Hornsea Project Four

G1.41 Calculation Methods of Hornsea Four's Proposed Compensation Measures for Features of the FFC SPA

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Hornsea 4 Ørsted

Calculation Methods of Hornsea Four's Proposed Compensation Measures for Features of the FFC SPA

Orsted Hornsea Project Four Ltd

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1.0	02/11/2021	All	All	First Draft	MB
1.1	08/11/2021	All	All	Technical Review	TK
1.2	10/11/2021	All	All	Review prior to client issue	SS
1.3	15/11/2021	All	All	Client Review	SMR
2.0	15/11/2021	All	All	Amends following Client Review	SS
3.0	22/02/2022	All	All	Updates relating to auks and kittiwakes	SS

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1. Introduction

1.1 Background

Orsted Hornsea Project Four Limited (hereafter the 'Applicant') is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). Hornsea Four's proposed array area is located approximately 69 km offshore, to the east of the East Riding of Yorkshire, in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone, should it receive consent. Hornsea Four includes both offshore and onshore infrastructure, including an offshore generating station (the offshore wind farm), export cables to landfall and connection to the electricity transmission network. Detailed information on the project design can be found in Volume A1, Chapter 1: Project Description (Orsted 2021a), with detailed information on the site selection process and consideration of alternatives described in Volume A1, Chapter 3: Site Selection and Consideration of Alternatives (Orsted 2021b).

The original Hornsea Four Agreement for Lease (AfL) area from The Crown Estate (TCE) was 846 km^2, which was used at the Scoping phase to assess initial project plans. In the spirit of keeping with Hornsea Four's approach to incorporate proportionate Environmental Impact Assessment (EIA) methods, the Applicant has given due consideration to the size, scale and location (within the existing AfL area) of the final project that is being taken forward to Development Consent Order (DCO) Application. This consideration is captured internally as the "Developable Area Process", which includes physical, biological and human constraints in refining the developable area, balancing consenting and commercial considerations with technical feasibility for construction.

The combination of Hornsea Four's proportionality in EIA and the Applicant's Developable Area Process has resulted in a marked reduction in the array area taken forward at the point of DCO application. Hornsea Four adopted a major site reduction from the array area presented at Scoping (846 km^2) to the Preliminary Environmental Information Report (PEIR) boundary (600 km^2), with a further reduction adopted for the Environmental Statement (ES) and DCO Application (486 km^2) due to the results of the PEIR, technical considerations and stakeholder feedback. The evolution of the Hornsea Four Order Limits is detailed in Volume A1, Chapter 3: Site Selection and Consideration of Alternatives and Volume A4, Annex 3.2: Selection and Refinement of the Offshore Infrastructure.

The Applicant submitted a DCO Application to the Planning Inspectorate (PINS), supported by a range of plans and documents including an ES, which sets out the results of the EIA for Hornsea Four and its associated infrastructure plans. The Applicant also submitted a Report to Inform Appropriate Assessment (RIAA) (Orsted 2021c) which sets out the information necessary for the competent authority (the Secretary of State (SoS) for the Department for Business, Energy & Industrial Strategy (BEIS) to undertake an Appropriate Assessment (AA) to determine if there is any Adverse Effect on Integrity (AEoI) on sites of European Importance and Ramsar sites as a result of the development of Hornsea Four (alone and or in-combination with other plans or projects). Should the conclusion of that AA be an AEoI (or there is uncertainty around this), that would raise the requirement for the Applicant to consider subsequent stages of the Habitats Regulation Assessment (HRA) process (typically referred to as the derogations), which brings a requirement, among other considerations, to secure compensatory measures.

In accordance with the Habitats Regulations, the RIAA (Orsted 2021c) considers whether Hornsea Four could result in an AEoI on a conservation site of European importance (European site). The Applicant's evidence presented within the RIAA concluded that the operation and maintenance of Hornsea Four will not result in an AEoI on any European site.

Although the RIAA concluded no AEoI for all assessments, based on the SoS recent ruling during the decision on Hornsea Three[1] the Applicant has provided a 'without prejudice' derogation case for designated features of the Flamborough and Filey Coast (FFC) Special Protection Area (SPA), to be relied upon by the SoS if required (BEIS 2020). This is despite the Applicant's firm position that it can be concluded beyond reasonable scientific doubt that Hornsea Four will not give rise to any AEoI, alone or in-combination with other projects or plans.

The qualifying features of the FFC SPA that are of relevance to the without prejudice compensation measures are:

- Kittiwake, *Rissa tridactyla*, in relation to potential collision mortality;
- Gannet, *Morus bassanus*, in relation to potential collision mortality and mortality as a consequence of disturbance and displacement;
- Guillemot, *Uria aalge*, in relation to potential mortality as a consequence of disturbance and displacement; and
- Razorbill, *Alca torda*, in relation to potential mortality as a consequence of disturbance and displacement.

The Applicant has investigated a long list of potential compensation measures and selected several methods, which have been ranked and consulted on through the Hornsea Four Evidence Plan process (Orsted 2021d). The measures considered include; the provision of artificial nesting sites, predator eradication at colony sites, methods to reduce fishing bycatch, the need for a government-led approach to address seabird prey availability and the need for further evidence, and fish habitat enhancement as a resilience measure. A summary of the compensation measures proposed for each of the above qualifying features of the FFC SPA is presented in **Table 1** with reference to supporting documentation.

