Hornsea Project Four

Indirect Effects of Forage Fish and Ornithology

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Checked Pinsent Masons, June 2022
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Approved Julian Carolan, Orsted, June 2022

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Glossary

Term	Definition
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four
Nearshore	Generally, a shallow water area close to the coast.
Offshore	Generally, a more exposed and deeper water area away from any coastal influence.
Order Limits	The limits within which Hornsea Project Four (the 'authorised' project) may be carried out.
Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO).
Sandwave	A bedform feature commonly formed of sands, defined here with a crest to crest wavelength greater than 25 m, often superimposed with megaripples.
Short-term	A sub-set of a repeating cycle, e.g. likely to be a few days, weeks, or months but much less than a year

Acronyms

Term	Definition
DCO	Development Consent Order
DGPS	Differential Global Positioning System
DGM	Digital Ground Models (DGMs)
EGA	Expert Geomorphological Assessment
EIA	Environmental Impact Assessment
ERYC	East Riding of Yorkshire Council
HTA	Historical Trend Analysis
LAT	Lowest Astronomical Tide
MCZ	Marine Conservation Zone
MMO	Marine Management Organisation
SAC	Special Area of Conservation
SPA	Special Protection Area
RIAA	Report to Inform the Appropriate Assessment
SSSI	Site of Special Scientific Interest
S-P-R	Source-Pathway-Receptor

1 Introduction

1.1 Background

1.1.1.1 Orsted Hornsea Project Four Limited (the 'Applicant') is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). Hornsea Four will be located approximately 69 km offshore of the East Riding of Yorkshire in the Southern North Sea (Figure 1) and will be the fourth project to be developed in the former Hornsea Zone. Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to the landfall, and onshore infrastructure including connection to the electricity transmission network.

1.1.1.2 The wind farm is located in the vicinity of the Flamborough Front, the boundary between two distinct water masses, and the export cable corridor crosses Smithic Bank with landfall south of Bridlington.

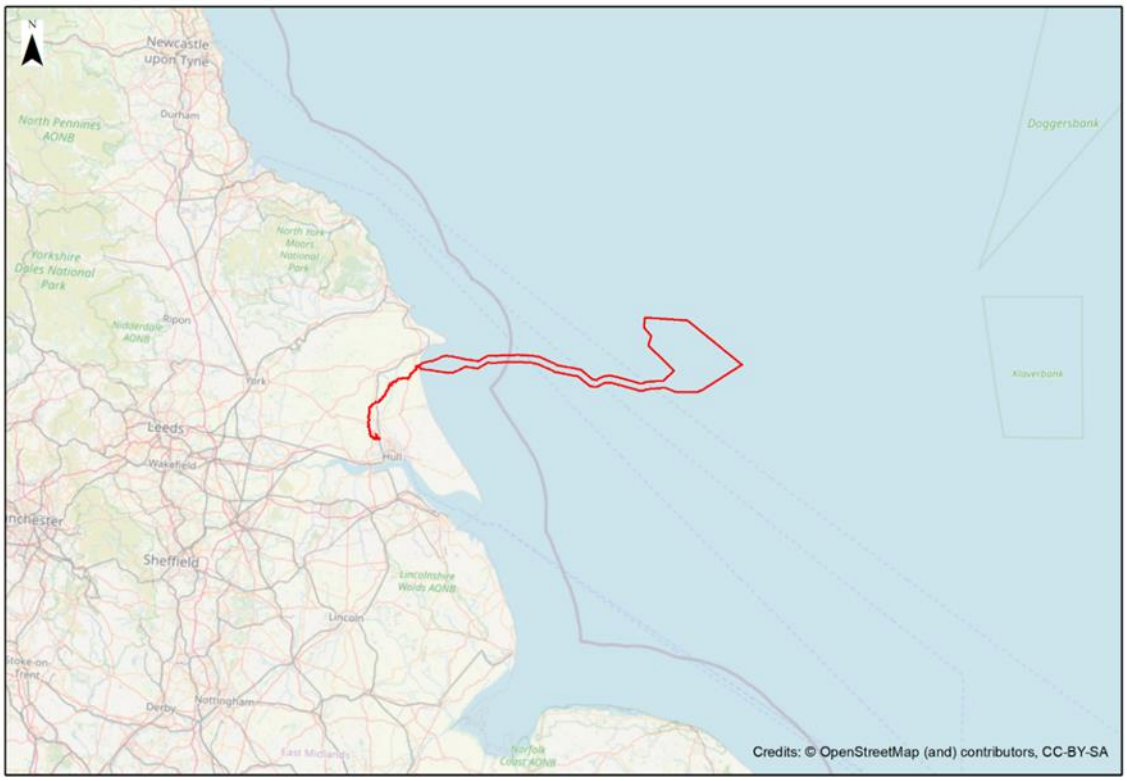

Figure 1: Hornsea Project Four Offshore Wind Order Limits

1.1.1.3 This report addresses the comments from Natural England and Marine Management Organisation (MMO) in their Relevant Representations (Planning Inspectorate Reference EN010098, RR-020 and RR-029) to the Hornsea Four Development Consent Order (DCO) Application on the topic of indirect effects on forage fish and ornithology. The main issues raised by Natural England and the MMO relate to the Flamborough Front, forage fish, seabird distributions, and auk post-breeding dispersal. The form and function of the Flamborough Front with regards to the proposed project has been reviewed in **A2.1 Marine Geology, Oceanography and Physical Processes (APP-013)** and **G4.9 Marine Processes Supplementary Report (REP4-043)**. A summary of the specific relevant representations that raised queries with regards to the topics covered in this report and where these are addressed is available below in **Table 1**.

1.1.1.4 This report provides a summary of the baseline information already presented in the Environmental Statement (ES), RIAA with regards to these queries and compiles this information to present an assessment of any indirect effects between the Flamborough Front and ornithology and forage fish receptors.

Table 1: Relevant Representation References.

Relevant Rep ID	Relevant Representation	Where addressed
Flamborough Front		
RR-029-5.56	The Flamborough Front is formed where the stratified water from the northern North Sea meets the mixed water from the southern North Sea. The mixing of these two waterbodies leads to an upwelling of nutrients, which in turn leads to increased plankton growth and associated productivity, giving rise to concentrations of forage fish which in turn provide a feeding ground for other species. It is therefore perhaps of no surprise that areas around the front support high densities of seabirds and marine mammals. Consequently, it is vital that the potential impacts of the project alone and in-combination with other plans and projects be adequately assessed. Natural England, therefore, considers this receptor to have high environmental value and not medium as indicated in the ES.	The form and function of the Flamborough Front is described in **G4.9 Marine Processes Supplementary Report (REP4-043).** It is the Applicant's position that the magnitude of the potential impact is negligible (see response to RR-029-APDX:E-55 and RR-029-APDX:E-56 in **G1.9 Applicant's comments on Relevant Representations (REP1-038)**) and therefore even if the sensitivity were increased if the sensitivity of the feature was considered high then the associated impact according to Table 1.16 would become slight (not significant) rather than neutral (not significant). Therefore, no significant effects in EIA would be predicted.
RR-029-APDX:B-97	NE require further evidence to be able to rule out the potential importance of both the Flamborough Front and wider prey availability issues in the immediate vicinity of the project on the success of birds at FFC SPA.	Section 8 presents the relationship between post-breeding dispersal of auks, commercial fisheries, and water depth.
RR-029-APDX:E-D	Data Gaps: .....Effects of the proposed foundation structures on turbulent wake-induced mixing, stratification, and, in turn, primary productivity in and around the Flamborough Front.	Please see comments above and specifically Section 4.3 of **G4.9 Marine Processes Supplementary Report (REP4-043)** for assessment of the proposed foundation structures on turbulent wake-induced mixing, stratification.
RR-029- APDX:E-8	The waters around Flamborough Head are particularly rich in marine life because of its proximity to an upwelling of nutrients and plankton caused by the Flamborough Front. Given the importance of this frontal system to primary productivity in the North Sea, it is vital to understand the potential impacts of the	The form and function of the Flamborough Front is detailed in **G4.9 Marine Processes Supplementary Report (REP4-043)**.

Relevant Rep ID	Relevant Representation	Where addressed
	HP4 alone, and in-combination with other plans and projects.	
RR-029- APDX:E-56	We would advise that the sensitivity of the Flamborough Front should be considered High until further evidence to the contrary has been provided.	The sensitivity of the Flamborough Front is described in Section 4 of G4.9 Marine Processes Supplementary Report (REP4-043).
RR-029- APDX:E-55	"Turbulent wakes are not expected to interact with the Flamborough Front." The magnitude of impact has been assessed as 'negligible' for this effect." The Flamborough Front is located close to/overlaps the HP4 array (and HP2 and HP1)/ Given the importance of the Front to primary productivity (and in turn secondary productivity), a better understanding of the potential impacts of the project alone (and in-combination) is required.	The sensitivity of the Flamborough Front is described in Sections 4.2 and 4.3 of G4.9 Marine Processes Supplementary Report (REP4-043).
RR-020-3.2.7	the impact on Flamborough front, especially any changes (positively and negatively) to primary productively (and subsequently secondary productivity) has not yet been fully addressed.	Section 8 presents an assessment of impacts to primary productivity and the Flamborough Front.
Forage Fish		
RR-029-APDX:B-11	Natural England advises that a summary of the outcomes of the relevant assessments on forage fish abundance and distribution in and around the project area should be included and discussed in relation to the implications for key seabird species.	Sections 5 and 8 present an assessment of impacts to primary productivity and key seabird species and the Flamborough Front
RR-029-APDX:B-11	Sprat also receive very little attention but are a key resource for many seabirds at different times of year. Further assessment is therefore needed to understand how more localised impacts on fish and shellfish might influence prey availability for seabirds	Sections 5 and 8 present an assessment of impacts to forage fish and the Flamborough Front
Seabird Distributions (functional links)		
RR-029-APDX:B-92 & RR-029-APDX:B-105	NE suggest that the proximity of the project area to FFC SPA and the high densities of guillemot and razorbill that appear to be present in August and September, could indicate functional linkages with the SPA colony that warrant consideration of SPA conservation objectives beyond population abundance i.e. in relation to supporting habitats.	Sections 6 and 7 present an assessment of the linkages between the FFC SPA and the Hornsea Four Array area.
Auk post-breeding dispersal		
RR-029-APDX:B-F	Whilst the Developable Area Approach undertaken by the Applicant excludes the highest areas of use, high numbers of these species are still recorded in the baseline surveys for the array area during this period. This is a key, sensitive period for guillemot and razorbill which may be in moult, and thus flightless, and are accompanied by dependent chicks. Given the proximity of the Hornsea 4 array to FFC SPA, we consider the high	Sections 6 and 7 present an assessment of the linkages between the FFC SPA and the Hornsea Four Array area.

Relevant Rep ID	Relevant Representation	Where addressed
	usage at a sensitive period could suggest functional linkages with the SPA colony which warrant further investigation.	
RR-029-APDX:B-50	Given the proximity of the array area to FFC SPA, lack of other large populations nearby and the fact that the birds will be moulting, and therefore flightless, we consider it likely that a large proportion of the birds will originate from FFC SPA, rather than other SPAs that are mainly in Scotland, at this time. We are therefore concerned that there is potential for the array area to have functional links with the FFC SPA colony and that displacement of birds from favoured areas could result in a loss of important supporting habitat for a key lifecycle stage, resulting in a range of effects including mortality. We therefore consider that the potential importance of this area to guillemot during August and September has not currently been accounted for in the Applicant's approach and warrants further exploration, as there could be merit in the application of a bespoke approach for this period.	Sections 6 and 7 present an assessment of the linkages between the FFC SPA and the Hornsea Four Array area.
RR-029-5.6	Baseline characterisation data for Hornsea 4 suggests that the array area (plus buffer) is used by considerable numbers of guillemot and razorbill both within and outside the breeding season, and particularly in August and September. This is a key, sensitive period for these two auk species as they head offshore to moult, the males accompanied by dependent chicks, and are flightless for several weeks potentially making them dependent on specific foraging areas. Given the proximity of the array area to the FFC SPA, we consider it likely that a large proportion of the auks present originate from the colony. We are therefore concerned that there is potential for the array area to have functional links with the FFC SPA colony and that displacement of birds from favoured areas could result in a loss of important supporting habitat for a key lifecycle stage, resulting in a range of effects including mortality.	Sections 6 and 7 present an assessment of the linkages between the FFC SPA and the Hornsea Four Array area.
RR-029-5.8	Natural England request that further consideration is given now to drivers of seasonal variations in the wider spatial distributions of auks, particularly during August and September, to determine the potential importance of this area.	Section 7 provides a review of the August and September seasonal variations in auk distribution.
Indirect effects		
RR-029-5.10 & RR-029-APDX:B-L	Natural England consider that an understanding of the relative importance of the site as a foraging area, and potential for any impacts on prey abundance and	Sections 5 and 8 present an assessment of the important of the site for forage fish and associated impacts.

Relevant Rep ID	Relevant Representation	Where addressed
	distribution is critical in framing the predicted impacts that can be quantified.	
RR-029-APDX:B-Q I	Natural England generally agree with the impact pathways identified and assessed, but do not consider that indirect and barrier effects have been adequately assessed for some relevant receptors (gannet, kittiwake, guillemot, razorbill and puffin).	**The document B2.2 Report to Inform Appropriate Assessment Part 1 (REP1-010)** and Section 8, below, describe the effects on key seabird species.

2 Signposting to the ES and RIAA

2.1 Signposting to the Environmental Statement

2.1.1.1 The Applicant has 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 Environmental Impact Assessment (EIA) on Hornsea Four and its associated infrastructure. The focus of the EIA included the assessment of the environmental effects which are likely to have significant effects on the environment, as well as identifying opportunities for beneficial impacts.

2.1.1.2 This report has sought to collate information from the following DCO Application documents (capturing any updates made to these documents during Examination):

- **A1.4: Project Description (APP-010)**, amended by **REP4-004**;
- **A2.1: Marine Geology, Oceanography and Physical Processes (APP-013)**;
- **A5.1.1: Marine Processes Technical Report (APP-067)**;
- **A2.2: Benthic and Intertidal Ecology (APP-014)**;
- **A5.2.1: Benthic and Intertidal Ecology Technical Report (APP-068)** amended by **AS-009**;
- **A5.2.3: Marine Conservation Zone Assessment (APP-070)**;
- **A2.3: Fish and Shellfish Ecology (APP-015)**;
- **A5.3.1: Fish and Shellfish Ecology Technical Report (APP-071)**;
- **A2.5: Offshore and Intertidal Ornithology (APP-017)**;
- **A5.5.1: Offshore and Intertidal Ornithology Baseline Characterisation Report (APP-074)**;
- **A5.5.4: Offshore Ornithology Population Viability Analysis (APP-077)**;
- **A5.5.5: Offshore Ornithology Migratory Birds Report (APP-078)** and
- **A5.5.6: Offshore Ornithology MRSea Report (APP-079)**.

2.1.1.3 The collated information is intended to provide the MMO and Natural England with sufficient information on the indirect effects that could occur in the Flamborough Front on forage fish and ornithology.

2.2 Signposting to the Report to Inform Appropriate Assessment

2.2.1.1 The Applicant has submitted a thorough Report to Inform Appropriate Assessment (RIAA) for Hornsea Four. The supporting Screening Report considers all National Site Network Sites and their features and concludes that some designated features and sites could be screened

out of the assessment, and therefore not included further within the RIAA. Several sites were screened out for coastal processes effects, including those presented in Table 2.

Table 2: Sites and features screened out in relation to physical processes assessments.

