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Volume 8 Additional Information

Appendix 2: Ecosystem Level Effects

Caledonia Offshore Wind Farm Ltd

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Volume 8 Appendix 2: Ecosystem Level Effects

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Acronyms and Abbreviations

AON	Apparently Occupied Nest
AOS	Apparently Occupied Site
CFP	Common Fisheries Policy
Chl-a	Chlorophyll-a
CMEMS	Copernicus Marine Service Information
DAS	Digital Aerial Survey
DDT	Dichlorodiphenyltrichloroethane
eDNA	Environmental DNA
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EMF	Electromagnetic Field
EU	European Union
HPAI	Highly Pathogenic Avian Influenza
IAMMWG	Inter-Agency Marine Mammal Working Group
ICES	International Council for the Exploration of the Sea
INNS	Invasive Non-Native Species
LSE	Likely Significant Effects
MD-LOT	Marine Directorate - Licensing Operations Team
MHWS	Mean High Water Springs
MU	Management Unit
NCMPA	Nature Conservation Marine Protected Area
OECC	Offshore Export Cable Corridor
OREI	Offshore Renewable Energy Industry

OSP	Offshore Substation Platform
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
OUT	Operational Taxonomic Unit
OWF	Offshore Wind Farm
PCB	Polychlorinated Biphenyl
PMF	Priority Marine Feature
POP	Persistent organic pollutant
PrePARED	Predators and Prey Around Renewable Energy Developments
RIAA	Report to Inform Appropriate Assessment
RSPB	The Royal Society for the Protection of Birds
SCM	Sub-surface chlorophyll maximum
SCOS	Special Committee on Seals
SMU	Seal Management Unit
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Area
SSB	Spawning Stock Biomass
SSC	Suspended Sediment Concentration
TKE	Total Kinetic Energy
UK	United Kingdom
UWN	Underwater Noise
WTG	Wind Turbine Generator

1 Introduction

1.1 Project Overview

1.1.1.1 In November 2024, Caledonia Offshore Wind Farm Limited (hereafter referred to as the 'Applicant') applied to the Scottish Ministers to develop the Caledonia Offshore Wind Farm (OWF) (hereafter referred to as the 'Proposed Development (Offshore)') within the Outer Moray Firth, off the north-east coast of Scotland.

1.1.1.2 The Proposed Development (Offshore) includes the Caledonia Array Area (hereafter referred to as 'Caledonia OWF') and the Caledonia Offshore Export Cable Corridor (OECC). To support with the deliverability of these phases, the Applicant has submitted two offshore consent applications (Section 36 and associated Marine Licences) for the Proposed Development (Offshore), referred to as Caledonia North and Caledonia South.

1.1.1.3 Further details on the Proposed Development (Offshore) Design Envelope and amendments to the design since submission of the Environmental Impact Assessment Report (EIAR) are presented in Section 4 of the Caledonia Offshore Wind Farm EIAR and HRA Addendum.

1.1.1.4 The relevant documents submitted as part of the EIAR that should be read in conjunction with this Technical Report are:

- Volume 1, Chapter 3: Proposed Development Description (Offshore);
- Volume 2, Chapter 2: Marine and Coastal Processes;
- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology;
- Volume 2, Chapter 5: Fish and Shellfish Ecology;
- Volume 2, Chapter 6: Offshore Ornithology;
- Volume 2, Chapter 7: Marine Mammals;
- Volume 7B, Appendix 2-1: Marine and Coastal Processes Baseline Technical Report;
- Volume 7B, Appendix 2-2: Marine and Coastal Processes Numerical Modelling Report;
- Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report;
- Application Document 13: Caledonia North Report to Inform Appropriate Assessment (Part 1-4); and
- Application Document 14: Caledonia South Report to Inform Appropriate Assessment (Part 1-4).

1.2 Purpose of the Report

1.2.1.1 Marine ecosystems host a diverse array of life, ranging from large marine mammals and megafauna to plankton. Marine developments, such as OWFs, can exert complex influences on these ecosystems. These environments deliver essential services, including food supply, carbon sequestration, biodiversity support and coastal protection, that are crucial for both ecological integrity and human well-being. Gaining a deeper understanding of the ecosystem-wide effects of such developments is key to minimising potential negative impacts. This, in turn, supports the long-term sustainability of marine ecosystems and the vital services they provide.