This document provides the proposed methods of calculating the required amount of compensation for each of the methods proposed in **Table 1** in order to mitigate the predicted impacts for the qualifying features of the FFC SPA.

[1] See para 6.4 of the letter of the Department for Business, Energy & Industrial Strategy Decision Letter for Hornsea dated 31 December 2020. Available here.

Table 1 Summary of the proposed compensation measures for the qualifying features of the FFC SPA.

Species	Proposed Compensation Measures	Supporting Evidence Documents
Kittiwake	Artificial nesting structure & fish habitat enhancement	B2.7.1 Compensation measures for FFC SPA: Offshore Artificial Nesting: Ecological Evidence (Orsted 2021e) B2.7.3 Compensation measures for FFC SPA: Onshore Artificial Nesting: Ecological Evidence (Orsted 2021f) B2.8.5 Compensation measures for FFC SPA: Fish Habitat Enhancement: Ecological Evidence (Orsted 2021h)
Gannet	Artificial nesting structure, bycatch reduction & fish habitat enhancement	B2.7.1 Compensation measures for FFC SPA: Offshore Artificial Nesting: Ecological Evidence (Orsted 2021e) B2.7.3 Compensation measures for FFC SPA: Onshore Artificial Nesting: Ecological Evidence (Orsted 2021f) B2.8.1 Compensation measures for FFC SPA: Bycatch Reduction: Ecological Evidence (Orsted 2021g) B2.8.5 Compensation measures for FFC SPA: Fish Habitat Enhancement: Ecological Evidence (Orsted 2021h)
Guillemot	Predator eradication, bycatch reduction & fish habitat enhancement	B2.8.3 Compensation measures for FFC SPA: Predator Eradication: Ecological Evidence (Orsted 2021i)

Species	Proposed Compensation Measures	Supporting Evidence Documents
		B2.8.1 Compensation measures for FFC SPA: Bycatch Reduction: Ecological Evidence (Orsted 2021g) B2.8.5 Compensation measures for FFC SPA: Fish Habitat Enhancement: Ecological Evidence (Orsted 2021h)
Razorbill	Predator eradication, bycatch reduction & fish habitat enhancement	B2.8.3 Compensation measures for FFC SPA: Predator Eradication: Ecological Evidence (Orsted 2021i) B2.8.1 Compensation measures for FFC SPA: Bycatch Reduction: Ecological Evidence (Orsted 2021g) B2.8.5 Compensation measures for FFC SPA: Fish Habitat Enhancement: Ecological Evidence (Orsted 2021h)

1.2 Updates Following DCO Submission

1.2.1 Updated auk predicted impacts

Since DCO Application submission at the request of Natural England (Natural England, 2021), the Applicant has recalculated predicted impacts on auks to include all behaviours. The auk predicted impact values in **Table 2** and calculated compensation values in **Section 3** and **Appendix 1**, have therefore been updated to reflect this.

1.2.2 Updated position on AEoI conclusion for kittiwake

After considering the Secretary of State's decision for Norfolk Boreas and the associated Habitats Regulations Assessment (HRA), which follows from the decision made for Hornsea Three, the Applicant has revisited its conclusion of no potential for adverse effects on integrity (AEoI) in respect of the black-legged kittiwake feature of the FFC SPA from Hornsea Four in-combination with other plans and projects.

In both of those decisions the Secretary of State found that the potential for AEoI as a result of those projects could not be excluded for kittiwake at the FFC SPA when considered on an in-combination basis.

The Applicant originally submitted its DCO application for Hornsea Four with evidence and assessments supporting its position that there was no potential for AEoI alone or in-combination with other projects. This drew on new assessment methodologies and analysis providing evidence considered sufficient to justify departing from the AEoI conclusion (in-combination) previously reached in the Hornsea Three decision.

The Applicant has carefully reviewed the Secretary of State's HRA for Norfolk Boreas and notes that the finding that the kittiwake population would continue to grow has not been accepted by the Secretary of State as a basis to exclude AEoI for Norfolk Boreas. Specifically, the Applicant notes that the Secretary of State's HRA (which did not include Hornsea Four or Sheringham and Dudgeon Extensions in the in-combination totals) states:

"*Furthermore, if the mortality from the windfarms is 432 adults per year, then the population of the SPA after 30 years will be 14.3% lower than it would have been in the absence of the Projects and the population growth rate would be reduced by 0.5%. This reduction in the population would be counter to the restore conservation objective for this feature of the SPA and would result in an adverse effect on the integrity of the site."*

Continued growth in the population of kittiwake at the FFC SPA, albeit at a reduced rate, was a factor relied upon by the Applicant to support its position that there would be no AEoI in-combination in respect of kittiwake at the FFC SPA. However, the Secretary of State, on advice from Natural England, has reached the alternative conclusion in the context of Norfolk Boreas.

The Applicant therefore considers that, despite its confidence that there is no potential for AEoI on kittiwake from Hornsea Four in-combination with other plans and projects as evidenced in its original DCO application, it is not a point that it wishes to pursue during Examination.

On that basis, the Applicant is presenting its derogation case based on an overall conclusion that there is potential for an AEoI on kittiwake at the FFC SPA from Hornsea Four in-combination with other projects. Consequently, to that extent only, compensatory measures for kittiwake will be necessary should the Secretary of State be minded to grant development consent.