Site	Feature	Effect	Justification	Location
Flamborough and Filey Coast SPA	All ornithological receptors	Indirect impacts through the effects on prey species	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) considers that **all designated species are not sensitive to insignificant effects on prey species** within the Hornsea Four array area (as identified by the findings reported in the project's Environmental Statement - **A2.3: Fish and Shellfish Ecology (APP-015)** and **A2.2: Benthic and Intertidal Ecology (APP-014)**) indirectly during the operation and maintenance phase. No potential for LSE.	Screening Matrices – Matrix 24: Flamborough and Filey Coast SPA – page 79/144 Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**
Humber Estuary SAC	Grey Seal	Temporary Increases in Suspended Sediment	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) considers that grey seal **frequently occur in relatively turbid environments and are thus adapted to locating prey in such conditions**. The construction, operation & maintenance and decommissioning activities **will be localised and intermittent in nature, and the extent and duration of any increase in suspended sediment (and subsequent deposition) being negligible**, therefore concluding that no LSE applies.	Screening Matrices – Matrix 6a: Humber Estuary SAC, Grey Seal – page 29/144 Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**
		Changes to physical processes	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) identifies that the Humber Estuary SAC at its closest point to Hornsea Four (avoiding straight lines crossing land) is 47 km. **A2.1: Marine Geology, Oceanography and Physical Processes (APP-013)** found the **maximum extent of change in physical processes to be insufficient to reach the Humber**. On this basis, it is determined there is no potential for Likely Significant Effects (LSE) from Hornsea Four to the habitats and supporting habitats of the Humber Estuary SAC.	
	Migratory Fish	Release of sediment suspension/smothering	The site does not overlap with Hornsea Four and is located at least 47 km from its boundary (excluding straight lines crossing land), with the array even further distance, **which is outside the potential range of effect for suspended sediment** (see Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**)). Therefore, no LSE applies.	Screening Matrices – Matrix 6b: 6b: Humber Estuary SAC, Migratory Fish – page 31/144 Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**
		Changes to physical processes	The Humber Estuary SAC at its closest point to Hornsea Four (avoiding straight lines crossing land) is 47 km. **A2.1: Marine Geology, Oceanography and Physical Processes (APP-013)** found **the maximum extent of change in physical processes to be insufficient to reach the Humber**. On this basis, it is determined there is no potential for LSE from Hornsea Four to the habitats and supporting habitats of the Humber Estuary SAC.	

Site	Feature	Effect	Justification	Location
	Habitats	Changes to physical processes	The Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) identifies that the Humber Estuary SAC at its closest point to Hornsea Four (avoiding straight lines crossing land), is 47 km. **A2.1: Marine Geology, Oceanography and Physical Processes (APP-013)** found **the maximum extent of change in physical processes to be insufficient to reach the Humber**. On this basis, it is determined there is no potential for Likely Significant Effects (LSE) from Hornsea Four to the habitats and supporting habitats of the Humber Estuary SAC	Screening Matrices – Matrix 6c: Humber Estuary SAC, Habitats – page 33/144 Appendix B of **B2.2: Report to Inform Appropriate Assessment (AS-013)**
Humber Estuary Ramsar	Migratory fish	Temporary increases in suspended sediments	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) identifies that the site is located 47km from the Hornsea four Order Limits, which is outside of the potential range of effect (16km) for this impact.. No LSE applies. Table 6 within the Screening Report also considers that the impacts during the decommissioning phase are similar and potentially less than those outlined in the construction phase. Therefore, a finding of no LSE is appropriate.	Screening Matrices – Matrix 7b: Humber Estuary Ramsar, Migratory fish – page 37/144 Appendix B of **B2.2: Report to Inform Appropriate Assessment (AS-013)**
	Grey seal	Temporary increases in suspended sediments	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) considers that **grey seal frequently occur in relatively turbid environments and are thus adapted to locating prey in such conditions.** The construction, operation & maintenance and decommissioning activities **will be localised and intermittent in nature and the extent and duration of any increase in suspended sediment (and subsequent deposition) being negligible**, no LSE applies	Screening Matrices – Matrix 7a: Humber Estuary Ramsar, Migratory fish – page 35/144 Appendix B of **B2.2: Report to Inform Appropriate Assessment (AS-013)**
	Habitats	Changes to physical processes	The Humber Estuary Ramsar at its closest point to Hornsea Four (avoiding straight lines crossing land) is 47 km. **A2. 1: Marine Geology, Oceanography and Physical Processes (APP-013)** and Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) considers the **maximum extent of change in physical processes to be insufficient to reach the Humber**. On this basis, it is determined there is no potential for LSE from Hornsea Four to the habitats and supporting habitats of the Humber Estuary Ramsar	Screening Matrices – Matrix 7c: Humber Estuary Ramsar, Habitats – page 39/144 Appendix B of **B2.2: Report to Inform Appropriate Assessment (AS-013)**
Southern North Sea SAC	Harbour porpoise	Temporary Increases in Suspended Sediment	Table 6 within the Screening Report (Appendix A of **B2.2: Report to Inform Appropriate Assessment (REP2-005)**) considers that **harbour porpoise frequently occur in relatively turbid environments and are thus adapted to locating prey in such conditions**. The construction, operation & maintenance and decommissioning activities **will be localised and intermittent in nature, and the**	Screening Matrices - Matrix 1: Southern North Sea – page 19/144

Site	Feature	Effect	Justification	Location
			extent and duration of any increase in suspended sediment (and subsequent deposition) being negligible, therefore concluding that no LSE applies	Appendix B of **B2.2: Report to Inform Appropriate Assessment (AS-013)**

2.2.1.2 In summary, the relevant conclusions from the Screening Report are:

- Flamborough and Filey Coast SPA bird features are not sensitive to insignificant effects on prey species.
- The Harbour Porpoise and Grey Seal features of the Southern North Sea SAC and Humber Estuary SAC/ Ramsar Sites respectively frequently occur in relatively turbid environments and are thus adapted to locating prey in such conditions.
- Hornsea Four activities will be localised and intermittent in nature and the extent and duration of any increase in suspended sediment (and subsequent deposition) will therefore be negligible/ insignificant.
- Any change in physical processes will be localised and insufficient to reach the Humber Estuary SAC and Ramsar sites.

2.2.1.3 Coastal processes have been screened in for Flamborough Head SAC, however the RIAA concluded that there was no potential for AEoI for impacts associated with suspended sediment concentration and deposition during construction following the short-term and temporary nature of the change in suspended sediment concentrations (SSC), existing levels of SSC in the area, the predicted lack of any accumulation of sediment within the SAC due to the distance from the release point, and the high mobility of sediment within the SAC. For more context see paragraph 10.2.3.10 within **B2.2: Report to Inform Appropriate Assessment** (page 112/489).

2.2.1.4 No AEoI was also concluded during operation and maintenance, given the small scale and magnitude of possible impact during operation and maintenance compared to the construction phase, together with the potential for effect being well within the relevant pressure benchmark. For more context see paragraph 10.2.4.8 within **B2.2: Report to Inform Appropriate Assessment** (page 122/489).

2.2.1.5 For the "change in coastal processes" effect itself, the assessment considered potential for change to sediment transport, wave climate and tidal flow from the project, including from the cable crossings seawards of Smithic Bank, concluding any changes to be localised, with no alteration to nearshore sediment transport. Further, the assessment found the seabed substrate around the headland at Flamborough to be mainly rock, indicating an area scoured of mobile sediments by the locally faster flows. No change in physical processes within the SAC were predicted, and therefore it was concluded that there is no potential for an AEoI. For more context see paragraph 10.2.4.19 within **B2.2: Report to Inform Appropriate Assessment** (page 124/489).

3 Flamborough Front

3.1.1 Flamborough Front

3.1.1.1 A detailed synopsis on the form and function of the Flamborough Front was provided in **G4.9 Marine Processes Supplementary Report** (**REP4-043**) to which the reader is referred. The Flamborough Front is strongly seasonal, forming in summer and breaking down in autumn. For detail on seasonal variation or peak occurrence of the front the reader is referred to **REP4-043**. **Figure 2** presents the northern and southern extent of peak summer occurrence of the Flamborough Front, which delineates the study area for the physical and biological receptors within this report. At its peak summer occurrence in July 2018 (see dashed blue line in **Figure 2**) the proposed Hornsea Four array is wholly within the dense and mixed water to the south of the front and therefore any mixing associated with the Hornsea Four foundations would not contribute to any potential instability to the boundary of the front but be wholly within the main body of colder and less dense stratified water to the south

(see Figure 2: Location of Hornsea Project Four offshore array area relative to potential northerly and southerly positions of Flamborough Front idealised from a number of datasets (see Figure 30 in REP4-043).**Figure 2**). No effect upon primary or secondary productivity is anticipated.

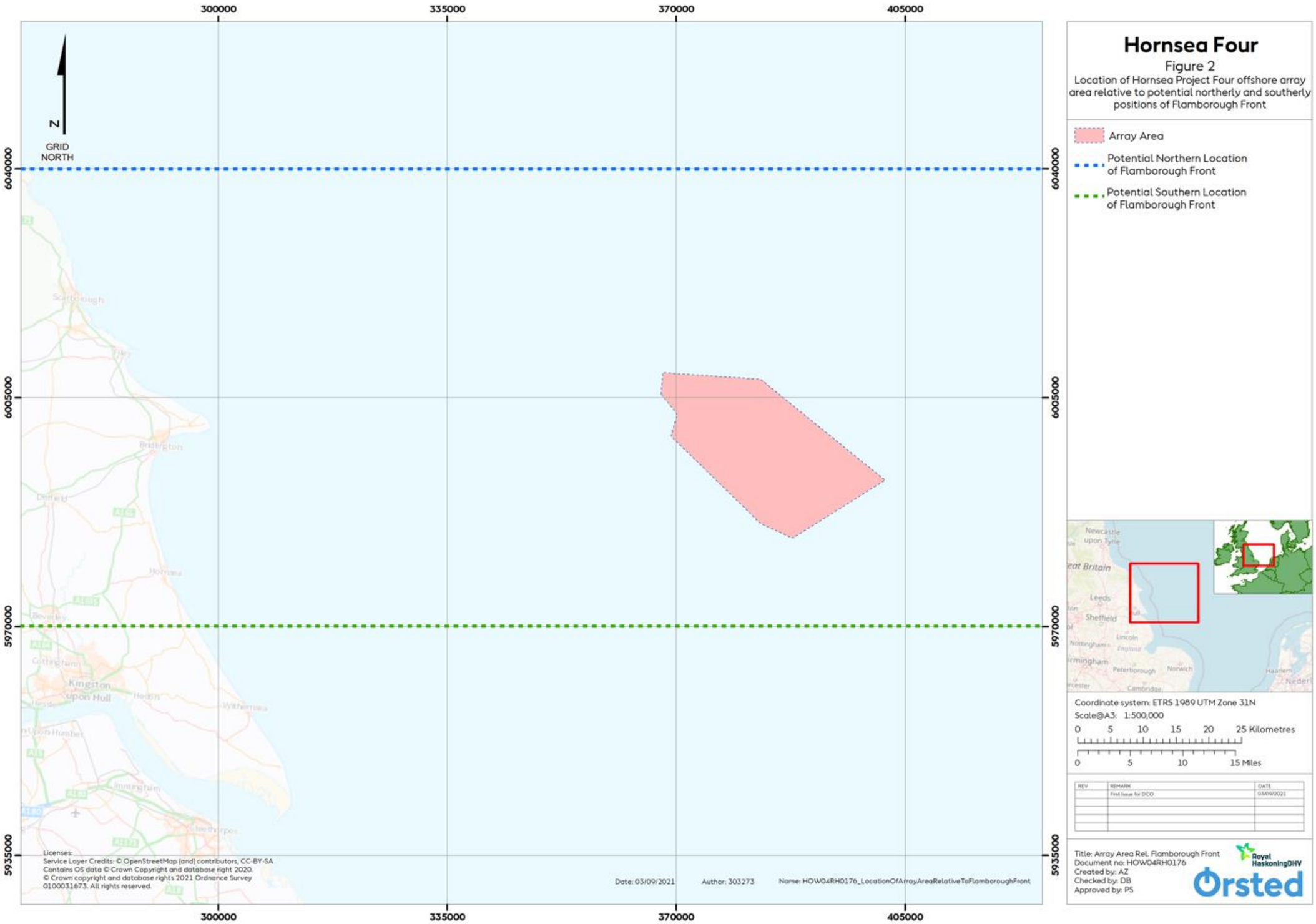

Figure 2: Location of Hornsea Project Four offshore array area relative to potential northerly and southerly positions of Flamborough Front idealised from a number of datasets (see Figure 30 in REP4-043).

3.1.1.2 At its peak southern summer occurrence (see dashed green line in Figure 2 as the southern boundary of the Flamborough Front) the proposed Hornsea Four array is wholly within the less dense and stratified water to the north of the front and therefore any mixing associated with the Hornsea Four foundations could contribute to potential instability to the boundary of the front. However, any mixing of less dense, stratified water would occur with water of similar density and stratification and thereby not adversely affect the form of function of the front. Also, the less dense overlying water would not mix with the lower lying, mixed dense water. Subsequently, no effect upon primary or secondary productivity is anticipated.

3.1.1.3 The Flamborough Front is a tidal mixing front (see Figure 3). The turbulence resulting from friction with the seabed causes vertical mixing of the water column, which can extend to the sea surface in areas where the water is shallow (e.g. towards the south of Hornsea Four) and/or where the tidal currents are strong enough. In other areas, where tidal currents are weaker and/or the water is deeper (e.g. towards the north of Hornsea Four), less mixing occurs, and stratification of layers of different densities can develop when surface waters are warmed in summer (see Section 4 of REP4-043). A schematic section through this idealised tidal mixing front is presented in Figure 3.

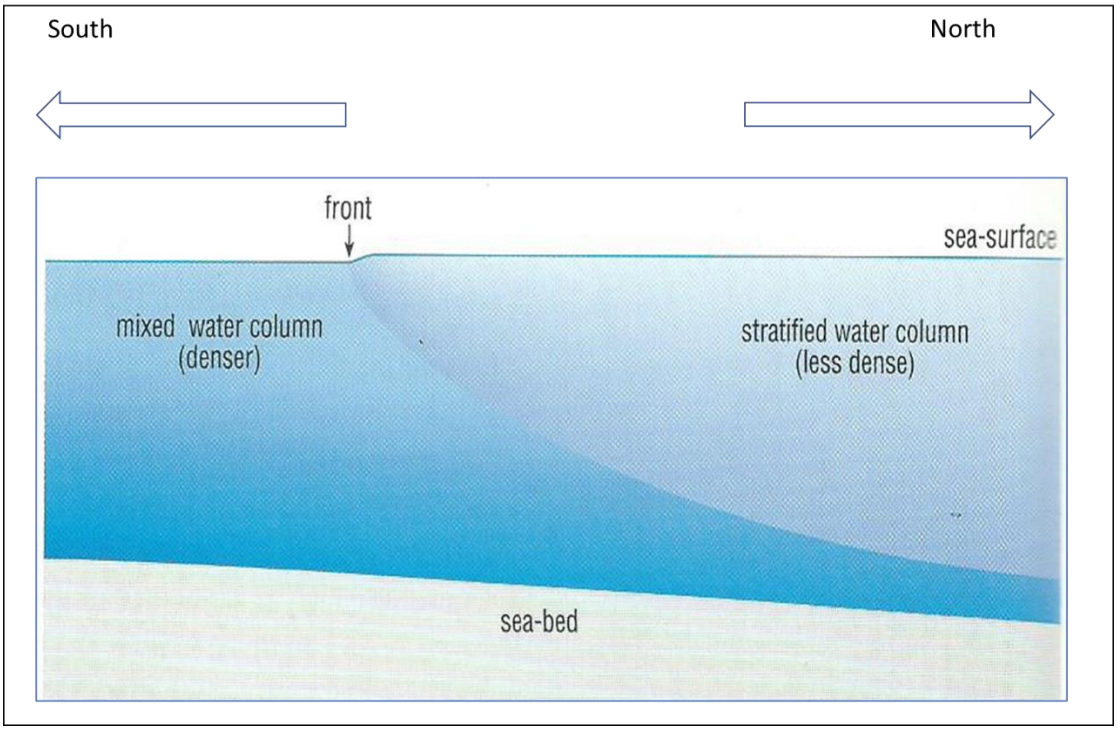

Figure 3: Schematic section with greatly exaggerated vertical scale through a tidal mixing front between stratified and tidally mixed waters in a shallow sea (such as the North Sea) (Open University 2001).