1.2.1.2 The potential impacts of the Proposed Development (Offshore) on key marine receptors, including cumulative and inter-related effects, are detailed within the relevant EIAR Chapters (Volume 2, Chapters 2-7), as well as for Caledonia North (Volume 3, Chapters 2-7) and Caledonia South (Volume 4, Chapters 2-7), which were submitted to MD-LOT as part of the offshore consent applications in November 2024. Following the submission of the Application, a formal consultation period was held, during which statutory consultees and the public were invited to provide feedback.

1.2.1.3 During this period, concerns were raised by key consultees, relating to the potential for ecosystem level effects from the Proposed Development (Offshore), such as implications from changes in prey availability. Subsequently, this report has been produced to address these concerns. The main objective of this report is to assess the potential impacts arising from the Proposed Development (Offshore), with the aim of identifying Likely Significant Effects (LSE) holistically, across key trophic levels. This includes a particular focus on prey species availability, reflecting feedback received during consultations with Statutory Nature Conservation Bodies (SNCBs) and other stakeholders during the determination phase.

1.2.1.4 This report draws on current literature to establish a baseline of the physical environment (stratification), primary producers, prey species and top predators (such as marine mammals and megafauna). This baseline supports an ecosystem-level assessment of the potential positive and negative impacts of the Proposed Development (Offshore).

1.2.1.5 In addition, this report considers the broader impacts that the ecosystem is facing, acknowledging a shifting baseline, and considering future trends across key trophic levels.

1.3 Document Structure

- Section 1: Introduction, including a brief outline of the Proposed Development (Offshore), the rationale for this document and the relevant consultation to date;
- Section 2: Ecosystem Baseline, outlining the baseline data and conclusions of the relevant EIAR Chapters and current status of the relevant physical and ecological receptor groups;
- Section 3: Ecosystem Level Impacts from the Proposed Development (Offshore), detailing the impacts (positive and negative) that may arise from the Proposed Development (Offshore) on the physical and ecological receptor groups: stratification of the water column and primary producers, prey species, seabirds, and marine mammals and megafauna;
- Section 4: Changing Baselines and Future Change, outlining the current and future anthropogenic driven ecosystem level impacts; and
- Section 5: Conclusions.

1.4 Consultation

1.4.1.1 A summary of the relevant consultation received during the Determination phase, and how these concerns have been addressed within this report, are outlined in Table 1-1.

1.4.1.2 Further details on the overall offshore consent application consultation process for the Proposed Development (Offshore) are presented in Volume 1, Chapter 8: Stakeholder Engagement and Consultation of the EIAR. Topic-specific consultation details and feedback can be found in the relevant chapters of the EIAR.

Table 1-1: Consultation Relevant to Ecosystem Level Effects.

Consultee	Description	How this has been Considered in the EIAR and Ecosystem Level Effects Assessment
NatureScot	Our advice on fish and shellfish is limited to consideration of potential impacts to protected species and/or the inter-relationship between prey, predators and healthy and diverse marine ecosystems.	Potential impacts have been holistically assessed at a wider ecosystem scale in Section 3 of this report. This assessment determines the potential for impacts across predator prey interactions from the Proposed Development (Offshore), with specific consideration given to the potential consequences of any potential changes in prey distribution and abundance on bird and mammal receptors. This report also considers the potential for wider impacts that the ecosystem is facing, highlighting a changing baseline, and considers the future trends across key trophic levels, this is detailed in Section 4 of this report.
NatureScot	In our scoping response, dated 4 November 2022, we identified that changes to prey species availability was not wholly captured within the impacts table. Changes in prey species availability should be assessed under its own impact category, with more attention given to key prey species (such as sandeel, herring, mackerel and sprat). It is important to understand impacts at the ecosystem scale and across key trophic levels. This does not appear to have been assessed in the EIA and if consented, this aspect should be considered further as part of any post-consent plans in respect of mitigation.	Potential impacts and changes in prey species availability have been assessed in Section 3.3, with attention given to key prey species (such as sandeel, herring, mackerel and sprat). Specifically, due consideration is given to the potential consequences of any potential changes in prey distribution and abundance on marine mammals (and other top predators). Consideration is also given to how the Proposed Development (Offshore) may affect the recruitment of key prey (fish) species through impacts to important spawning or nursery ground habitats in Section 3.3 of this Report.
NatureScot	In the Scoping Opinion, it was asked that Caledonia assess ecosystem effects – this has not been covered within this EIA.	Potential ecosystem level effects have been holistically assessed in Section 3 of this report. This assessment determines the potential for impacts across predator prey