For the avoidance of doubt, the Applicant's position remains that there will be no AEoI from Hornsea Four alone on the kittiwake feature and, aside from the overall (in-combination) conclusion on integrity noted above, the Applicant maintains its position in all other respects as regards its methodology and assessment of the effects on the FFC SPA features. The Applicant also maintains its position of no AEoI alone or in-combination for all other qualifying species or seabird assemblage of the FFC SPA and for all other European sites.

2. Assessment of Potential Effects from Hornsea Four on Qualifying Features of Flamborough and Filey Coast SPA

2.1 Conservation Objectives of the FFC SPA

The FFC SPA is designated for a number of breeding seabird species (including gannet, kittiwake, guillemot and razorbill) as well as for its breeding seabird assemblage (including fulmar, cormorant, shag, herring gull and puffin). The importance of FFC SPA is acknowledged through it being mainland England's only gannetry, the UK's largest kittiwake colony and England's largest guillemot and razorbill colony. The site covers colonies located along the cliffs on the southern and northern sides of Filey Bay and the north and south sides of Flamborough Head on the east coast of Yorkshire. In total the site supports over 200,000 seabirds during the breeding season, offering secure nesting sites due to its sheer cliffs rising out of the North Sea.

The site's conservation objectives apply to the site and the individual species and/or assemblage of species for which the site has been classified (qualifying features). The conservation objectives are to ensure that, subject to natural change, the integrity of the site is maintained or restored as appropriate and that the site contributes to achieving the aims of the Birds Directive, by maintaining or restoring:

- the extent and distribution of the habitats of the qualifying features;
- the structure and function of the habitats of the qualifying features;
- the supporting processes on which the habitats of the qualifying features rely;
- the populations of each of the qualifying features; and
- the distribution of qualifying features within the site.

Potential impacts from collision risk and displacement resulting from the operation and maintenance of an OWF may adversely affect the conservation objective relating to the maintenance of qualifying feature populations.

2.2 Potential Impacts from Hornsea Four on the Qualifying Features of the FFC SPA

Within the Hornsea Four RIAA (Orsted 2021c) the potential impacts from Hornsea Four relating to collision risk and displacement have been assessed for the qualifying features of the FFC SPA. A summary of the potential impacts attributed to the FFC SPA qualifying features from Hornsea Four are presented in **Table 2** of this report, based on the Applicant's evidence-led approach to assessment. Based on the evidence presented within the Hornsea Four RIAA, it was concluded that any potential impacts resulting from Hornsea Four alone and in-combination on the qualifying features of the FFC SPA would not lead to an AEoI, with the exception of kittiwake (See **Section 1.2.2**). Despite the conclusion of no AEoI, the Applicant has sought to calculate the level of compensation required to fully mitigate the level of predicted impacts presented in **Table 2**.

Although the predicted level of impacts to be compensated for are based on the impacts attributed to the FFC SPA, no feasible compensation measures were identified which would directly benefit the FFC SPA colony only. This is primarily because the qualifying features of the FFC SPA are known to be stable with the annual colony average growth rates (Lloyd et al. 2019) already higher than that observed for the UK populations as a whole (JNCC, 2021). Furthermore, no negative pressure on the colony was identified which could be feasibly be mitigated by the Applicant. With this in mind the compensation measures proposed in **Section 3** are focused on providing compensation mitigation to the wider biogeographic region, which will in turn provide net benefits to the national site network, which includes the FFC SPA. It is important to note that the compensation calculations presented in **Section 3** are flexible and can be adjusted depending on the scale of compensation required.

Table 2 Summary of the Hornsea Four predicted impacts based on the Applicant's evidence-led position for qualifying features of the FFC SPA.

Species	Impact	Predicted level of impact (breeding adult mortalities)	Conclusion from Hornsea Four impacts alone	Conclusion from Hornsea Four impacts in-combination
Gannet	Collision risk and Displacement	11.8 – 12.9	No AEoI	No AEoI
Kittiwake	Collision risk	21.2	No AEoI	AEoI[2]
Guillemot	Displacement	36.6	No AEoI	No AEoI
Razorbill	Displacement	1.7	No AEoI	No AEoI

[2] See **Section 1.2.2** for rationale regarding this conclusion.

3. Proposed Compensation Measures and Calculation Methods

As presented in **Table 1** a number of different compensation measures have been proposed for the qualifying features of the FFC SPA. The sections below provide a summary of each of the proposed measures for the four qualifying features and the methods of how the required level of compensation has been calculated to fully compensate for the level of impacts predicted for Hornsea Four in **Table 2**. A 1:2 ratio is applied to the compensation package in the DCO submission, for clarity we provide all the calculations in this note on a 1:1 ratio to help inform discussions at the Compensation Workshop.

3.1 Kittiwake

3.1.1 Artificial Nesting Structure

For kittiwake the provision of an artificial nesting structure is proposed as the primary compensation measure. The artificial nesting structure will provide nesting space for prospective breeding adults to occupy, increasing the biogeographic population growth as described within the evidence reports (Orsted 2021e; 2021f). The structure is proposed to be located in an area of the southern North Sea identified as being ecologically beneficial to kittiwake and away from human disturbance. Further details of the site selection process are provided in B2.7.5: Compensation measure for the FFC SPA: Artificial Nesting: Site Selection and Design (Orsted 2021j).