3.1.1.4 As highlighted in Figure 3, the Flamborough Front is predominantly a near-bottom feature (i.e. dense and mixed water near or at the seabed), that when present at its maximum extent, is an approximate 320km-long zone located off the East Riding of Yorkshire coast (see Figures 22, 23 and 24 in REP4-043).

3.2 Flamborough Front in Autumn

3.2.1.1 This short section summarises the key characteristics of the Flamborough Front to address comments from Natural England (see **Table 1**) in relation to productivity, inter-related effects and forage fish and bird distributions (post-breeding dispersal of guillemot).

3.2.1.2 Due to the theme of post-breeding dispersal of guillemot and the establishment of relationships between guillemot distribution and inter-related effects associated with fixed physical and mobile biological receptors, the detail of the Flamborough Front presented here focusses only on the autumn. **Figure 4** presents the autumn seasonal front (Inset A) and seasonal front interannual variability (Inset B). Data have been taken from a numerical model based on tidal currents and bathymetry; taken from Miller and Christodolou (2014) as this relates to the post-breeding dispersal period of guillemot (August and September).

3.2.1.3 Inset A (**Figure 4**) shows that the position of the Flamborough Front in autumn is predominantly to the north of the Array Area over the analysed period (1998 to 2008) and displays relative consistency, being present >40% of the time. By contrast, Inset B shows there is no consistent pattern (spatial extent and location) of the Flamborough Front being characterized by a high degree of interannual variability being potentially present (~20% of the time) at any location over the southern North Sea (see UK Map on the right of Inset A of **Figure 4**).

3.2.1.4 As presented in the Marine Management Organisation (MMO) Deadline 3 comments on the Flamborough Front (see Responses to Examiners Questions 1 deferred from Deadline 2 in **REP3-052**), changes in the intensity of the stratification can arise due either to colder than normal deep water to the north or additional heating to the south. This can be caused by the increase of cloudless and windless days that allow stratification to build from the surface. The magnitude, size and frequency of the meanders of the Front can change due to changes in wind strength/direction and those factors described above.

3.2.1.5 Such variability in the external forcing parameters of wind strength/direction and cloud cover are broadly accepted to be more variable and or greater intensity in autumn. This is reflected in the more diffuse boundary of the Flamborough Front at this time and decreased frequency of occurrence at Hornsea Four Array Area as presented in **Figure 4**.

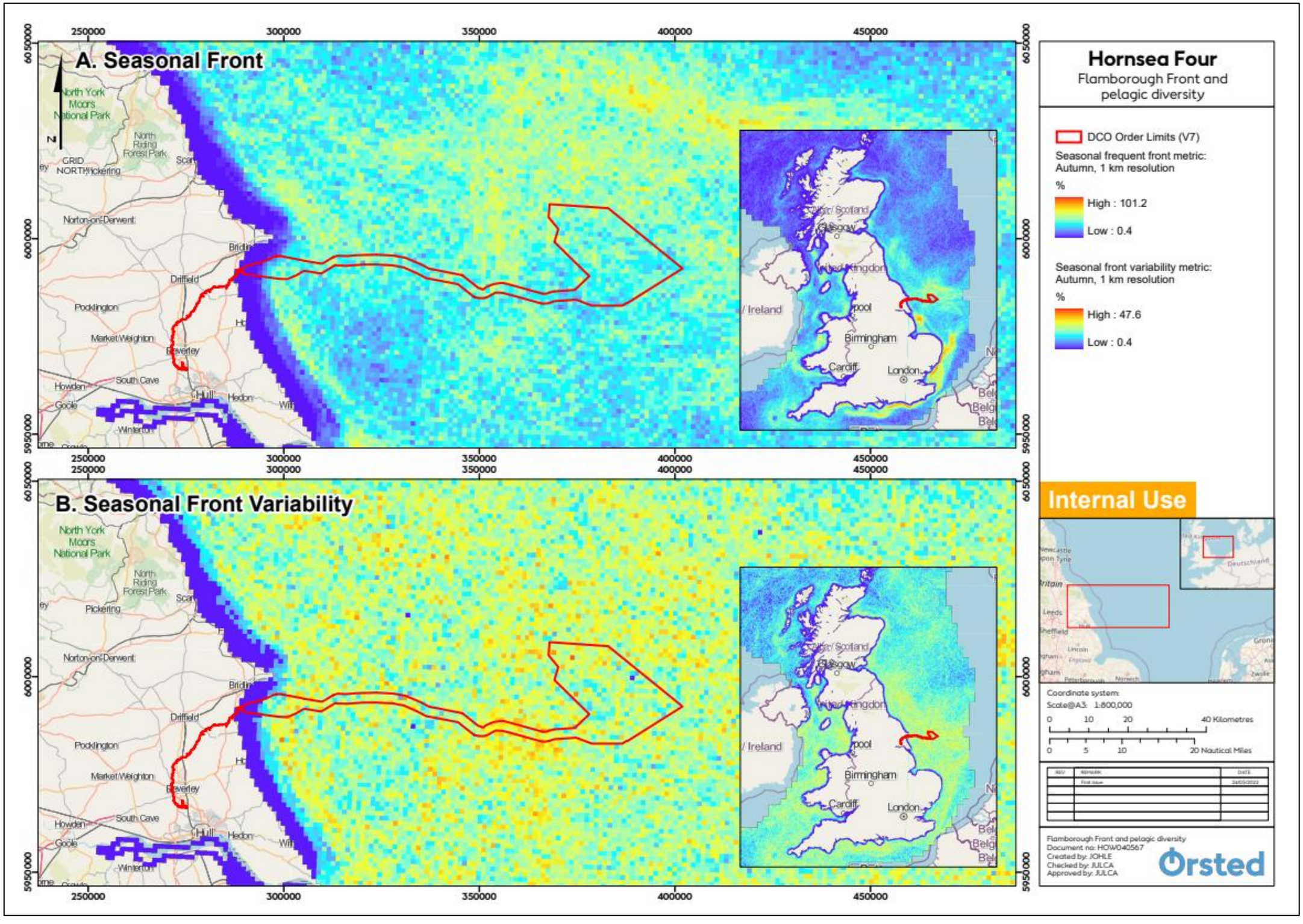

Figure 4: Flamborough Front position variability based on data from Miller and Christodolou (2014).

3.3 Updates to the Impacts Assessments

3.3.1.1 The Hornsea Project Four offshore array is likely to be located within a zone bounded to the north and south by the various reported positions of the Flamborough Front (Figure 4). This means that the array could sit within the well-mixed waters to the south, the stratified waters to the north, or on the Front itself. The potential impact of the MDS would be to change tidal mixing processes which may inhibit formation of the Flamborough Front through blockage of flows by the foundations leading to increased turbulence.

3.3.1.2 As highlighted by the MMO (or their scientific advisors CEFAS in the MMO Deadline 3 comments on the Flamborough Front (see Responses to Examiners Questions 1 deferred from Deadline 2 in REP3-052)) turbulent mixing of surface waters by winds will break down the upper layers of stratification and will reinforce mixing by tidal currents. The position of a vertical front is also variable on shorter timescales of hours to days as the water body is advected back and forth by local (ebb and flood) currents. This natural background process will be at a scale to be indifferentiable from effects/changes associated with turbulent wake formation from foundation structures.

3.3.1.3 This natural background process is anticipated to be at a scale that is indifferentiable from effects/changes associated with turbulent wake formation (10's to 100's of metres) from foundation structures as highlighted in Marine Processes Supplementary Report (REP4-043).

3.3.1.4 Given that the Flamborough Front is a highly dynamic and ephemeral landscape-scale feature, it would not be affected by localised, small-scale changes in water column turbulence induced by individual wakes at foundation locations.

3.3.2 Summary

3.3.2.1 The Flamborough Front is strongly seasonal, forming in summer and breaking down in autumn. At its peak summer occurrence, the proposed Hornsea Four array is wholly within the front and therefore any mixing associated with the Hornsea Four foundations would not contribute to the boundary of the front but be wholly within the main body of colder and less dense stratified water to the north (see Figure 3). This would create mixing of less dense water with the same stratified less dense waters and thereby not adversely affect the form of function of the front.

3.3.2.2 In autumn there is no discernible pattern to the form and function of the Flamborough Front (see Inset B in Figure 4). Furthermore, as concluded by Miller and Christodolou (2014), ocean fronts (of which the Flamborough Front is one) are a proxy for enhanced biodiversity, not a direct measure. This is predominantly due to their inference being based on satellite observations of sea surface temperature (SST) which are in turn related to the formation of surface fronts through persistence of occurrence.

3.3.2.3 Greater variability in the external forcing parameters of wind strength/direction and cloud cover are expected to be more variable and of greater intensity in autumn, thereby contributing significantly to the breakdown of the front and its relative inconsistent spatial extent and location as evidenced at this time of the year.

4 Bathymetry

4.1.1 The general seabed profile within the southern and northern extents of the summer Flamborough Front (Area A in Figure 5) is broadly characterised by a northerly gradient of increasing water depth. The shallowest waters being in the south. This is illustrated within the detailed bathymetry of the Hornsea Four AfL (Area B in Figure 5).

4.1.2 Outer Silver Pit, a large geological "tunnel valley" depression, establishes the north-westerly / south-easterly alignment of the eastern boundary of the offshore array (see **Figure 5** and inset for detail). The shallowest water depth being to the south. This is illustrated within the detailed bathymetry of the Hornsea Four AfL (Area B in **Figure 5**) where shallow water depths are attributable to the occurrence of sandwave field overlying an area of, relatively, elevated seabed within the former Scoping Array Area.

4.1.2.1 At the Scoping stage, water depth varied from 24-63m, while within the Preliminary Environmental Information Report (PEIR), water depth varied from 30 to 60m. These water depths are consistent with the DCO Array Area at Application. Area A in **Figure 5** clearly highlights that largest expanse of shallow seabed being within the southern extent of the former Scoping Array Area, to the south of the DCO Array Area. These areas and their associated water depths are presented in **Figure 5** (see Area B for detail).

4.1.3 Summary

4.1.3.1 As stated in **Section 2**, turbulence resulting from friction with the seabed causes vertical mixing of the water column, which can extend to the sea surface in areas where the water is shallow, such as the southern extent of the Hornsea Four Array Area (see **Figure 5**). Bathymetry therefore exerts a primary control on the extent of the Flamborough Front, with the delineation of its peak summer southern extent correlating with rising seabed and shallow water depths which promote mixing (see **Figure 5**)

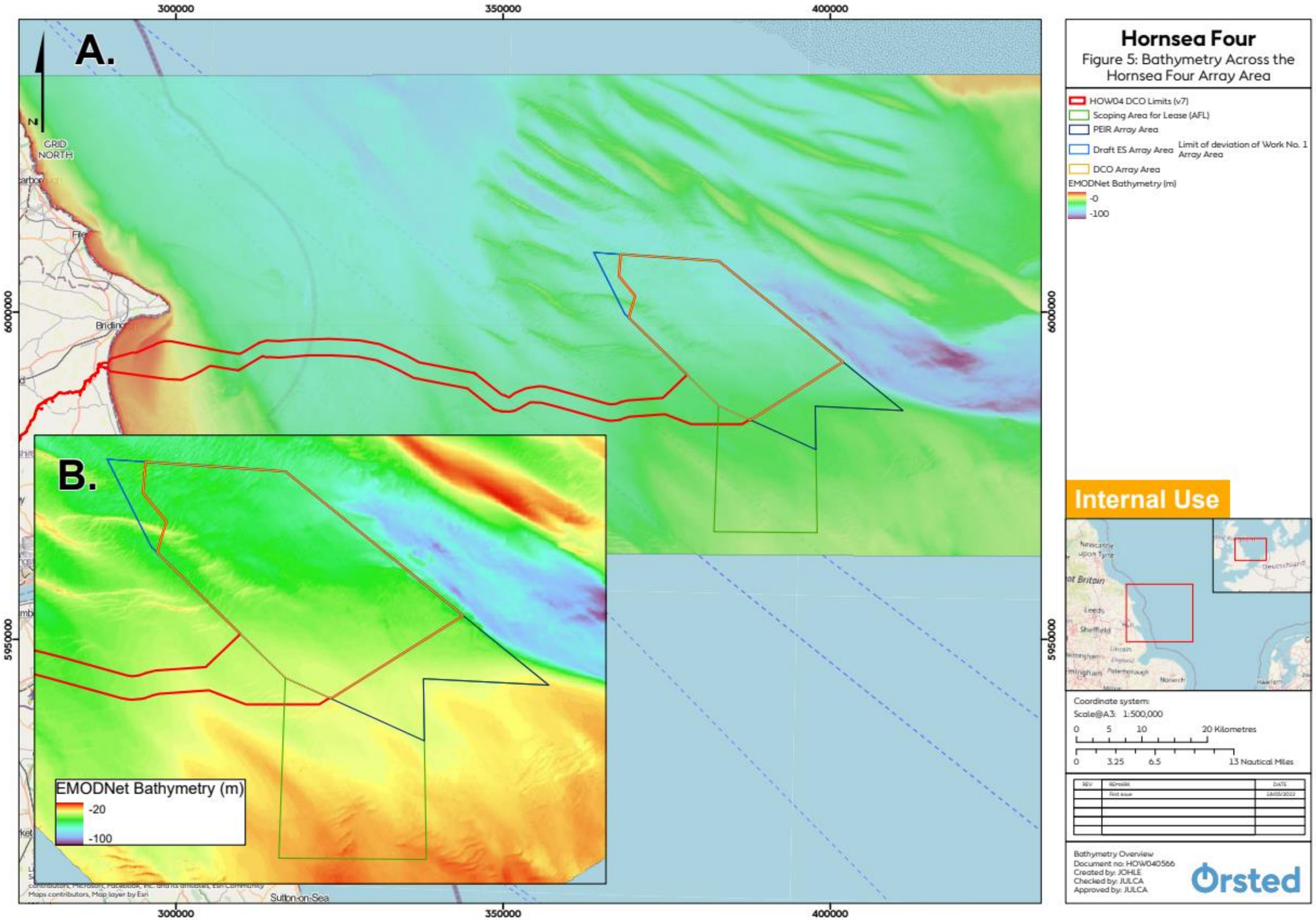

Figure 5: Bathymetry across the Hornsea Four array area.

5 Forage Fish

5.1.1.1 Given the relationship of the Flamborough frontal system to North Sea primary productivity, it is important to understand the project's potential impacts on fish ecology, both alone and in-combination with other plans and projects. The Flamborough Front is formed where stratified water from the northern North Sea meets mixed waters from the southern North Sea. This can lead to the upwelling of nutrients, which in turn can lead to increased plankton growth and associated productivity. This consequently may give rise to concentrations of forage fish, providing a feeding ground for seabird species (though the exact mechanism, timing and intensity has yet to be scientifically established).