Consultee	Description	How this has been Considered in the EIAR and Ecosystem Level Effects Assessment
		interactions from the Proposed Development (Offshore), with specific consideration given to the potential consequences of any potential changes in prey distribution and abundance on bird and mammal receptors.
NatureScot	In our scoping response, dated 4 November 2022, we identified that changes to prey species availability was not wholly captured within the impacts table. Changes in prey species availability should be assessed under its own impact category, with more attention given to key prey species (such as sandeel, herring, mackerel and sprat). It is important to understand impacts at the ecosystem scale and across key trophic levels. This does not appear to have been assessed in the EIA and if consented, this aspect should be considered further as part of any post-consent plans in respect of mitigation.	Potential impacts and changes in prey species availability have been assessed in Section 3.3, with attention given to key prey species (such as sandeel, herring, mackerel and sprat). Specifically, due consideration is given to the potential consequences of any potential changes in prey distribution and abundance on marine mammals (and other top predators). Consideration is also given to how the Proposed Development (Offshore) may affect the recruitment of key prey (fish) species through impacts to important spawning or nursery ground habitats in Section 3.3 of this report.
The Royal Society for the Protection of Birds (RSPB)	As set out in Searle et al (2023a), assessing impacts of offshore windfarms and other renewables developments is inherently uncertain. This uncertainty is propagated throughout the impact assessments, as there are not only direct impacts, but ecosystem wide impacts that can change, for example, the abundance and availability of prey. Multiple data sources and modelling techniques are used to capture a simplified version of reality. They do not fully capture the complexity of seabird behavioural or demographic processes in an inherently dynamic marine environment.	The potential for ecosystem level effects, arising from changes in the abundance and/or distribution of forage fish (such as sandeel) are addressed in Section 3 of this report, with specific consideration given to the potential for secondary impacts to seabirds and other sandeel-dependent species.

Consultee	Description	How this has been Considered in the EIAR and Ecosystem Level Effects Assessment
RSPB	Of relevance to achieving sustainable development in our seas is the Marine Strategy Framework Directive. This was developed in response to concerns that although existing legislation protected the sea from some specific impacts, it was sectoral and fragmented. To overcome this, the directive seeks to reduce impacts on marine waters regardless of where impacts occur by applying an ecosystem approach.	Changes to mixing and stratification and their potential for ecosystem level effects from the Proposed Development (Offshore), are assessed in Section 3.2 of this report.
RSPB	Applying an ecosystem approach is important. Our natural environment is complicated, and the outcome of an impact may manifest elsewhere. It also feeds into the concept of sustainable development and the vision for clean, healthy, safe, productive, and diverse seas; managed to meet the long-term needs of nature and people as set out Scotland's National Marine Plan.	Potential impacts have been holistically assessed at a wider ecosystem scale in Section 3 of this report. This assessment determines the potential for impacts across predator prey interactions from the Proposed Development (Offshore), with specific consideration given to the potential consequences of any potential changes in prey distribution and abundance on bird and mammal receptors. This report also considers the potential for wider impacts that the ecosystem is facing, highlighting a changing baseline, and considers the future trends across key trophic levels, this is detailed in Section 4 of this report.
RSPB	Seabirds are relatively long-lived, and as a result, their populations are sensitive to small increases in adult mortality. Their survival and productivity rates can be impacted by offshore windfarms directly (i.e. collision) and indirectly (e.g. displacement from foraging areas, additional energy expenditure, potential impacts on forage fish and wider ecosystem impacts such as changes in stratification).	Potential impacts on seabirds from changes to stratification and changes to the availability and abundance of prey species have been holistically assessed in Section 3 of this report.