The compensation measure comprises of the delivery of one artificial nesting structure in either the offshore or onshore environment (preferred option being offshore). The structure would be designed to accommodate additional breeding pairs to subsequently produce enough offspring to offset predicted impacts from the operation and maintenance of Hornsea Four (**Table 2**) back into the wider biogeographic population to be recruited at breeding age to other colonies (which includes the FFC SPA). In order to derive the number of additional breeding pairs required to nest on the structure to offset the predicted impacts presented in **Table 2**, the following demographic parameters are required:

- Age of kittiwake recruitment to breeding colonies;
- Productivity rate; and
- Survival rate of both immature and adult kittiwakes.

The age at which kittiwakes are first recruited into a colony and begin to breed for the first time is highly variable. The average age at which a kittiwake first breeds is cited as four years old, based on the literature review undertaken by Horswill and Robinson (2015), however kittiwakes have been known to begin breeding as early as 2 years old or as late as 10 years old (Coulson, 2011). To account for this large variation in age of recruitment a proportional range has been used within the model, based on the observations presented within Coulson (2011) of age at first breeding at the North Shields kittiwake colony (**Table 3**).

Table 3 Age of recruitment of breeding kittiwakes observed at North Shields colony based on observations cited in Coulson (2011).

Age at Recruitment (years)	1	2	3	4	5	6	7	8	9	10
% of recruits	0.0	0.7	26.5	35.2	22.7	10.5	2.5	0.9	0.9	0.4

The average productivity rate of kittiwake colonies varies depending on the geographical region (Horswill and Robinson 2015). Based on the regional-specific productivity rates presented in Horswill and Robinson (2015), the East region productivity rate of 0.819 was selected as the most appropriate for inclusion in the calculation, due to proposed location of the structure being the Southern North Sea. Although in the first couple of years after implementation the productivity rates of breeding pairs on the structure might be lower than 0.819 due to majority of birds likely to be recruited being first time breeders, once the colony is established, due to its preferential location it's possible the average productivity rate could increase higher than that of the East Region.

Survival rate of kittiwake is also known to vary by age. The most applicable survival rates for both juvenile and adult kittiwakes were derived from Horswill and Robinson (2015) and are presented in **Table 4**. A summary of the demographic input parameters included within the compensation calculation are presented in **Table 4**.

Table 4 Summary of the demographic parameters included in the kittiwake artificial nesting structure compensation calculation.

Demographic Parameter	Value
Productivity rate	0.819
Juvenile survival (0-1 year)	0.790
Adult survival (≥2 year)	0.854

Using the above demographic parameters for kittiwake, the first step in the compensation calculation is to calculate the predicted age at which the first-time breeders are recruited to colonies using the age of recruitment proportions in **Table 3**. This is expressed in the equation below;

$$New\ recruits_{Age=i} = (Total\ new\ recruits\ required) * Proportion\ of\ new\ recuits_{Age=i}$$

Following this, the total number of fledglings required can be estimated by calculating the number of birds in each age category required to both contribute the number of new recruits for that calculated, in addition to birds to survive into the subsequent age category (based on survival rates given in **Table 4**). This is expressed in the equations below;

$$New\ recruits_{Age=10} = \left(All\ birds_{Age=9} - New\ recruits_{Age=9}\right) * Survival_{Age=9}$$

$$\therefore All\ birds_{Age=9} = \frac{New\ recruits_{Age=10}}{Survival_{Age=9}} + New\ recruits_{Age=9}$$

$$All\ birds_{Age=0\leq i\leq 8\}} = \frac{All\ birds_{Age=i+1}}{Survival_{Age=i}} + New\ recruits_{Age=i}$$

$$N_{Fledglings} = All\ birds_{Age=0}$$

Finally, the sum of the total number of fledglings required to produce first-time breeders for each age category is multiplied by the productivity rate in **Table 4**. This is to calculate the number of breeding pairs the structure needs to accommodate to produce enough first-time breeders to fully mitigate the predicted impacts in **Table 2**.

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings}}{Productivity}$$

An illustrative guide of the kittiwake artificial nesting structure compensation calculation is provided in **Appendix 1**for reference.

When using the above calculation method, the number of additional breeding pairs required at the artificial nest structure to mitigate the predicted impacts on kittiwakes from Hornsea Four (providing enough first-time breeders back into the biogeographic region) is calculated as 57 (56.7), based on the predicted impact in **Table 2**.

3.2 Gannet

3.2.1 Artificial Nesting Structure

For gannet, the provision of an artificial nesting structure is proposed as the primary compensation measure. The artificial nesting structure would provide nesting space for prospective breeding adults to occupy, increasing the biogeographic population growth as described within the evidence reports (Orsted 2021e; 2021f). The structure is proposed to be located in an area of the Southern North Sea identified as being ecologically beneficial to gannets and away from human disturbance. Further details of the site selection process is provided in B2.7.5: Compensation measure for the FFC SPA: Artificial Nesting: Site Selection and Design (Orsted 2021j).

The compensation measure comprises of the delivery of one artificial nesting structure in either the offshore or onshore environment (preferred option being offshore and a repurposed offshore nesting structure). The structure would be designed to accommodate additional breeding pairs to subsequently produce enough offspring to offset predicted impacts from the operation and maintenance of Hornsea Four (**Table 2**) back into the wider biogeographic population. In order to derive the number of additional breeding pairs required to nest on the structure to offset the predicted impacts presented in **Table 2**, the following demographic parameters are required:

- Age of gannet recruitment to breeding colonies;
- Productivity rate; and
- Survival rate of both immature and adult gannets.