5.1.1.2 Forage fish are planktivorous pelagic species; the key forage fish of relevance to features of the Flamborough and Filey Coast (FFC) Special Protection Area (SPA) (gannet, kittiwake, guillemot and razorbill) that have nursery grounds within the vicinity of the Flamborough Front are Atlantic herring (*Clupea harengus* – hereafter herring), sandeel (*Ammodytes tobianus* - hereafter sandeel), and sprat (*Sprattus sprattus* - hereafter sprat). As such, this data review focusses on these three species.

5.1.1.3 A detailed baseline description of fish and shellfish ecology resources across the Hornsea Four fish and shellfish study areas, and wider southern North Sea, is presented within **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**.

Herring

5.1.1.4 High abundances of herring were recorded in historic surveys across the Hornsea Four fish and shellfish study area, immediately to the south of the central section of the former Hornsea Zone, and in the inshore sections of the mouth of the Humber Estuary area. International Bottom Trawl Surveys (IBTS) data show that herring occur throughout the North Sea, although juvenile herring are restricted to within the 100 m depth contour and are most abundant in the south-eastern North Sea. Mature herring (i.e. 3+ years) occur primarily along a westerly bank running from the Southern Bight to the Northern North Sea (encompassing the former Hornsea Zone), with limited records in the eastern North Sea (ICES 2005a).

5.1.1.5 Herring were recorded primarily during historic otter trawl surveys in the study area, though small numbers of this species were also recorded in historic epibenthic beam trawls. As with sprat, there was a strong seasonal pattern in the data for this species, with highest abundances recorded within the fish and shellfish study area during spring (up to 900 per 500 m) and lower abundances in autumn (up to 100 per 500m) (Figure 14 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**).

5.1.1.6 The Hornsea Four array area and offshore ECC coincide with low intensity nursery habitat for herring as shown in Figure 14 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)** and **Figure 6** below.

Sandeel

5.1.1.7 The presence of lesser sandeel has been recorded in historic surveys conducted within the Hornsea Four fish and shellfish study area. Lesser sandeel abundances were generally highest in epibenthic beam trawls (up to 30 per 500 m) compared to abundances recorded in otter trawls (up to 10 per 500 m). This is likely to be due to the narrow body shape and small size of these species (adults typically less than 20 cm in length; (Rowley 2008)) and the relatively large mesh size (40 mm cod end) used during otter trawling, together with the difference in how these gear types target benthic and demersal species). Sandeel were generally recorded at highest abundances along the eastern boundary of the Hornsea Four array area and also in the central part of the former Hornsea Zone (Figure 17 and Figure 18 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**).

5.1.1.8 Surveys undertaken within the nearshore section of the Hornsea Four ECC, showed relatively high abundances of sandeel, with a peak in catches observed in August; this is likely due to the seasonal cycle of the species, with the August data collected at the end of the feeding season, likely best representing the distribution of sandeels in the sediment (as recorded in Dogger Bank A and B surveys).

5.1.1.9 Sandeel spawning habitats are known to occur throughout the Southern North Sea, with habitats occurring to the north and north west of the former Hornsea Zone, and further north of Dogger Bank. Lower intensity lesser and greater sandeel spawning and nursery habitats are located within the Hornsea Four array area. Higher intensity lesser and greater sandeel spawning habitats are located on the eastern boundary of the Hornsea Four array area (Figure 17 and Figure 18 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**) as recorded in historic trawl surveys.

Sprat

5.1.1.10 Sprat are widely distributed within the North Sea and are an important potential prey resource for a number of piscivorous fish, marine mammals and sea birds. IBTS data show that that the highest concentrations of sprat generally occur to the east and northwest of the former Hornsea Zone. Data from the IBTS also show that sprat largely occur within the 50 m depth contour throughout the Southern North Sea (including the former Hornsea Zone).

5.1.1.11 Sprat was one of the main characterising species in the historic otter trawls conducted within the Hornsea Four fish and shellfish study area. Figure 13 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)** shows that there was a strong seasonal difference in the abundances of this species, with notably higher catches in spring than autumn. Sprat was recorded at low abundances in historic epibenthic beam trawls, though as a pelagic species sampled with a demersal/benthic trawl, this result was to be expected. Beam trawl surveys undertaken in the nearshore section of the Hornsea Four ECC, showed a peak in catches of sprat in October, although low abundances of the species were observed in trammel net surveys in the same area (as recorded in the Dogger Bank A and B surveys).

5.1.1.12 Within the North Sea, spawning occurs in both coastal and offshore waters, with IBTS data indicating important sprat spawning areas located in the inner German Bight, off Jutland, along the English coast, and in areas west and north of Scotland (ICES, 2005b). The Hornsea Four array area and offshore section of the ECC are located within both spawning and

nursery grounds for sprat (Coull et al. 1998) (Figure 13 of **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**).

Nursery grounds

5.1.1.13 The nursery grounds of the relevant forage fish within the Hornsea Four Order Limits are presented in **Figure 6** below. As detailed within **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**, nursery grounds for sprat (Coull *et al.* 1998), herring, and sandeel (Ellis *et al.* 2010) are located across the Hornsea Four Order Limits and the Flamborough Front. On a broader scale, these grounds are located across the entire North Sea, rather than focussed on a particular area near the frontal system and as such, distribution of these grounds does not appear linked to the Flamborough Front.

5.1.1.14 It is important to note that Coull et al. (1998) and Ellis et al. (2010, 2012) that are used in **Figure 6** are considered the key references for providing broad scale overviews of the potential spatial extent of nursery habitats and the relative intensity and duration of spawning. Both Coull et al. (1998) and Ellis et al. (2010, 2012) are based on a collection of various historic data sources. Many of the conclusions drawn by Coull et al. (1998) are based on historic research and may fail to account for more recent changes in fish distributions and spawning behaviour. Ellis et al. (2010, 2012) also face limitations due to the wide scale distribution of sampling sites used for the annual international larval survey data, consequently resulting in broad scale grids of spawning and nursery grounds.

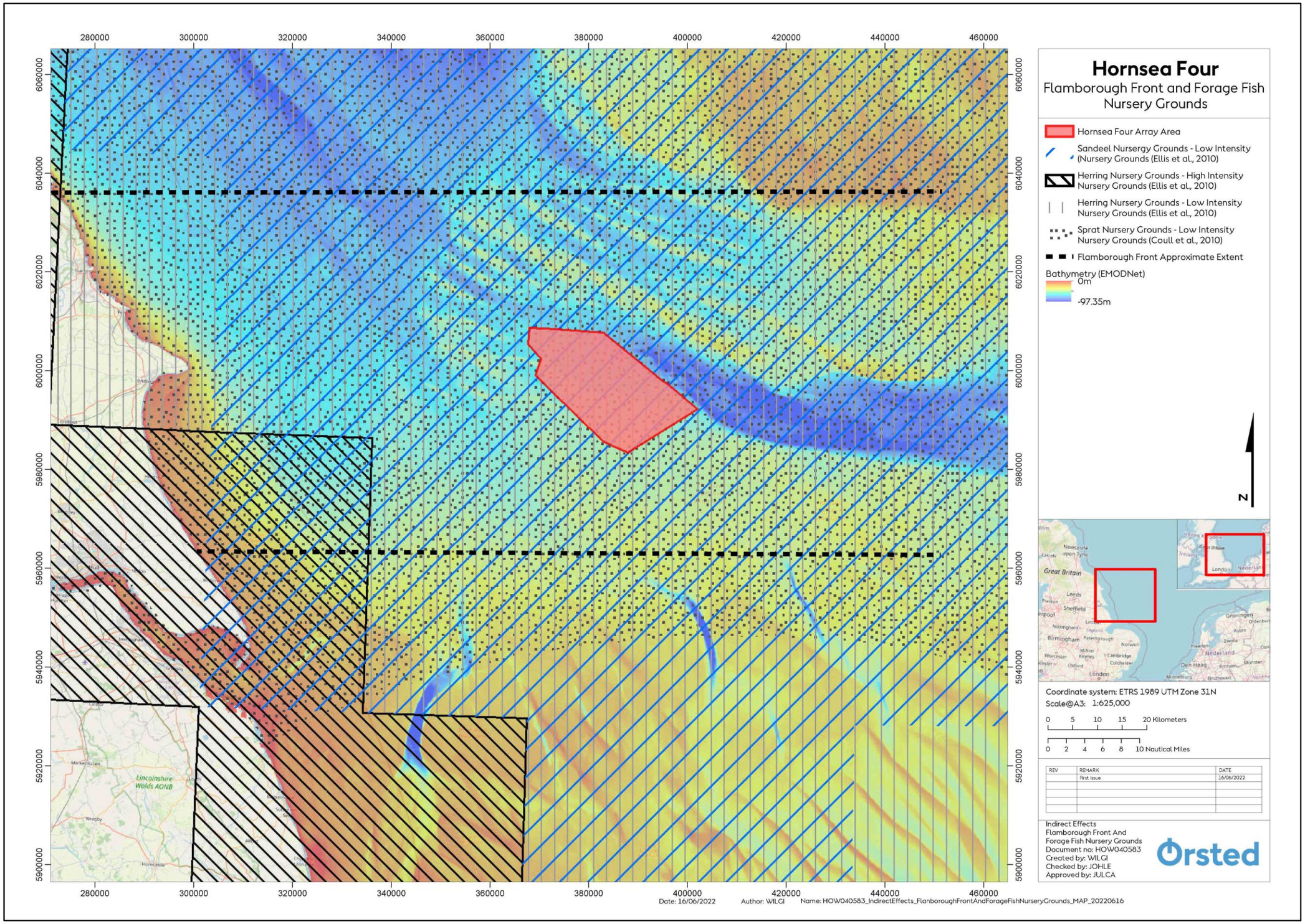

Figure 6: Forage fish nursery grounds in relation to the northerly and southernly extents of the Flamborough Front.

6 Seabird Distribution

6.1 Seabird Distribution in North Sea

6.1.1.1 The North Sea is an important corridor for seabird migration with an estimated 1-1.3 million seabirds dispersing and flying through each year (Stienen et al, 2007) as well as an important area for several million seabirds to reside in during the non-breeding season (Furness, 2015). It also contains important numbers of breeding seabirds, hosting some of UK's larger colonies of gannet, guillemot, razorbill, kittiwake, lesser black-backed gull, Sandwich terns and little terns in particular (JNCC, 2022).

6.1.1.2 The combined movements of breeding and non-breeding birds into and out of the North Sea means populations can be very transient, with peaks typically occurring during the post-breeding dispersal and migratory periods in the late summer and early autumn (Furness, 2015). These peaks are due to adult birds being supplemented by juveniles during this period, increasing overall populations ahead of the more testing winter weather conditions, which some birds try to avoid by exiting to reach warmer climes to the south. Some breeding species groups that nest earlier and have shorter chick rearing periods depart their breeding locations in the mid-late summer, including gulls, terns and auks, whilst species with more prolonged chick rearing periods depart later at the end of the summer or even into the autumn such as fulmars and gannets (Stone et al, 1995 and Furness, 2015).

6.1.1.3 The distribution of birds through the North Sea is therefore in a continual cycle through the year as birds migrate to breeding locations, breed, migrate away from breeding locations and reside in wintering locations at different stages following individual species' patterns and in response to other environmental conditions. The distribution during these different stages mean that seabirds tend to reside in more coastal and nearshore environments during their breeding seasons, when they are more constrained as central placed foragers (Woodward et al, 2019), whilst dispersing or migrating from those locations further into the UK Southern North Sea post-breeding, where they are joined by birds from the UK's Northern North Sea and continental birds, some of which remain throughout the winter (Furness, 2015).

6.1.1.4 The region also benefits from the shifting fronts that occur at the boundaries between different water types as described in **Section 3**. These fronts occur where thermal stratification may develop offshore in the summer months, which then break down into the autumn. Several fronts exist in the North Sea, including areas off the Scottish and Northumberland coasts as well as the Flamborough Front (Stone et al, 1995). The Flamborough Front is a typically dynamic and variable seasonal front occurring primarily to the north of the Hornsea Zone (Diagram A in **Figure 4**), but with a high degree of variability in its position (Diagram B in **Figure 4**). This variability means that the entire region is subjected to the meeting of mixed and stratified waters, with nutrient levels increasing that promotes phytoplankton growth, which benefit fish and seabirds (Stone et al, 1995).

6.2 Zonal Seabird Distribution in Hornsea Zone

6.2.1 Hornsea Zonal Surveys

6.2.1.1 The Hornsea Zone is located in the north of the Southern North Sea, so experiences similar peaks and troughs in bird numbers as other locations across the region, with clear migratory movements of all seabird species through the area during spring and autumn periods. The region experiences migratory bird movements from breeding colonies to the north, whilst also playing host to considerable number of birds throughout the non-breeding period. Two years of boat-based ornithology surveys were undertaken of the Hornsea Zone between

March 2011 and February 2013 (Smartwind, 2015a), which provided an account of the variety of species, spatial and temporal distributions. These data are broadly aligned with the findings of regional studies of the North Sea, with peaks of some seabirds during migratory periods, peaks of others during the breeding season and / or post-breeding season months and others during the non-breeding season.

6.2.1.2 Of the key species of interest to Hornsea Four (gannet, kittiwake, great black-backed gull, guillemot and razorbill) different peaks of usage across the Hornsea Zone were apparent, as described in the brief accounts below.

6.2.2 Gannet distribution in Hornsea Zone

6.2.2.1 Gannet abundance peaked in both survey years during the late autumn months of October and November, with population estimates of 6,306 in November 2011 and 6,259 in October 2012 (Smartwind, 2015a). These peaks coincide with the post-breeding dispersal of adults from breeding colonies across the North Sea, which are mostly to the north.

6.2.2.2 Gannets were reported as being loosely distributed in low densities across the Hornsea Zone during the pre-breeding season months (Dec-Mar), though during year two there were higher densities in the east of the zone (Figures B.3.7 and B.3.10, Smartwind, 2015b).

6.2.2.3 During the breeding season months (Apr-Aug) higher densities were apparent across the entire Hornsea Zone in comparison to the pre-breeding season, though no hotspots were evident. Both years of surveys suggested a bias of birds towards the west of the zone, which is to be expected as the nearest colony is at the FFC SPA, demonstrating density decay with distance from their nesting locations (Figures B.3.5 and B.3.8, Smartwind, 2015b).

6.2.2.4 Gannets were reported as being loosely distributed in similar densities across the Hornsea Zone in year one and year two during the post-breeding season months (Sep-Nov), though during year two there were higher densities in the east of the zone (Figures B.3.6 and B.3.9, Smartwind, 2015b).

6.2.2.5 Overall, these data do not suggest any specific distribution associated with frontal features or that gannets rely on any specific areas within the Hornsea Zone more than others. The only exception was the observation of densities reducing from the west to the east of the Hornsea Zone in the breeding season months, which is more likely to relate to simple density decay with increasing distance from the nearest colony than anything else.

6.2.3 Great black-backed gull distribution in Hornsea Zone

6.2.3.1 Great black-backed gull abundance peaked in both survey years during the non-breeding season months between August and April, with population estimates of 5,984 in November 2011 and 11,104 in January 2013 (Smartwind, 2015a). These peaks follow with the post-breeding dispersal of adults from breeding colonies from the northern reaches of the North Sea and continental Europe that spend the winter in the North Sea.

6.2.3.2 During the breeding season months (May-Jul) very low densities were apparent across the entire Hornsea Zone in comparison to the non-breeding, with no hotspots evident. Surveys suggested a bias of birds towards the east of the zone in year two, though it is not known

why and they are more likely to be non-breeding birds in the summer months as the area is well outside of their foraging range (Smartwind, 2015b).

6.2.3.3 Great black-backed gull were reported as being loosely distributed in similarly low densities across the Hornsea Zone in year one and year two during the non-breeding season months (Aug-Apr) (Figures B.3.32 and B.3.34, Smartwind, 2015b).

