it was tested using population simulations based on the logistic model of population growth (Fig. 1), using a value for theta of 1. This was considered to be conservative, since marine mammals (and also seabirds) have growth curves consistent with higher values of theta. This aspect is important for interpretation of PBR since populations which exhibit growth like that for theta = 2 in Figure 1 also have a greater capacity to recover from additional mortality (Figure 2).

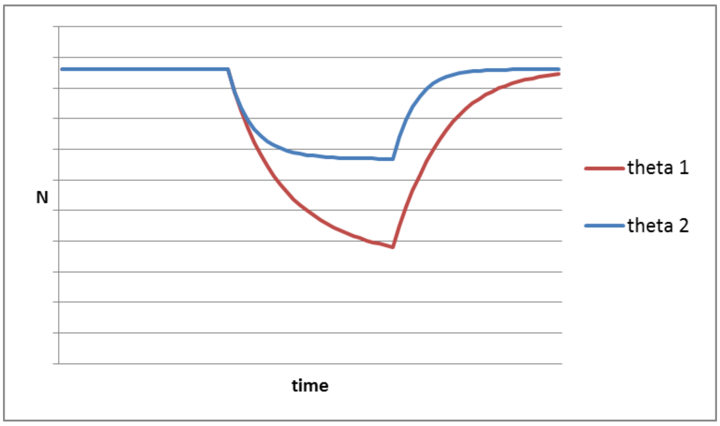

Figure 2. Illustration of population size (N) against time under the theta-logistic model of population growth, in the presence of additional mortality. When additional mortality is applied, the population decreases from its carrying capacity to a new one, at a level controlled by the value of theta. Keeping all other factors the same, the reduction in size for a population modelled with theta = 1 (as per PBR) is twice that for one with a theta = 2.

As a consequence, because PBR is based on an unrealistic model of seabird population growth, the values of PBR calculated overestimate the impact on the population. In other words, even before any consideration is given to the selection of PBR parameter values, the underlying basis is highly precautionary.

It has been suggested that PBR outputs contradict those from population models (RSPB 2013). This conclusion was based on the fact that an estimated PBR value was at a level which a population model predicted would have a high likelihood of causing a decline in population size. However, the harvesting theory on which PBR is based predicts that, all else being equal, the maximum sustainable yield (i.e. the maximum annual harvest which can be take in perpetuity) is obtained when the population is at half the carrying capacity. Therefore, unless the population is already below this size, harvesting up to the PBR derived permissible level will almost certainly lead to a reduction in the population size. Thus, not all of the outputs from PBR and population modelling are strictly comparable, and the results obtained from the two are not necessarily contradictory.

A further criticism of the use of PBR in relation to offshore wind farm assessment relates to the suggestion that it relies on feedback monitoring to permit modification of harvesting rates, and this is not considered to be possible for offshore wind farms (RSPB 2013):

Furthermore, PBR is unvalidated for offshore wind farms and relies on feedback monitoring to permit modifications of "harvesting" rates for quarry species or bycatch, to ensure that removal is maintained within sustainable limits. It is difficult to see how such a feedback mechanism would apply for offshore wind farms; hence PBR may not indicate sustainable levels of "take" via collision or displacement.

However, in the current context PBR is being used to identify the point at which annual harvesting would be considered unsustainable. As such it is simply a tool for pre-construction assessment, but it is incorrect to suggest that its use for this purpose means that it must be used for subsequent monitoring.

Selection of appropriate PBR parameters for FHFC pSPA populations of kittiwake and gannet

When Dillingham and Fletcher (2008) first suggested PBR as a tool for estimating tolerable limits for incidental bird mortality they stressed the precautionary nature of PBR:

> *The PBR mortality limits tend to be precautionary as little is assumed about the population structure, a conservative population estimate is used, and the potential for biased population estimates is generally included by setting $f < 1$. The selection of f is a management decision and should be done with care, balancing conservation goals, stakeholder desires, and the ability to monitor the population. Coupled with conservative estimates for survival and age at first reproduction, estimates may become overly conservative.*

Cooke et al. (2012) discuss the fact that for marine mammals in the United States the default value for F_R is 0.5, with this being increased up to 1.0 for populations where there is reasonable scientific evidence that there are no large biases in estimates of abundance, mortality or R_{max}. They go on to state that use of F_R = 0.1 is reserved for species classed as endangered in order that population recovery is delayed as little as possible.

Application of PBR to New Zealand seabird populations has followed the IUCN classifications, for example setting F_R to 0.1 for critically endangered populations, 0.2 for endangered ones, 0.3 for vulnerable ones, 0.4 for near threatened and 0.5 for other species (Dillingham and Fletcher 2011, Sharp et al. 2011, Richard and Abraham 2013). Application of this approach to British seabirds would lead to the use of 0.5 for all populations.

In light of the above and taking all of the precautionary aspects of PBR into account, the values for F_R used here (0.3 for kittiwake, 0.5 for gannet) are considered entirely in keeping with the original intentions of the method and inherently precautionary.

The estimates of population size and its adjustment (i.e. N_{min}), adult survival and age at first breeding are considered to add further layers of precaution to the PBR calculations and consequently the PBR values presented here for the total populations (kittiwake: 2,148, gannet: 659) provide robust, precautionary estimates of sustainable levels of additional mortality on these populations.

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