The most appropriate source of gannet demographic rates was identified as the literature review undertaken by Horswill and Robinson (2015), a summary of the demographic input parameters included within the compensation calculation are presented in **Table 5**. The national average productivity rate was selected as the most appropriate rate to use due to gannet having a large foraging range and regional differences in population trends were largely attributed to local differences in breeding success (Cook and Robinson 2010).

Table 5 Summary of the demographic parameters included in the gannet artificial nesting structure compensation calculation.

Demographic Parameter	Value
Age of recruitment (years)	5
Productivity rate	0.700
Juvenile survival (0-1 year)	0.424
Immature survival (1-2 years)	0.829
Immature survival (2-3 years)	0.891
Immature survival (3-4 years)	0.895
Adult survival (≥5 year)	0.919

Using the above demographic parameters for gannet, the first step in the compensation calculation is to work out the number of fledgling gannets required to reach breeding adult age of 5 years old to offset the predicted impacts in **Table 2**, using the known juvenile and immature survival rates in **Table 5**. The equation used to calculate this is shown below;

$$N_{Fledglings\ required} = \frac{N_{New\ breeding\ recruits\ required}}{\prod_{Age=0}^{Age=5} Survival_{Age}}$$

Once the number of fledgling gannets required is known, the gannet productivity rate presented in **Table 5** is applied to calculate the number of breeding gannet pairs required to occupy the structure to produce the required number of fledglings to offset the predicted impacts from Hornsea Four (**Table 2**). The equation used to calculate this is shown below;

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings\ required}}{Productivity}$$

An illustrative guide of the gannet artificial nesting structure compensation calculation is provided in **Appendix 1**for reference.

When using the above calculation method, the number of additional breeding pairs required at the artificial nest structure to mitigate the predicted impacts on gannet from Hornsea Four (to provide enough first time breeders back into the biogeographic region) is calculated as 65 (65.3), when considering a predicted impact from Hornsea Four of 12 (11.77) breeding adults, or 71 (71.3) when considering a predicted impact from Hornsea Four of 13 (12.85) breeding adults.

3.3 Guillemot

3.3.1 Predator Eradication and / or Control

Predation of seabird eggs, nestlings and adult birds by mink, brown rat and black rat is known to be a driver of population decline in auk species (Olsson, 1974; Barrett, 2015; Swann, 2002; Mavor et al., 2004; Russell, 2011). The excessive predation by mammalian predators on auk colonies leads to reduction in chick survival rates (Barrett, 2015) and reduction in appropriate nesting habitat as auks are forced to nest only in areas inaccessible to predators (Booker et al., 2018; Andersson, 1999; Mavor et al., 2004). As detailed in the predator eradication evidence report (Orsted 2021i) there is substantial evidence to support that the implementation of predator eradication programmes will lead to improvement in colony productivity and provide new areas of suitable breeding habitat for occupation (Booker et al. 2018). A screening process was conducted in order to identify potential locations for a predator eradication programme to be successfully implemented. A short list of potential locations were identified including; Baliwick of Guernsey, Isles of Scilly, Rathlin Island and several islands/ islets along the south coast of England as the preferred locations for an eradication programme to be implemented. Further details of the site selection process are provided in the evidence report (Orsted 2021i).

This compensation measure comprises the delivery of a predator eradication programme, which would lead to the availability of additional nesting space for breeding guillemots to occupy, thus increasing the number of offspring able to be produced by the colony per annum. The number of additional offspring produced would be enough to offset predicted impacts from the operation and maintenance of Hornsea Four (**Table 2**) back into the wider biogeographic population. In order to derive the number of additional breeding pairs (additional nest space) required, the following demographic parameters are required:

- Age of guillemot recruitment to breeding colonies;
- Productivity rate; and
- Survival rate of both immature and adult guillemots.

The most appropriate source of guillemot demographic rates was identified as the literature review undertaken by Horswill and Robinson (2015), a summary of the demographic input parameters included within the compensation calculation are presented in **Table 6**. The national average productivity rate was selected as the most appropriate rate to use due to the possibility of the predator eradication programme being implemented in different regional locations.

Table 6 Summary of the demographic parameters included in the guillemot predator eradication calculation.

Demographic Parameter	Value
Age of recruitment (years)	6
Productivity rate	0.672
Juvenile survival (0-1 year)	0.560
Immature survival (1-2 years)	0.792
Immature survival (2-3 years)	0.917
Adult survival (≥4 year)	0.939

Using the above demographic parameters for guillemot, the first step in the compensation calculation is to work out the number of fledgling guillemots required to reach breeding adult age of 6 years old to offset the predicted impacts in **Table 2**, using the known juvenile and immature survival rates in **Table 6**. This is shown in the equation below;

$$N_{Fledglings\ required} = \frac{N_{New\ breeding\ recruits\ required}}{\prod_{Age=0}^{Age=6} Survival_{Age}}$$

Once the number of fledgling guillemots required is known, the guillemot productivity rate presented in **Table 6** is applied to calculate the number of breeding guillemot pairs required (amount of additional nest space required) to produce the required number of fledglings to offset the predicted impacts from Hornsea Four (**Table 2**). The equation used to calculate this is shown below;

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings\ required}}{Productivity}$$

An illustrative guide of the guillemot predator eradication compensation calculation is provided in **Appendix 1**for reference.