6.2.3.4 Overall, these data do not suggest any specific distribution associated with frontal features or that great black-backed gulls rely on any specific areas within the Hornsea Zone more than others. This is also evident from these data, as great black-backed gulls peak in the Hornsea Zone during the winter months, which are outside of those when the Flamborough Front is active during the summer and into early autumn.

6.2.4 Kittiwake distribution in Hornsea Zone

6.2.4.1 Kittiwake abundance peaked in both survey years in June, with population estimates of 19,608 in 2011 and 24,703 in 2012 (Smartwind, 2015a). These peaks coincide with the breeding season across the Southern North Sea, with birds from coastal and island colonies joined by breeding birds from offshore oil and gas platforms and roaming non-breeding birds.

6.2.4.2 Kittiwakes were reported as being loosely distributed in medium densities across the Hornsea Zone during the pre-breeding season months (Jan-Apr) (Figures B.3.37 and B.3.40, Smartwind, 2015b).

6.2.4.3 During the breeding season months (May-Jul) higher densities were apparent across the entire Hornsea Zone in comparison to the pre-breeding season, with higher densities of birds towards the west of the zone in year one and in the centre of the zone in year two (Figures B.3.35 and B.3.38, Smartwind, 2015b).

6.2.4.4 Kittiwakes were reported in much lower densities across the Hornsea Zone in year one and year two during the post-breeding season months (Aug-Dec), with more birds recorded in the west of the zone in year one and more in the east in year two (Figures B.3.36 and B.3.39, Smartwind, 2015b).

6.2.4.5 Overall, these data do not suggest any specific distribution associated with frontal features or that kittiwakes rely on any specific areas within the Hornsea Zone more than others. The only exception was the observation of densities reducing from the west to the east of the Hornsea Zone in the breeding season months, which is more likely to relate to simple density decay with increasing distance from the nearest colonies than anything else.

6.2.5 Guillemot distribution in Hornsea Zone

6.2.5.1 Guillemot abundance peaked in both survey years during non-breeding season month of August, with population estimates of 155,392 in 2011 and 173,412 in 2012 (Smartwind, 2015a). These peaks coincide with the post-breeding dispersal of adults from breeding colonies from the northern reaches of the North Sea and continental Europe that spend the winter in the North Sea.

6.2.5.2 During the breeding season months (Mar-Jul) medium densities were apparent across the entire Hornsea Zone, with no hotspots evident. Surveys suggested a bias of birds towards the centre of the zone in both years, though this is not strongly defined (Figures B.3.45 and B.3.47, Smartwind, 2015b).

6.2.5.3 Guillemots were reported as being loosely distributed in similarly or lower densities across the Hornsea Zone in both year one and year two during the non-breeding season months

across the entire season (Aug-Feb), which included the peak month of August (Figures B.3.46 and B.3.48, Smartwind, 2015b).

6.2.5.4 Overall, these data do not suggest any specific distribution associated with frontal features or that guillemots rely on any specific areas within the Hornsea Zone more than others. However, the population estimates for the month of August are higher than that from local colonies, suggesting an influx of birds from more distant colonies does occur during the late summer months.

6.2.6 Razorbill distribution in Hornsea Zone

6.2.6.1 Razorbill abundance peaked in both survey years during non-breeding season month of August, with population estimates of 59,276 in 2011 and 44,810 in 2012 (Smartwind, 2015a). These peaks coincide with the post-breeding dispersal of adults from breeding colonies from the northern reaches of the North Sea and continental Europe that spend the winter in the North Sea.

6.2.6.2 During the pre-breeding season months (Jan-Mar) very low densities were apparent across the entire Hornsea Zone, with no hotspots evident. Surveys suggested a slight bias of birds towards the east and centre of the zone, which may reflect an influence of migratory birds moving through the area (Figures B.3.52 and B.3.56, Smartwind, 2015b).

6.2.6.3 During the breeding season months (Apr-Jul) higher densities were recorded in the west of the zone in year one and in the centre of the zone in year two, though no hotspots were evident (Figures B.3.49 and B.3.53, Smartwind, 2015b).

6.2.6.4 Razorbills were reported as being loosely distributed in lower densities across the Hornsea Zone in both year one and year two during the post-breeding season months across the entire season (Aug-Oct), which included the peak month of August (Figures B.3.50 and B.3.54, Smartwind, 2015b). Surveys suggested a slight bias of birds towards the east and centre of the zone in year one and year two, respectively.

6.2.6.5 Razorbills were reported less commonly and in very low densities across the Hornsea Zone in both year one and year two during the non-breeding season months (Nov-Dec) (Figures B.3.51 and B.3.55, Smartwind, 2015b).

6.2.6.6 Overall, these data do not suggest any specific distribution associated with frontal features or that razorbills rely on any specific areas within the Hornsea Zone more than others.

6.3 Seabird Distribution in Hornsea Four Agreement for Lease (AfL) Area

6.3.1 Developable Area Process

6.3.1.1 The Applicant has undertaken multiple reviews of the offshore ornithology data to refine the final proposed developable area for Hornsea Four. This included reviewing data sets from the wider AfL plus 4km buffer of key seabirds to determine areas that may be considered of higher importance and thus trying to avoid those areas.

6.3.1.2 Consideration was provided to the breeding and post-breeding months (an extended breeding season) with site-specific survey data pooled from gannet, kittiwake, guillemot and razorbill to assess where higher densities existed across the AfL and 4km buffer. The data that fed into this process included flying bird data for gannet and kittiwakes for consideration of collision risk and all behaviours for guillemot and razorbill to consider displacement risks. The distribution data from these species were overlaid into a single figure

initially, which identified areas with highest densities combined for consideration of design changes to the Hornsea Four array area.

6.3.1.3 The Developable Area process identified areas in the south, east and northwest of the AfL plus 4km buffer as containing the highest densities of key species. However, it was the area to the south that was determined to be of greatest importance for all key species, which is likely to be due to shallower waters across that area (see **Figure 5** and Section 4).

6.3.1.4 The first DAA Biological Workshop (February 2019) resulted in a major site reduction which was determined by the density and distribution of gannet, kittiwake, and guillemot within the Hornsea Four array (as surveyed pre-development). The reduction resulted in ~54% reduction in bird numbers (density of key species over the 2-year survey period) between what was observed in the original AfL (846 km^2) to that reduced AfL (600 km^2).

6.3.1.5 Over the course of two additional design changes each of the areas identified as being of higher densities for the key species (kittiwake, gannet, guillemot and razorbill) were removed from the final Hornsea Four Array Area. The final reduction within the north of the AfL was undertaken in an effort to reduce/eliminate the potential for AEoI upon the guillemot and razorbill features of the FFC SPA by removing the remaining areas of high auk (guillemots and razorbills) density to the northwest of the AfL and thereby significantly reducing bird numbers within the final development footprint (~7% reduction in the mean peak abundance across all bioseasons). Figure 12-4of the B2.5 Volume B, Chapter 5: Without Prejudice Derogation Case (**APP-182**) presents the predicted density of all auks for the extended breeding season for the entire AfL and the reduced AfL at the point of DCO Application. Figure 12-4 clearly demonstrates that in consideration of auks within the extended post-breeding season (the most critical from an assessment and impact perspective) that Hornsea Four has taken significant steps to reduce the impact upon these features via the consideration and implementation of material alternatives that bring forward a project that has taken due consideration of the environmental sensitivities of the site and designed the proposed project in full recognition of these constraints.

6.3.1.6 The evolution of the Hornsea Four Order Limits is summarised in Section 5.5.1 (**APP-017**) with respect to offshore ornithology considerations and detailed more widely in the Site Selection and Consideration of Alternatives (**APP-009**) and Selection and Refinement of the Offshore Infrastructure (**APP-037**).

6.3.1.7 Overall, the review of data from the AfL plus 4km buffer during the summer and early autumn months did not suggest any specific distribution associated with frontal features or that any species rely on any specific areas within the final Hornsea Four array area more than others. However, these data did provide evidence that most key seabirds had a preference to utilise the area of shallower waters in the south of the AfL, which were subsequently avoided from the final Hornsea Four array area. This is further demonstrated from the site-specific survey data collected from the AfL and 4km buffer, presented in Figure **7**to **Figure 9** on guillemot and razorbills from July through to October from the MRSea_v2 modelling outputs. Guillemot were present in higher densities further to the south and to the northwest of the Hornsea Four array area during the months of August and September, whilst razorbill were further to the south.

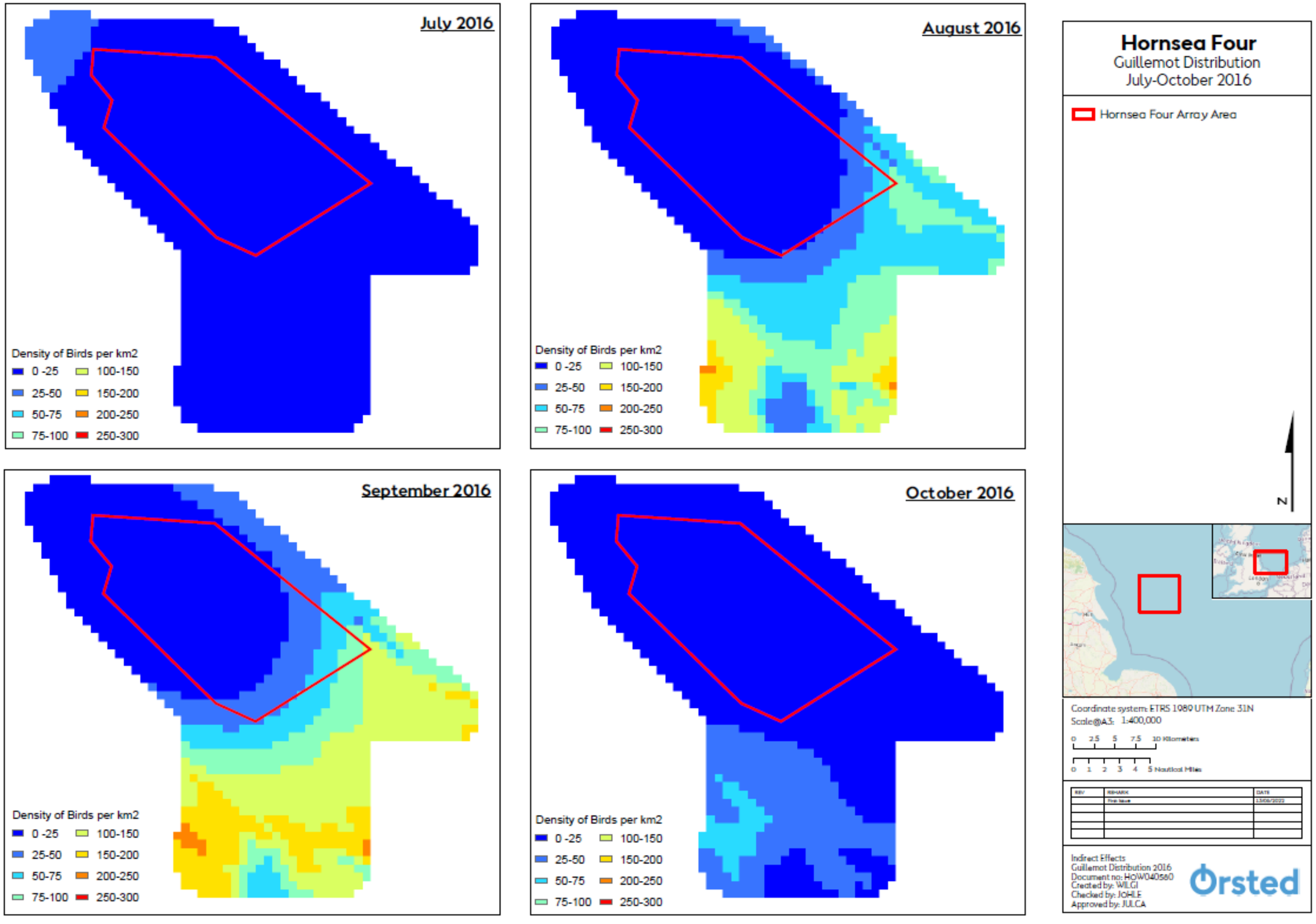

Figure 7: Guillemot Distribution from July to October 2016 from MRSea_V2 modelling outputs.

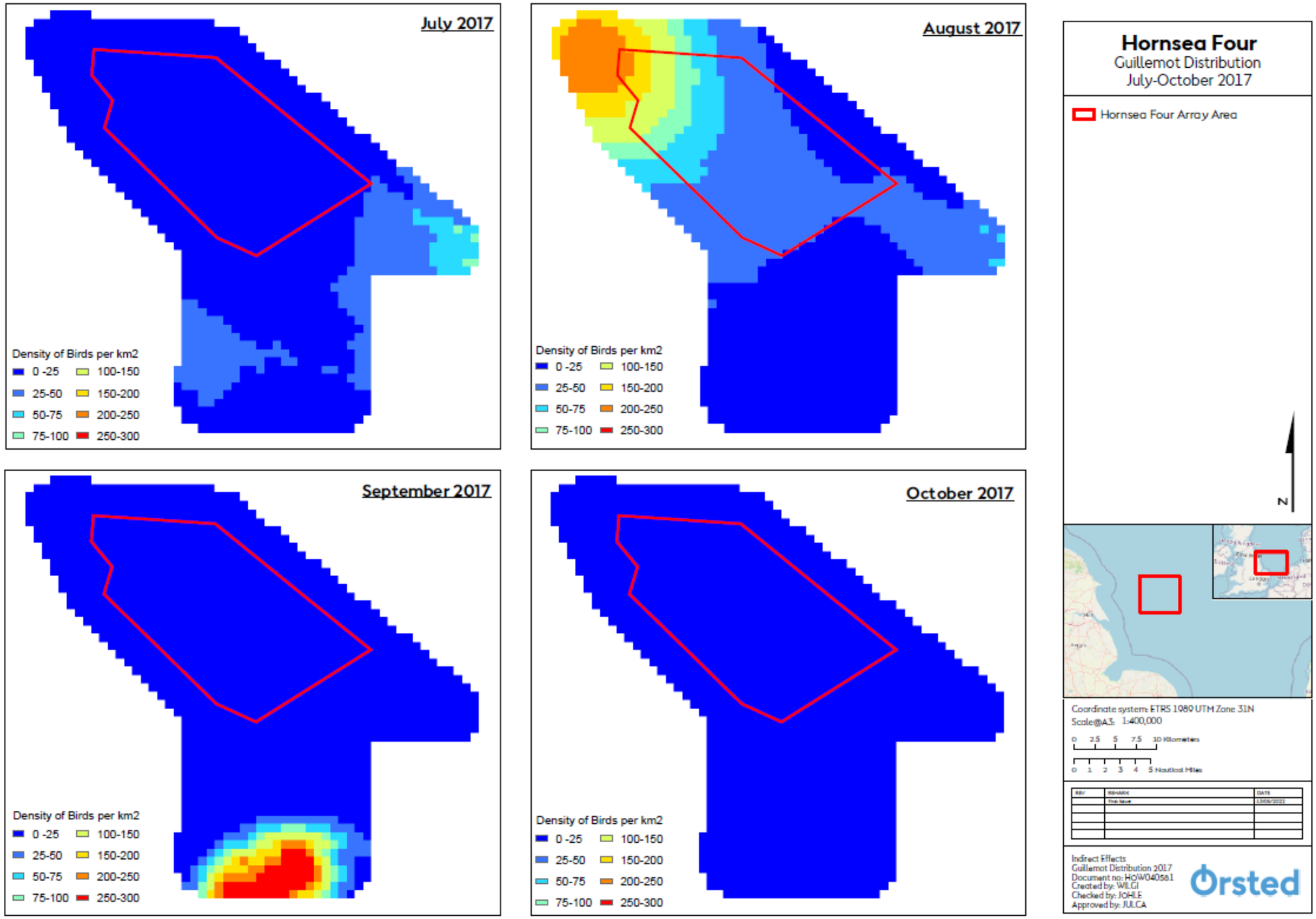

Figure 8: Guillemot Distribution from July to October 2017 from MRSea_V2 modelling outputs.

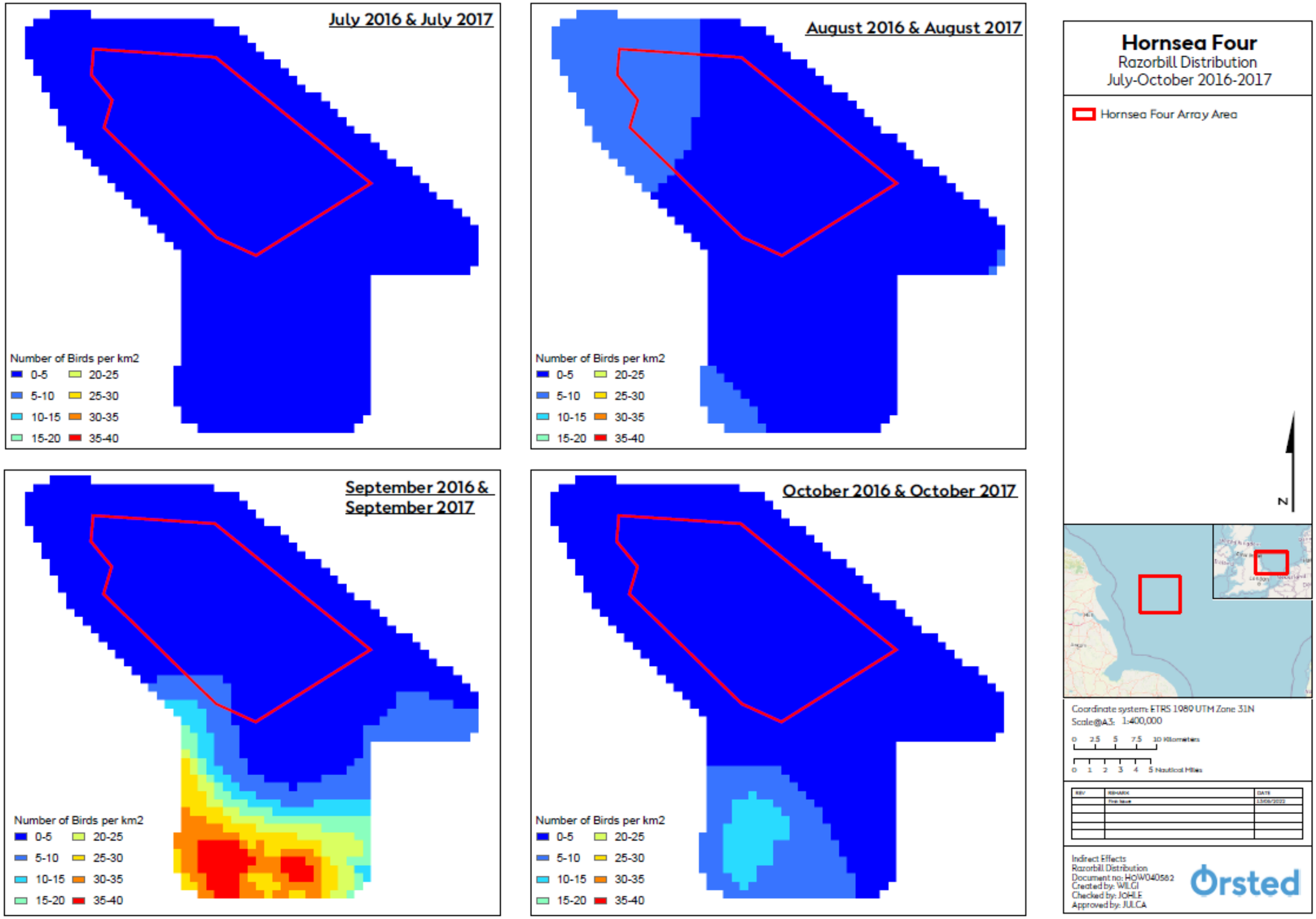

Figure 9: Razorbill Distribution from July to October 2016 and 2017 from MRSea_V2 modelling outputs.

7 Auk post-breeding dispersal

7.1 Auk Behaviour Post-breeding

7.1.1.1 The UK North Sea and English Channel Biologically Defined Minimum Population Scale (BDMPS) plays host to over three million auks (mostly guillemot and razorbill, with approximately 870,000 puffins) during the breeding season (including breeding adults and immatures) (Furness, 2015). However, for this report the focus is on guillemot and razorbill only, as the majority of puffins migrate north out of the North Sea post-breeding and into the North Atlantic (Harris & Wanless, 2012). Within the UK North Sea and English Channel BDMPS both guillemots and razorbills nest in colonies on cliff faces and islands mostly along the northeast coast and islands in English waters and eastern coasts and islands and northern isles in Scottish waters.

7.1.1.2 During the full UK breeding season (between March/April and July) and during the migration-free breeding season (between March/April and June) for guillemot and razorbill (Furness, 2015), breeding birds are mostly restricted to foraging within the mean and mean-max foraging ranges from their colonies. This means that the majority of the adult breeding guillemot and razorbills within the UK North Sea and English Channel BDMPS reside within approximately 33km to 73km or 61km to 89km from their colonies, respectively (Woodward et al, 2019) during the migration-free months of March/April through to June.

7.1.1.3 After June birds start to leave their colonies in both the UK and on the continent, including both successful and unsuccessful breeders. For guillemots and razorbill, as males stay with their flightless chicks for up to two months after leaving the colony, they tend to disperse more slowly than females that have no such restrictions and can migrate further afield post-breeding (Gaston & Jones, 1998). It is also noteworthy that for both species, the females tend to remain at the colony for a week or two more than the males (Wanless and Harris, 1986), therefore undertaking their dispersal slightly later. During this post-breeding period UK birds are joined by over half a million adults and immatures from continental colonies between July and October. Such movements and the wide distribution across the North Sea of guillemot and razorbills are captured from geolocator studies, including that presented in **Figure 10** (St John Glew, 2018). It is during this later period that all adult guillemots and razorbills undertake a moult of their primary and secondary feathers for between four and six weeks across August and September, which renders them flightless (Birkhead & Taylor 1977, Harris & Wanless 1990).

7.1.1.4 Therefore, during the initial post-breeding months of July and August when birds are dispersing from their colonies at least 2.7 million guillemots and razorbills are present in the UK North Sea and English Channel BDMPS. During these months both species are regularly recorded in peak abundances within regional and OWF site-specific surveys, demonstrating wide-scale distribution from breeding colonies across the BDMPS during this period.

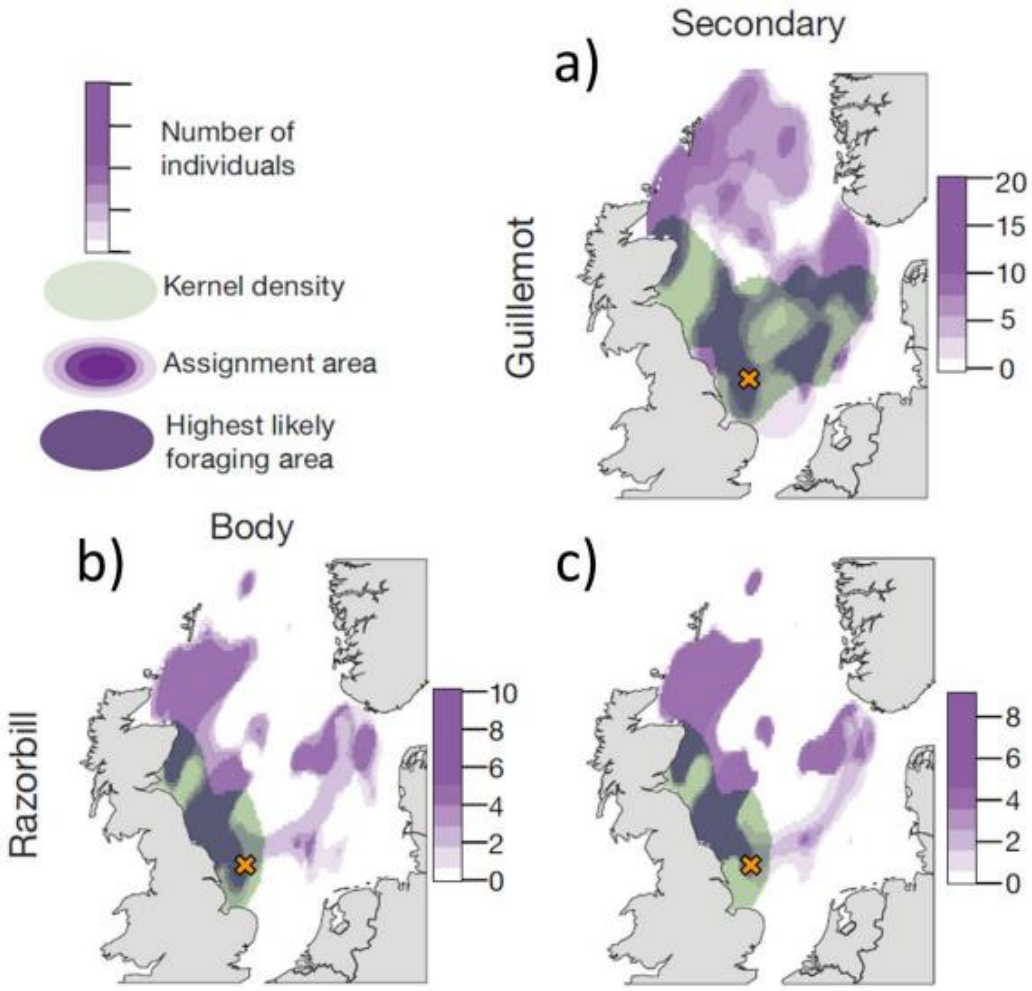

Figure 10: Most likely foraging areas of auks from the Isle of May during the post-breeding moult (July-September) from isotope mapping (purple) and geolocator core areas (density values were >0.01); green), with overlap of the two (dark purple) showing greatest confidence. Isotope feather samples were obtained from the same birds upon geolocator retrieval. a) shows foraging areas of adult guillemots from secondary feather regrowth (no. of birds = 19), b) and c) show foraging areas of adult Razorbills from body and secondary feather regrowth respectively (both occurring in July-September; no. of birds = 9), figure from St. John Glew (2018). Orange cross denotes approximate location of Hornsea Four (size of cross not to scale of array).

7.2 Guillemot Post-breeding Seabird Dispersal

7.2.1.1 During the post-breeding dispersal months of July through to October the number of guillemots within the UK North Sea and English Channel BDMPS is in excess of 2.1 million adults and immatures. In order to review where these birds may disperse during this period a review of OWF baseline technical reports for other Development Applications was undertaken. This was to determine the distribution of guillemots during this period in order to consider if any areas may be more likely to host birds more than others or if any links to the Flamborough Front may be apparent.

7.2.1.2 The data collected from individual OWFs and OWF zones presented in Table 3 and Table 4 provide a comparison of guillemot abundances across the Southern North Sea that

demonstrates peaks between July and October for different locations. It also suggests that considerable inter-annual variation occurs between and within different locations. However, it does provide evidence that more significant numbers of guillemots are recorded across the more northern areas of the Southern North Sea in the late summer that must arise from colonies further to the north (Scotland and continental Europe) and are not concentrated consistently within a more limited region such as the Hornsea Four array area for instance.

Table 3: Southern North Sea guillemot monthly average abundance estimates from OWF surveys

Guillemot				
OWF Site	**July**	**Aug**	**Sept**	**Oct**
Doggerbank Zone 2010/11	17,522	34,615	41,391	42,519
Hornsea Zone Year 1 /2	91,627	164,402	66,652	23,966
Norfolk Boreas 2016/17/18	9,925	3,477	2,393	1,072
Norfolk Vanguard East 2012/13/15	251	579	1,648	1,864
Norfolk Vanguard West 2015/16/17	2,408	568	2,318	1,161
East Anglia ONE 2010/11	60	183	62	103
East Anglia ONE North 2016/17	480	1,004	130	317
East Anglia TWO 2016/17	664	371	206	199
East Anglia THREE 2011/12/13	163	556	1,517	896
Greater Gabbard 2004/05	267	323	26	112
Triton Knoll 2008/09	388	756	2,063	2,050
Westernmost Rough 2012/13/14	804	269	665	1,818
Totals	**124,556**	**207,102**	**119,070**	**76,076**

Table 4: Southern North Sea guillemot monthly peak abundance estimates from OWF surveys

Guillemot				
OWF Site	**July**	**Aug**	**Sept**	**Oct**
Doggerbank Zone 2010/11	21,834	45,576	69,204	76,441
Hornsea Zone Year 1 /2	98,316	173,412	66,652	23,966
Norfolk Boreas 2016/17/18	17,497	4,235	4,061	1,762
Norfolk Vanguard East 2012/13/15	492	927	1,933	4,138
Norfolk Vanguard West 2015/16/17	3,856	659	2,899	2,062
East Anglia ONE 2010/11	119	366	124	206
East Anglia ONE North 2016/17	480	1,004	131	336
East Anglia TWO 2016/17	664	371	254	348
East Anglia THREE 2011/12/13	271	577	2,172	1,004
Greater Gabbard 2004/05	533	422	52	112
Triton Knoll 2008/09	750	1,600	7,500	3,300
Westernmost Rough 2012/13/14	2,310	348	1,764	4,850
Totals	**147,122**	**229,497**	**156,746**	**118,525**

7.2.1.3 The wider distribution of guillemots in the more northern areas of the Southern North Sea in the late summer and early autumn months may be a reflection of the Flamborough Front being a highly variable and disperse system influencing a much wider area than a simple front line, as described in **Section 3.2**. This may help to explain why higher abundances of guillemots are found across multiple OWF sites and their wider zones during this period, rather than being consistently in one more restricted area.

7.2.1.4 If the mean of specific zonal data and / or OWF data were to be considered in a similar manner to how cumulative data are collated from OWFs then guillemot abundances within these surveys during the months of July through to October would be 124,556 (July), 207,102 (Aug), 119,070 (Sep) and 76,076 (Oct). If the peak values from each specific zonal data and / or OWF data were to be considered the guillemot abundances within these survey areas would be 147,122 (July), 229,497 (Aug), 156,746 (Sep) and 118,525 (Oct). These zonal and OWF site areas provide some evidence that higher abundances are found in the more northern reaches of the Southern North Sea during the post-dispersal period. However, it is also evident that the more northern areas of the Southern North Sea and Northern North Sea are subjected to a wider and more generalised influx of birds from more northern colonies (including those off the northeast coast of England and those in Scotland).

7.2.1.5 This is supported by the guillemot distribution mapped out in **Figure 10** following their dispersion from the Isle of May from July to September (St John Glew, 2018), which is likely to be similar to other northern colonies and correlates with increases in guillemot numbers across the Southern North Sea during this period. This provides a rationale for the higher abundances recorded within OWF zones within the more northern reaches of the Southern North Sea (including the Hornsea and Dogger Bank zones), which is likely to be a similar phenomenon across the wider region with a more uniform distribution of guillemots from multiple colonies spread from the north east coasts of Scotland and England out to the UK's maritime border with other European countries and beyond into the central North Sea during this period (Buckingham et al, 2018). Therefore, the higher levels of abundance recorded in

the Hornsea and Dogger Bank zones reflect a much wider regional dispersion from guillemot arrivals during this post-breeding period than previously considered, spreading birds more widely and reducing overall risk to them from individual OWFs or in relation to a more limited area influenced by a restricted front area.