When using the above calculation method, the number of additional breeding pairs (additional nesting space) required to mitigate the predicted impacts on guillemot from Hornsea Four (provide enough first-time breeders back into the biogeographic region) is calculated as 162 (161.6), when considering a predicted impact from Hornsea Four of 37 (36.6) breeding adults. It should be noted that the number of breeding pairs required is highly likely to be an overestimate. This is because the productivity rate of breeding pairs and fledgling survival rate is highly likely to significantly increase after removal of predators in comparison to national average demographic rates used in the calculation, as observed at Lundy Island (Booker et al. 2018).

3.4 Razorbill

3.4.1 Predator Eradication and / or Control

Evidence relating to the feasibility of predator eradication as a suitable compensation measure is summarised in **Section 3.3.1** with further details found in the corresponding evidence report (Orsted 2021i).

This compensation measure comprises the delivery of a predator eradication programme, which would lead to the availability of additional nesting space for breeding razorbills to occupy, thus increasing the number of offspring able to be produced by the colony per annum. The number of additional offspring produced would be enough to offset predicted impacts from the operation and maintenance of Hornsea Four (**Table 2**) back into the wider biogeographic population. In order to derive the number of additional breeding pairs (additional nest space) required, the following demographic parameters are required:

- Age of razorbill recruitment to breeding colonies;
- Productivity rate; and
- Survival rate of both immature and adult razorbills.

The most appropriate source of razorbill demographic rates was identified as the literature review undertaken by Horswill and Robinson (2015), a summary of the demographic input parameters included within the compensation calculation are presented in **Table 7**. The national average productivity rate was selected as the most appropriate rate to use due to the possibility of the predator eradication programme being implemented in different regional locations.

Table 7 Summary of the demographic parameters included in the razorbill predator eradication calculation.

Demographic Parameter	Value
Age of recruitment (years)	5
Productivity rate	0.570
Juvenile survival (0-2 year)	0.630
Adult survival (≥3 year)	0.895

Using the above demographic parameters for razorbill, the first step in the compensation calculation is to work out the number of fledgling razorbills required to reach breeding adult age of 5 years old to offset the predicted impacts in **Table 2**, using the known juvenile and immature survival rates in **Table 7**. This is shown in the equation below;

$$N_{Fledglings\ required} = \frac{N_{New\ breeding\ recruits\ required}}{\prod_{Age=0}^{Age=5} Survival_{Age}}$$

Once the number of fledgling razorbills required is known, the razorbill productivity rate presented in **Table 7** is applied to calculate the number of breeding razorbill pairs required (amount of additional nest space required) to produce the required number of fledglings to offset the predicted impacts from Hornsea Four (**Table 2**). The equation used to calculate this is shown below;

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings\ required}}{Productivity}$$

An illustrative guide of the razorbill predator eradication compensation calculation is provided in **Appendix 1**for reference.

When using the above calculation method, the number of additional breeding pairs (additional nesting space) required to mitigate the predicted impacts on razorbills from Hornsea Four (provide enough first time breeders back into the biogeographic region) is calculated as 10 (10.3) when considering a predicted impact from Hornsea Four of two (1.7) breeding adults. It should be noted that the number of breeding pairs required is highly likely to be an overestimate. This is because the productivity rate of breeding pairs and fledgling survival rate is highly likely to significantly increase after removal of predators in comparison to national average demographic rates used in the calculation, as observed at Lundy Island (Booker et al. 2018).

3.5 Bycatch Reduction

Modern commercial fishing activities are acknowledged as being one of the biggest threats to seabird species globally (Dias et al. 2019). In UK waters, gannet, guillemot and razorbill are species known to be commonly caught as bycatch with current annual mortality estimates reported as hundreds of gannets, between 1,800 and 3,300 guillemots and between 100 to 200 razorbills (Northridge et al. 2020). However, it is likely that these annual mortality rates are underestimates due to a lack of monitoring coverage in comparison to the current scale of commercial fishing (Pott and Wiedenfeld 2017).

Auk species are considered primarily susceptible to trammel nets, set gillnets, set longlines and purse seines, whereas gannets are considered primarily susceptible to longline and static net fisheries. Further information on each of these different types of fishing techniques and their respective risks to UK seabirds is provided in the bycatch evidence report (Orsted 2021g). A review carried out on the most up-to-date bycatch reduction technologies, which identifies the methods to yield the greatest reduction in auk bycatch mortality, concluded that above water deterrents (looming eye) are the most effective method (Orsted 2021g). For gannet the review concluded that warp lines and reducing access to hooks are the most effective methods (Orsted 2021g).

3.5.1 Auk species

For auk species, the compensation measure comprises the delivery of providing looming eye deterrents to commercial fishing vessels working in known bycatch high risk areas (Orsted 2021g). The implementation of looming eye deterrents would reduce the number of auks being subject to mortality as a result of incidental bycatch, therefore, offsetting the predicted impacts from the operation and maintenance of Hornsea Four (**Table 2**). In order to derive the number of vessels required, to be supplied with looming eye deterrents, to fully offset the predicted impacts from Hornsea Four the following parameters were identified as being required:

- The predicted reduction in auk bycatch due to looming eye deterrents per vessel; and
- The juvenile to adult proportion within the North Sea and English Channel BDMPS population.