7.3 Razorbill Post-breeding Seabird Dispersal

7.3.1.1 During the post-breeding dispersal months of July through to October the number of razorbills within the UK North Sea and English Channel BDMPS is in excess of 600,000 adults and immatures. In order to review where these birds may disperse during this period a review of OWF baseline technical reports for other Development Applications was undertaken. This was to determine the distribution of razorbills during this period in order to consider if any areas may be more likely to host birds more than others or if any links to the Flamborough Front may be apparent.

7.3.1.2 The data collected on individual OWFs presented in Table 5 and Table 6 provide a comparison of guillemot abundances across the Southern North Sea that demonstrates peaks between July and October. It also suggests that considerable inter-annual variation occurs between and within different locations. However, it does provide evidence that more significant numbers of razorbills are recorded across the more northern areas of the Southern North Sea in the late summer that must arise from colonies further to the north (Scotland and continental Europe) and are not concentrated consistently within a more limited region such as the Hornsea Four array area for instance.

Table 5: Southern North Sea razorbill monthly average abundance estimates from OWF surveys

Guillemot				
OWF Site	**July**	**Aug**	**Sept**	**Oct**
Doggerbank Zone 2010/11	703	3,457	6,157	21,823
Hornsea Zone Year 1 /2	30,985	52,043	5,970	414
Norfolk Boreas 2016/17/18	1,025	247	228	111
Norfolk Vanguard East 2012/13/15	55	457	632	445
Norfolk Vanguard West 2015/16/17	408	111	498	86
East Anglia ONE 2010/11	10	32	95	32
East Anglia ONE North 2016/17	64	152	33	71
East Anglia TWO 2016/17	166	49	91	105
East Anglia THREE 2011/12/13	41	71	589	1,503
Greater Gabbard 2004/05	0	0	0	0
Triton Knoll 2008/09	20	10	1,496	975
Westernmost Rough 2012/13/14	494	199	3,233	618
Totals	**33,969**	**56,827**	**19,019**	**26,181**

Table 6: Southern North Sea razorbill monthly peak abundance estimates from OWF surveys

Guillemot				
OWF Site	**July**	**Aug**	**Sept**	**Oct**
Doggerbank Zone 2010/11	1,142	6,767	12,232	43,295
Hornsea Zone Year 1 /2	1,142	6,767	12,232	43,295
Norfolk Boreas 2016/17/18	1,565	359	332	111
Norfolk Vanguard East 2012/13/15	100	852	824	1,022
Norfolk Vanguard West 2015/16/17	593	193	813	160
East Anglia ONE 2010/11	20	63	189	64
East Anglia ONE North 2016/17	64	152	65	111
East Anglia TWO 2016/17	166	49	91	105
East Anglia THREE 2011/12/13	51	78	865	1,689
Greater Gabbard 2004/05	0	0	0	0
Triton Knoll 2008/09	55	30	5,900	1,900
Westernmost Rough 2012/13/14	1,746	365	8,672	1,192
Totals	**49,368**	**68,184**	**35,953**	**50,063**

7.3.1.3 The wider distribution of razorbills in the more northern areas of the Southern North Sea in the late summer and early autumn months may be a reflection of the Flamborough Front being a highly variable and disperse system influencing a much wider area than a simple front line, as described in **Section 5**. This may help to explain why higher abundances of razorbills are found across multiple OWF sites and their wider zones during this period, rather than being consistently in one more restricted area.

7.3.1.4 If the mean of specific zonal data and / or OWF data were to be considered in a similar manner to how cumulative data are collated from OWFs then razorbill abundances within these surveys during the months of July through to October would be 33,969 (July), 56,827 (Aug), 19,019 (Sep) and 26,181 (Oct). If the peak values from each specific zonal data and / or OWF data were to be considered the razorbill abundances within these survey areas would be 49,368 (July), 68,184 (Aug), 35,953 (Sep) and 50,063 (Oct). These zonal and OWF site areas provide some evidence that higher abundances are found in the more northern reaches of the Southern North Sea during the post-dispersal period. However, it is also evident that the more northern areas of the Southern North Sea and Northern North Sea are subjected to a wider and more generalised influx of birds from more northern colonies (including those off the northeast coast of England and those in Scotland). This is supported by the razorbill distribution mapped out in **Figure 10** following their dispersion from the Isle of May from July to September (St John Glew, 2018), which is likely to be similar to other northern colonies and correlates with increases in guillemot numbers across the Southern North Sea during this period.

7.3.1.5 This provides a rationale for the higher abundances recorded within OWF zones within the more northern reaches of the Southern North Sea (including the Hornsea and Dogger Bank zones), which is likely to be a similar phenomenon across the wider region with a more uniform distribution of razorbills from multiple colonies spread from the north east coasts of Scotland and England out to the UK's maritime border with other European countries and beyond into the central North Sea during this period (Buckingham et al, 2018). Therefore, the higher levels of abundance were recorded in the Hornsea and Dogger Bank zones reflect a much wider regional dispersion from razorbill arrivals during this post-breeding period than

previously considered, spreading birds more widely and reducing overall risk to them from individual OWFs or in relation to a more limited area influenced by a restricted front area.

8 Indirect effects and conclusions

8.1 Flamborough Front, Bathymetry and Productivity

8.1.1.1 The Flamborough Front is inferred to be associated with high pelagic productivity and biodiversity (Miller and Christodolou, 2014), the exact mechanism, timing and intensity of which have yet to be scientifically established. As the warm and cold waters mix, it creates conditions that increase plankton growth and secondary productivity which increases the seasonal availability of food to fish and shellfish species (ICES, 2008).

8.1.1.2 The top panel of **Figure 11** presents the AEI score (based on data from the Wildlife Trusts (2010)) and the lower panel presents Thermal Front (TF) Class (as provided by Miller and Christodolou (2014)). The areas of additional pelagic ecological importance (AEI) data layer was created in 2010 from several NGO datasets and two data layers provided by JNCC.

8.1.1.3 The AEI score highlights that the Hornsea Four array area is an area of medium productivity in UK terms (see inset in top panel). The detail in the upper panel provides context for Hornsea Four within the regional study area (northern and southern summer extent of the Flamborough Front to the east of Flamborough Head). This indicates that the Hornsea Four AfL is an area of mid-range productivity, relative to the area inshore (to the west of the AfL) and to the north, which is characterised by relatively high AEI scores (relative to the Hornsea Four AfL).

8.1.1.4 As concluded by TWT (2010), the purpose of this data layer (AEI Score) is to provide additional ecological information to be used alongside existing ecological datasets submitted by JNCC and NGOs and is not to be considered a substitute for these data. The degree to which primary and secondary productivity varies at Hornsea Four is inferred upon the physical (see **Sections 3 and 4**) biological (see **Section 5 to 8**) data sets collected as part of the Environmental Impact Assessment (EIA) process.

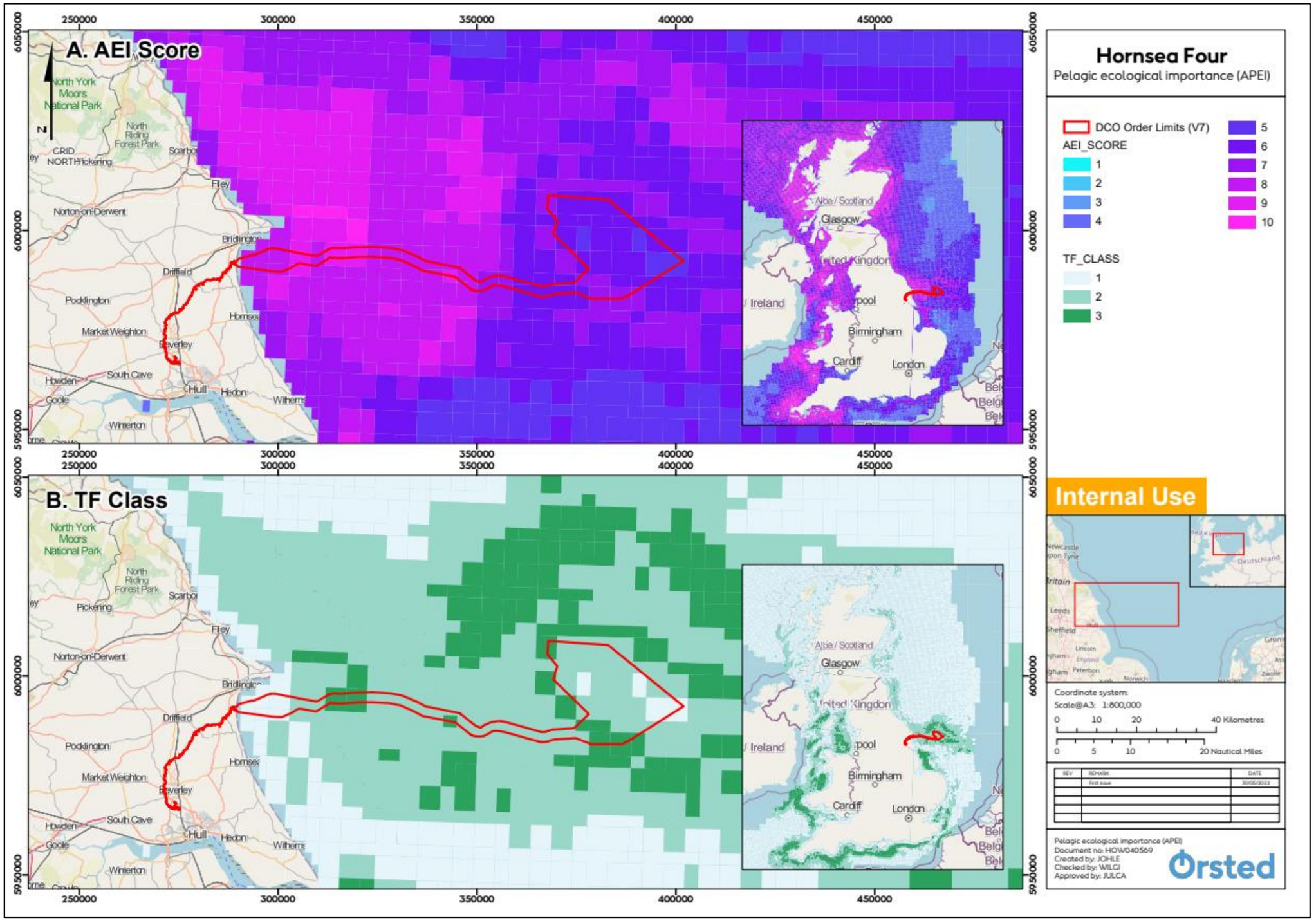

Figure 11: Pelagic ecological importance (APEI) around the Hornsea Four array area from the Wildlife Trusts 2010.

8.2 Forage Fish and Productivity

8.2.1.1 Mobile species such as fish, exhibit varying spatial and temporal patterns. Survey data presented in **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**, collected from surveys undertaken from across the former Hornsea Zone (i.e. otter and epibenthic beam trawls) provide a semi-seasonal description of the fish and shellfish assemblages within the fish and shellfish study area. It should be noted, however, that the data collected during these surveys represent snapshots of the fish and shellfish assemblage within the study area at the time of sampling and the fish and shellfish assemblages may vary considerably both seasonally and annually. As such, it's not possible to infer broad seasonal or interannual patterns from this data or use these to discuss linkages between the Flamborough Front and wider fish distributions.

8.2.1.2 In order to investigate broader patterns of forage fish distribution and how they may relate to the Flamborough Front, Vessel Monitoring System (VMS) data from the International Council for the Exploration of the Sea (ICES) representing locations of fishing grounds have been used as a loose proxy for the relative abundances of their target species (**Figure 12**). This dataset contains VMS and logbook data for Belgian, Danish, Dutch, French, German, and Norwegian registered vessels with a resolution of 1/200th of an ICES rectangle amalgamated for all mobile vessels. For the forage fish discussed in this section, otter trawl data has been used as this is the primary fishing gear used to target herring. sandeel and sprat (noting that the dataset will also contain data on fisheries of other species that are targeted using the same otter trawl gear).

8.2.1.3 In relation to the three forage fish species described in **Section 5** above, and using fishing activity and catch values as a loose proxy, it can be seen that catches are highest generally to the north of the Hornsea Four array area, with some overlap between the fishing activity and the array area. Overall, these data do not suggest any specific distribution of fishing activity (or forage fish distribution as a proxy) associated with frontal features and no clear area of increased activity or focus across the Hornsea Four array area in particular.

8.2.1.4 The nursery grounds of the relevant forage fish within the Hornsea Four Order Limits are presented in **Figure 6** below. As detailed within **A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**, nursery grounds for sprat (Coull *et al.* 1998), herring, and sandeel (Ellis *et al.* 2010) are located across the Hornsea Four Order Limits and the Flamborough Front. On a broader scale, these grounds are located across the entire North Sea, rather than focussed on a particular area near the frontal system and as such, distribution of these grounds does not appear linked to the Flamborough Front with no particular focus in the Hornsea Four array area.

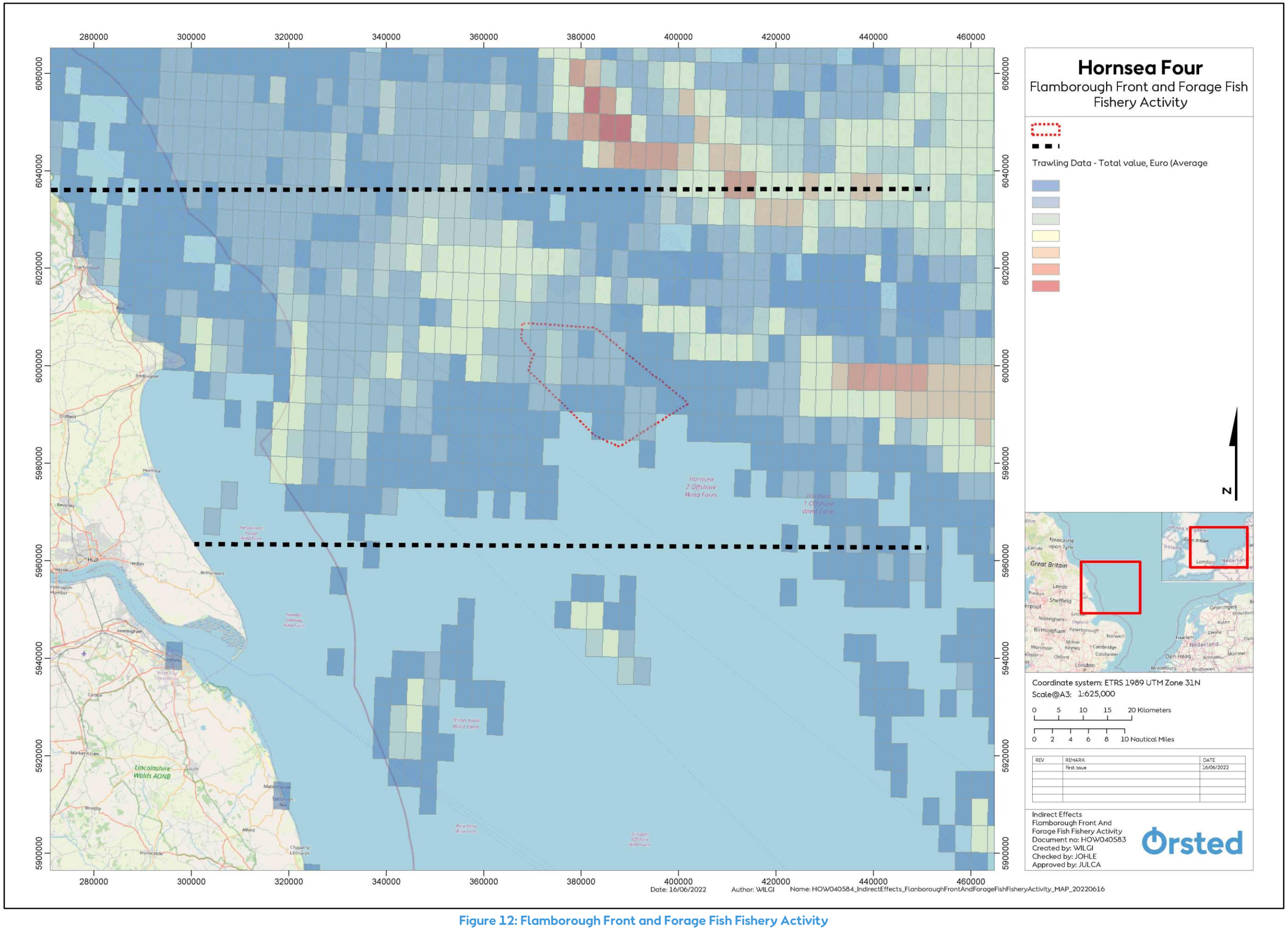

Figure 12: Flamborough Front and Forage Fish Fishery Activity

8.3 Forage Fish and Ornithology

8.3.1.1 Outside of the Hornsea Four array area there are higher density hotspots of both forage fish and seabird species that broadly align. The greatest hotspots occur to the north or the south of the Hornsea Four array area and were identified through both site-specific surveys and desk studies undertaken for the baseline characterisation for both species groups, which are demonstrated in **Section 5** for fish and **Section 6** for seabirds. It is noted that the higher density areas to the south of the Hornsea Four array area coincide with shallower depth waters, where more of the water column is accessible to seabirds to exploit forage fish more easily than other areas that have deeper waters.

8.3.1.2 As forage fish are the main component for seabird diets throughout the year it is no surprise that, following the breeding season, adults and their young are found in areas where higher densities of forage fish are found and where such food resources are accessible with less effort. On review of commercial fishing activities (**Figure 12**) it is also apparent that fishing activities area highest within the waters to the north, west and east as well as a hotspot to the south of the Hornsea Four array area, suggesting higher yields of fish are available from those areas.

8.3.1.3 As the Flamborough Front is more typically located to the north of the Hornsea Four array area (**Figure 2**) it may be that the higher catch rates of fish in those waters is in part related to the front system. However, the presence of higher density hotspots for seabirds and forage fish to the south of the Hornsea Four array area is not likely to be linked to any front systems and is more likely to be a consequence of the natural bathymetry occurring there of shallower waters.

8.4 Ornithology and Productivity

8.4.1.1 As demonstrated in **Figure 11** the Hornsea Four array area sits within a much wider region of thermal fronts, though it is clear that areas to the north, south and west have significantly higher instances of thermal front occurrence. The thermal front distribution is broadly aligned with productivity across the wider region too (**Figure 11**), though again the Hornsea Four array area is comprised of the lower to medium productivity waters in comparison to the medium to high and very high areas of productivity.

8.4.1.2 Following the patterns evident from the thermal front modelling and productivity mapping it can be identified that forage fish, commercial fisheries and bird distribution match these patterns also, with higher densities of auks from the site-specific survey data to the northwest and to the south of the Hornsea Four array area (**Figure 7** to **Figure 9**). Therefore, it is evident that the Hornsea Four array area is of lesser importance both with regards to the occurrence of regular thermal fronts and any associated increased productivity in comparison to other areas. As demonstrated within **Figure 4** the location of the Flamborough Front is consistently to the north of the array area, which is likely to again explain the higher productivity occurring to the north of this area too.

9 Conclusions

9.1 Flamborough Front

9.1.1.1 The spatial and temporal aspects of the Farmborough Front are highly variable. There is no agreed upon line on a map that depicts the location of the Farmborough Front as the location of this features varies seasonally, annually and inter-annually, see **Figure 2**. The feature shows strong seasonality forming in summer and dissipating in autumn, thereby making it difficult to conclude strong relationships between post breeding auk dispersal and the front formation and extent.

9.1.1.2 During the front's summer formation its position varies interannually, though appears to display a strong linkage to bathymetric conditions curtailing its southern extent. This southern bathymetric controlled extent shows a strong correlation with post-breeding auk dispersal (see **Figure 7** to **Figure 9**).

9.1.1.3 The Flamborough Front is inferred to be associated with high pelagic productivity and biodiversity (Miller and Christodolou 2014), though the exact mechanism, timing and intensity has yet to be scientifically established. The degree to which primary and secondary productivity varies at Hornsea Four is inferred upon the physical and biological data sets collected as part of the Environmental Impact Assessment (EIA) process, see Sections 5 to 7 above. These data sets indicate that the primary driver for productivity (inferred from a strong spatial relationship between post breeding auk density and distribution, commercial fisheries activity and bathymetry) is bathymetry, with both auk and commercial fisheries density (both proxies for fish density and distribution) showing a strong positive relationship with water depth.

9.1.1.4 The distributions of forage fish and seabird density may be linked to the position of the Flamborough Front at certain times throughout the year (summer). Outside of the summer the distributions of forage fish and seabird density may be linked to water depth (bathymetry) and benthic ecology.

9.1.1.5 The above sections and figures demonstrate that the productivity of the Flamborough Front area is linked to multiple factors such as bathymetry and is not solely to the annual formation of the Flamborough Front. The Hornsea Four Array area is located in an area of comparatively lower productivity, and the Applicant's Developable Area Approach has further reduced the potential for impacts by removing from the array area, areas of higher productivity (as inferred from the density and distributions of auks in the post breeding period). As such, the Applicant remains confident in the assessment undertaken to the potential impacts of the project on the surrounding features.

Table 7: Relevant Representation Responses

Relevant Rep ID	Relevant Representation	Conclusions
Flamborough Front		
RR-029-5.56	The Flamborough Front is formed where the stratified water from the northern North Sea meets the mixed water from the southern North Sea. The mixing of these two waterbodies leads to an upwelling of nutrients, which in turn leads to increased plankton growth and associated productivity, giving rise to concentrations of forage fish which in turn provide a feeding ground for other species. It is therefore perhaps of no surprise that areas around the front support high densities of seabirds and marine mammals. Consequently, it is vital that the potential impacts of the project alone and in-combination with other plans and projects be adequately assessed. Natural England, therefore, considers this receptor to have high environmental value and not medium as indicated in the ES.	The Applicant confirms that the front is near bottom feature (denser water at or near the seabed) upon which rests less-dense warmer waters. The Flamborough Front is therefore stratified (less-dense water on top of denser water) and any upwelling is associated with the interaction between background hydrodynamic processes (near bed tidal currents) and bathymetry and not a function discrete to the Flamborough Front. It is the Applicant's position that the magnitude of the potential impact is negligible (see response to RR-029-APDX:E-55 and RR-029-APDX:E-56 in **G1.9 Applicant's comments on Relevant Representations (REP1-038)**) and therefore even if the sensitivity were increased if the sensitivity of the feature was considered high then the associated impact according to Table 1.16 would become slight (not significant) rather than neutral (not significant). Therefore, no significant effects in EIA would be predicted.
RR-029-APDX:B-97	NE require further evidence to be able to rule out the potential importance of both the Flamborough Front and wider prey availability issues in the immediate vicinity of the project on the success of birds at FFC SPA.	The impacts of the Hornsea Four upon the Flamborough Front were presented in Section 4.3: Updates to the Impact Assessment of **G4.9 Marine Processes Supplementary Report** (**REP4-043**), which concluded "given that the Flamborough Front is highly dynamic and ephemeral landscape-scale feature, it would not be affected by localised, small-scale changes in water column turbulence induced by individual near-field wakes at foundation locations".
RR-029-APDX:E-D	Data Gaps: .....Effects of the proposed foundation structures on turbulent wake-induced mixing, stratification, and, in turn, primary productivity in and around the Flamborough Front.	The Applicant was unable to attain any evidence that suggests that negligible changes to the form and function (physical processes) adversely affects primary productivity (biological processes) at the Flamborough Front.

Relevant Rep ID	Relevant Representation	Conclusions
RR-029-APDX:E-8	The waters around Flamborough Head are particularly rich in marine life because of its proximity to an upwelling of nutrients and plankton caused by the Flamborough Front. Given the importance of this frontal system to primary productivity in the North Sea, it is vital to understand the potential impacts of the HP4 alone, and in-combination with other plans and projects.	The Applicant reiterates that the front is near bottom feature and that any upwelling is associated with the interaction between background hydrodynamic processes and bathymetry and not a function discrete to the Flamborough Front. While the Applicant agrees that the Flamborough Front plays a role in the productivity (biological processes) of the North Sea, the interaction with the physical processes' changes associated with the proposed Hornsea Four project would not alter biological functioning at a regional sea scale (North Sea) but be limited to 10s or 100s of metres in the location of individual foundations. The project alone and in-combination assessments are presented in **A2.1 Marine Geology Oceanography and Physical Processes (APP-013).**
RR-029-APDX:E-55	"Turbulent wakes are not expected to interact with the Flamborough Front." The magnitude of impact has been assessed as 'negligible' for this effect." The Flamborough Front is located close to/overlaps the HP4 array (and HP2 and HP1)/ Given the importance of the Front to primary productivity (and in turn secondary productivity), a better understanding of the potential impacts of the project alone (and incombination) is required.	
RR-020-3.2.7	the impact on Flamborough front, especially any changes (positively and negatively) to primary productively (and subsequently secondary productivity) has not yet been fully addressed.	
Forage Fish		
RR-029-APDX:B-11	Natural England advises that a summary of the outcomes of the relevant assessments on forage fish abundance and distribution in and around the project area should be included and discussed in relation to the implications for key seabird species.	The presence of higher density hotspots for seabirds and forage fish to the south or the Hornsea Four array area is not likely to be linked to any front systems and is more likely to be a consequence of the natural bathymetry occurring there of shallower waters.
RR-029-APDX:B-11	Sprat also receive very little attention but are a key resource for many seabirds at different times of year. Further assessment is therefore needed to understand how more localised impacts on fish and shellfish might influence prey availability for seabirds	
Seabird Distributions (functional links)		
RR-029-APDX:B-92 and RR-029-APDX:B-105	NE suggest that the proximity of the project area to FFC SPA and the high densities of guillemot and razorbill that appear to be present in August and September, could indicate functional linkages with the SPA colony that warrant consideration of SPA conservation objectives beyond population abundance i.e. in relation to supporting habitats	All areas of the Southern North Sea could be regarded as functionally linked habitats and all hydrodynamic processes are supporting processes on which the habitats of the qualifying features of FFC SPA rely.
Auk post-breeding dispersal		

Relevant Rep ID	Relevant Representation	Conclusions
RR-029-APDX:B-F	Whilst the Developable Area Approach undertaken by the Applicant excludes the highest areas of use, high numbers of these species are still recorded in the baseline surveys for the array area during this period. This is a key, sensitive period for guillemot and razorbill which may be in moult, and thus flightless, and are accompanied by dependent chicks. Given the proximity of the Hornsea Four array to FFC SPA, we consider the high usage at a sensitive period could suggest functional linkages with the SPA colony which warrant further investigation.	The DAA has sought to avoid the areas of highest auk densities. It is not, proportionate, reasonable or possible to bring forth a wind farm project that totally avoids areas of sea that have significant numbers of auks in the post-breeding season (Section 5.5.1 (APP-017)).
RR-029-APDX:B-50	Given the proximity of the array area to FFC SPA, lack of other large populations nearby and the fact that the birds will be moulting, and therefore flightless, we consider it likely that a large proportion of the birds will originate from FFC SPA, rather than other SPAs that are mainly in Scotland, at this time. We are therefore concerned that there is potential for the array area to have functional links with the FFC SPA colony and that displacement of birds from favoured areas could result in a loss of important supporting habitat for a key lifecycle stage, resulting in a range of effects including mortality. We therefore consider that the potential importance of this area to guillemot during August and September has not currently been accounted for in the Applicant's approach and warrants further exploration, as there could be merit in the application of a bespoke approach for this period.	Other OWFs and OWF zones in the Southern North Sea and areas in the Northern North Sea show the same post-breeding peaks for guillemots, so therefore it is not a phenomenon that it is unique to Hornsea Four. (Section 7.2). This being the case all of the Southern North Sea could be defined as functionally linked habitat to FFC SPA or all of the North Sea could be defined as functionally linked habitat to all English and Scottish SPAs and therefore the Hornsea Four array area is not unique in this aspect as it is a small constituent part of a spatially extensive area.
RR-029-5.6	Baseline characterisation data for Hornsea 4 suggests that the array area (plus buffer) is used by considerable numbers of guillemot and razorbill both within and outside the breeding season, and particularly in August and September. This is a key, sensitive period for these two auk species as they head offshore to moult, the males accompanied by dependent chicks, and are flightless for several weeks potentially making them dependent on specific foraging areas. Given the proximity of the array area to the FFC SPA, we consider it likely that a large proportion of the auks present originate from the colony. We are therefore concerned that there is potential for the array area to have functional links with the FFC SPA colony and that displacement of birds from favoured areas could result in a loss of important supporting habitat for a key lifecycle stage, resulting in a range of effects including mortality.	Other OWF in the Southern North Sea and areas in the Northern North Sea show the same post-breeding peaks for guillemots and razorbills, so therefore it is not a phenomenon that it is unique to Hornsea Four. (Section 7.2 and Section 7.3). This being the case all of the southern North Sea could be defined as functionally linked habitat to FFC SPA or all of the North Sea could be defined as functionally linked habitat to all English and Scottish SPAs and therefore the Hornsea Four array area is not unique in this aspect as it is a small constituent part of a spatially extensive area. It is also apparent that through the Developable Area process for Hornsea Four all areas of higher density for both guillemot and razorbill have been avoided, therefore ensuring that the most

Relevant Rep ID	Relevant Representation	Conclusions
		important areas for both species during the post-breeding dispersal months from July through to October have been avoided.
RR-029-5.8	Natural England request that further consideration is given now to drivers of seasonal variations in the wider spatial distributions of auks, particularly during August and September, to determine the potential importance of this area.	This report provides an account of seasonal variations across the North Sea, Hornsea Zone and the Hornsea Four array area during the wider post-breeding dispersion months of July through to October. This demonstrates that significant numbers of auks are present across the wider region and not just within the Hornsea Four array area, providing evidence that no specific drivers are present within the array area to attract auks more so than other areas within the region.
Indirect effects		
RR-029-5.10	Natural England consider that an understanding of the relative importance of the site as a foraging area, and potential for any impacts on prey abundance and distribution is critical in framing the predicted impacts that can be quantified.	An understanding of the importance of the wider region and North Sea for auks throughout the wider post-breeding dispersal period of July through to October has been demonstrated in this report, providing evidence that no specific links are applicable to the Hornsea Four array area.
RR-029-APDX:B-L	NE consider that an understanding of the relative importance of the site as a foraging area, and potential for any impacts on prey abundance and distribution is critical in framing the predicted impacts that can be quantified.	An understanding of the importance of the wider region and North Sea for forage fish, commercial fisheries and seabirds throughout the wider post-breeding dispersal period of July through to October has been demonstrated in this report, providing evidence that no specific links are applicable to the Hornsea Four array area.
RR-029-APDX:B-Q I	Natural England generally agree with the impact pathways identified and assessed, but do not consider that indirect and barrier effects have been adequately assessed for some relevant receptors (gannet, kittiwake, guillemot, razorbill and puffin).	This report provides evidence that any indirect effects have been accounted for and that forage fish, commercial fisheries and seabirds throughout the wider post-breeding dispersal period of July through to October would not be subjected to any adverse effects as they rely more on areas outside of the Hornsea Four array area.

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