The first step in the compensation calculation is to estimate the number of auks to be caught as bycatch, before and after the installation of looming eye deterrents, to calculate their efficiency per vessel. In order to quantify the current number of seabirds subject to bycatch mortality in UK waters the Applicant carried out a series of questionnaires with fisherman. The results of the questionnaire indicated that on average 30 (29.8) auks are caught by each vessel per annum (Orsted 2021g). During the bycatch technology selection phase, in Section 10.3 of the evidence report (Orsted 2021g), it was identified that the use of looming eye deterrents is anticipated to cause a reduction of 30% in seabirds caught as bycatch. Using these data to estimate possible reductions in auk bycatch mortality, the implementation of looming eye deterrents would lead to a reduction of nine (8.9) auk mortalities per vessel per annum. The method for the reduction in bycatch mortality following the implementation of looming eye deterrents is shown in the calculation below;

$$N_{auks\ avoiding\ bycatch\ per\ vessel} = N_{auks\ caught\ as\ bycatch} \times Looming\ eye\ deterrent\ reduction\ in\ bycatch$$

Based on the population ratios presented in Appendix A of Furness (2015), not all auks avoiding bycatch mortality from the implementation of looming eye deterrents would be adult birds, with roughly 60% of guillemots and 52% of razorbills estimated to be made up of adult birds. Therefore, to account for the fact that some of the auks avoiding bycatch mortality would not be adult birds, the number of birds that would need to avoid bycatch mortality is increased by 40% for guillemot and 48% for razorbill. This also adds a layer of precaution to the assessment as any juvenile saved from bycatch mortality has the potential to go on to reach adulthood, increasing the biogeographic breeding population. When considering the predicted impacts from Hornsea Four in **Table 2**, 51 (51.2) guillemots and two (2.5) razorbills equating to a total of 54 (53.7) auks would be required to avoid bycatch mortality in order to offset the predicted impacts from Hornsea Four, accounting for the likelihood of only adult birds being caught. The method to determine this is shown in the calculation below;

$$N_{auks\ avoiding\ bycatch\ to\ compensate\ for\ predicted\ impacts} = (guillemot\ predicted\ impacts\ \times guillemot\ Juvenile\ proportion\ rate\ ) + (razorbill\ predicted\ impacts\ \times razorbill\ Juvenile\ proportion\ rate\ )$$

When considering looming eye deterrents are calculated as reducing bycatch mortality by nine auk mortalities per vessel per annum and the requirement for a total of 54 auks per annum to compensate for the predicted impacts of Hornsea Four in **Table 2**, the total number of vessels required to be fixed with looming eye deterrents equates to six (6.0). The method to determine this is shown in the calculation below;

$$N_{vessels\ required} = \frac{N_{auks\ avoiding\ bycatch\ to\ compensate\ for\ predicted\ impacts}}{N_{auks\ avoiding\ bycatch\ per\ vessel}}$$

An illustrative guide of the auk bycatch reduction compensation calculation is provided in **Appendix 1**for reference.

3.5.2 Gannet

During the bycatch technology selection phase (Orsted 2021g) it was identified that Northridge et al. (2020) states hundreds of gannets suffer mortality as consequence of bycatch. However, it was not possible to accurately quantify the reduction in gannet bycatch mortality that may be realised through the implementation of warp lines and reducing access to hooks at this time, although there is ongoing research. Without this information it is currently not feasible to calculate how many vessels would be required to compensate for the predicted gannet impacts from Hornsea Four, but as the predicted impact is 11.77 - 12.85 breeding adult individuals it is expected that the bycatch reduction technology would be able to fully compensate for the predicted impacts from Hornsea Four. In addition, gannet can also be compensated through artificial nesting where it is possible to calculate the compensation required as described in **Section 3.2**.

3.6 Fish Habitat Enhancement

Additional resilience measures have also been proposed for all four qualifying features to offset any impacts, which may occur from the operation and maintenance of Hornsea Four, in the form of fish habitat enhancement (seagrass meadow restoration). Although increases in the abundance of prey available is expected to lead to a positive impact on all piscivorous seabird population numbers, it is not feasible to quantify exactly how this measure would directly mitigate the predicted impacts from Hornsea Four. Therefore, no calculation for fish habitat enhancement impact mitigation has been provided, although such a large-scale habitat enhancement (up to a total of 30 ha, as set out in the compensation plan (Orsted 2021k)) would support a number of fish species upon which seabirds (kittiwake, gannet, guillemot and razorbill) target as prey resource and would serve as an indirect means to offer resilience that would be effective, sustainable and robust.

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Appendix 1 Compensation calculation Examples

Artificial nesting platforms – gannet

The example below shows compensation calculations to estimate the number of additional breeding pairs required to achieve compensation of Hornsea Four's impacts for gannets, based on a mortality of 13 (12.9) birds.

Equation 1:

$$N_{Fledglings\ required} = \frac{N_{New\ breeding\ recruits\ required}}{\prod_{Age=0}^{Age=5} Survival_{Age}}$$

Equation 2:

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings\ required}}{Productivity}$$

Example values for Equation 1:

$$N_{Fledglings\ required} = \frac{12.85}{0.424 * 0.829 * 0.891 * 0.895 * 0.919} = 49.88$$

Example values for Equation 2:

$$N_{Breeding\ pairs\ required} = \frac{49.88}{0.7} = 71.28$$

Therefore, an artificial colony that supports 71 (71.3) breeding pairs would be required to compensate for the mortality of 13 adult gannets.

Artificial nesting platforms – kittiwake

The example below shows compensation calculations to estimate the number of additional breeding pairs required to achieve compensation of Hornsea Four's impacts for kittiwakes, based on a mortality of 21 (21.2) birds.

$$Total\ new\ recruits\ required\ =\ 21.22$$

$$New\ recruits_{Age=i} = (Total\ new\ recruits\ required) * Proportion\ of\ new\ recuits_{Age=i}$$

Age at Recruitment (years)	1	2	3	4	5	6	7	8	9	10
% of recruits	0.0	0.7	26.5	35.2	22.7	10.5	2.5	0.9	0.9	0.4
New recruits	0.00	0.14	5.61	7.47	4.81	2.22	0.52	0.19	0.19	0.07

The number of new recruits age 10 must equal the number of birds age 9 that firstly don't recruit that year, and then go on to survive the year.

$$New\ recruits_{Age=10} = \left(All\ birds_{Age=9} - New\ recruits_{Age=9}\right) * Survival_{Age=9}$$

This equation can be rearranged in order to calculate the number of birds aged 9 required in order to satisfy that condition.

$$All\ birds_{Age=9} = \frac{New\ recruits_{Age=10}}{Survival_{Age=9}} + New\ recruits_{Age=9}$$

$$All\ birds_{Age=9} = \frac{0.07}{0.854} + 0.19 = 0.28$$

The same logic applies to each age category.

$$All\ birds_{Age=0\leq i\leq 8\}} = \frac{All\ birds_{Age=i+1}}{Survival_{Age=i}} + New\ recruits_{Age=i}$$

$$All\ birds_{Age=8} = \frac{0.28}{0.854} + 0.19 = 0.52$$

$$All\ birds_{Age=7} = \frac{0.52}{0.854} + 0.52 = 1.12$$

$$All\ birds_{Age=6} = \frac{1.12}{0.854} + 2.22 = 3.53$$

$$All\ birds_{Age=5} = \frac{3.53}{0.854} + 4.81 = 8.94$$

$$All\ birds_{Age=4} = \frac{8.94}{0.854} + 7.47 = 17.94$$

$$All\ birds_{Age=3} = \frac{17.94}{0.854} + 5.61 = 26.62$$

$$All\ birds_{Age=2} = \frac{26.62}{0.854} + 0.14 = 31.31$$

$$All\ birds_{Age=1} = \frac{31.31}{0.854} + 0.0 = 36.67$$

$$All\ birds_{Age=0} = \frac{36.67}{0.79} + 0.0 = 46.41$$

Therefore, 46.41 fledglings are required.

$$N_{Breeding\ pars} = \frac{46.41}{0.819} = 56.67$$

Therefore, 57 (56.7) additional breeding pairs are required to recruit 21 kittiwakes into the regional population and hence compensate for Hornsea Four's impacts.

Predator Eradication

The example below calculates the number of additional breeding adults needed to compensate for the mortality of 37 (36.6) guillemots as a result of Hornsea Four. The same approach is applicable to razorbill, although noting that razorbills are assumed to recruit at age five.

Equation 1:

$$N_{Fledglings\ required} = \frac{N_{New\ breeding\ recruits\ required}}{\prod_{Age=0}^{Age=6} Survival_{Age}}$$

Equation 2:

$$N_{Breeding\ pairs\ required} = \frac{N_{Fledglings\ required}}{Productivity}$$

Equation 1 with example values:

$$N_{Fledglings\ required} = \frac{36.58}{0.56 * 0.792 * 0.917 * 0.939 * 0.939 * 0.939} = 108.62$$

Equation 2 with example values:

$$N_{Breeding\ pairs\ required} = \frac{108.62}{0.672} = 161.64$$

Therefore, space for an additional 162 (161.6) breeding pairs would be required to recruit 37 guillemots into the regional population and hence compensate for Hornsea Four's impacts.

Bycatch Reduction

The example below calculates the number of vessels required to compensate for the mortality of 37 (36.6) adult guillemots and two (1.7) adult razorbills as a result of Hornsea Four.

Equation 1:

$$N_{auks\ avoiding\ bycatch\ per\ vessel} = N_{auks\ caught\ as\ bycatch} \times Looming\ eye\ deterrent\ reduction\ in\ bycatch$$

Equation 2:

$$N_{auks\ avoiding\ bycatch\ to\ compensate\ for\ predicted\ impacts} = (guillemot\ predicted\ impacts\ \times guillemot\ Juvenile\ proportion\ rate\ ) + (razorbill\ predicted\ impacts\ \times razorbill\ Juvenile\ proportion\ rate\ )$$

Equation 3:

$$N_{vessels\ required} = \frac{N_{auks\ avoiding\ bycatch\ to\ compensate\ for\ predicted\ impacts}}{N_{auks\ avoiding\ bycatch\ per\ vessel}}$$

Example values for Equation 1:

$$N_{auks\ avoiding\ bycatch\ per\ vessel} = 29.8\ \times 30\% = 8.9$$

Example values for Equation 2:

$$N_{auks\ avoiding\ bycatch\ to\ compensate\ for\ predicted\ impacts} = (36.58\ \times 140\%\ ) + (1.67\ \times 148\%\ ) = 53.68$$

Example values for Equation 3:

$$N_{vessels\ required} = \frac{51.3}{8.9} = 6.03$$

Therefore, six (6.0) vessels would need to be supplied with looming eye deterrents in order to compensate for Hornsea Four’s impacts on guillemot and razorbill.