Consultee	Description	How this has been Considered in the EIAR and Ecosystem Level Effects Assessment
SFF	This response should be read with the SFF response to the scoping report. The concerns raised in that earlier response are adopted herein. Our further concerns are set out in this response. The fact that so much traditional fishing opportunities will be lost in place of an energy industry that, to date there is no scientific evidence to prove that an OWF of this size will not have an impact on the ecosystem and the marine environment (resulting from the development's physical presence, noise, vibration, damage to seabed from cables, EMF and wake effects, stratification, and more). Much has been said about the Spatial Squeeze as a result of the exponential growth of the Offshore Renewable Energy Industry (OREI) however very little has been said about the consequential environmental squeeze.	Potential impacts on the ecosystem and the marine environment (resulting from the development's physical presence, noise, vibration, damage to seabed from cables, Electromagnetic Fields (EMF),wake effects in the water column, stratification, and more) have been assessed in full details across Volume 2 of the EIAR. Potential impacts have been holistically assessed at a wider ecosystem scale in Section 3 of this report. This assessment determines the potential for impacts across predator prey interactions from the Proposed Development (Offshore), with specific consideration given to the potential consequences of any potential changes in prey distribution and abundance on bird and mammal receptors. This report also considers the potential for wider impacts that the ecosystem is facing, highlighting a changing baseline, and considers the future trends across key trophic levels, this is detailed in Section 4 of this report.
SFF	The EIA underscores the need for a more holistic approach to ocean management that considers the cumulative effects of multiple projects. It is crucial to balance the need for renewable energy with the need to protect the marine environment and livelihoods of fishers and the wider communities which depend upon them. There must be recognition that this is not just about one wind farm, but about the broader impact on the entire ecosystem.	Potential impacts have been holistically assessed at a wider ecosystem scale in Section 3 of this report. This assessment determines the potential for impacts across predator-prey interactions from the Proposed Development (Offshore), with specific consideration given to the potential consequences of any potential changes in prey distribution and abundance on bird and mammal receptors. This report also considers the potential for wider impacts that the ecosystem is facing, highlighting a changing baseline, and considers the future trends across key trophic levels, this is detailed in Section 4 of this report.

2 Ecosystem Baseline

2.1 Overview

2.1.1.1 This section provides an overview of the current status of key trophic levels of the marine ecosystem, based on the information presented in the relevant EIAR Chapters. The section is structured by trophic level, beginning with the stratification of the water column and its influence on primary production, followed by prey species and higher trophic levels, including seabirds, marine mammals, and other megafauna such as elasmobranchs.

2.2 Stratification and Primary Producers

2.2.1 Stratification

2.2.1.1 This section provides a summary of the baseline provided in Volume 7B, Appendix 2-1: Marine and Coastal Processes- Baseline Technical Report and Volume 8, Appendix 1: Marine and Coastal Processes Stratification Technical Note, and wider evidence that is relevant to this Ecosystem Level Effects assessment.

2.2.1.2 Frontal zones mark boundaries between water masses, including tidally mixed and stratified areas, and are numerous on the European continental shelf (BEIS, 2022[1]). Fronts play an important role in enabling the circulation and transport of nutrients and heat. Frequently reoccurring fronts (e.g., spatially and/or seasonally) are widely recognised as supporting enhanced biological activity such as primary photosynthetic production, which is the foundation of marine ecosystems and a major contributor to global oxygen generation and carbon cycling (NatureScot, 2024[2]).

2.2.1.3 Stratification is a hydrodynamic feature defined by vertical density gradients, occurring over relatively short distances within the water column and driven by the distribution of seawater temperature and salinity (Huthnance, 1991[3]). In the North Sea, regional stratification is mainly influenced by factors such as water depth, the strength of tidal currents, proximity to the shelf edge (which enables exchange with oceanic waters) and the presence of fresher, coastal water (Huthnance, 1991[3]).

2.2.1.4 The Proposed Development (Offshore) is located to the west of the Dooley Current, which predominately flows eastward to the North Sea with a smaller flow southwards towards the Outer Moray Firth. This results in the establishment of a front between this cooler water and the warm waters from the inner Moray Firth (Tetley *et al*., 2008[4]).

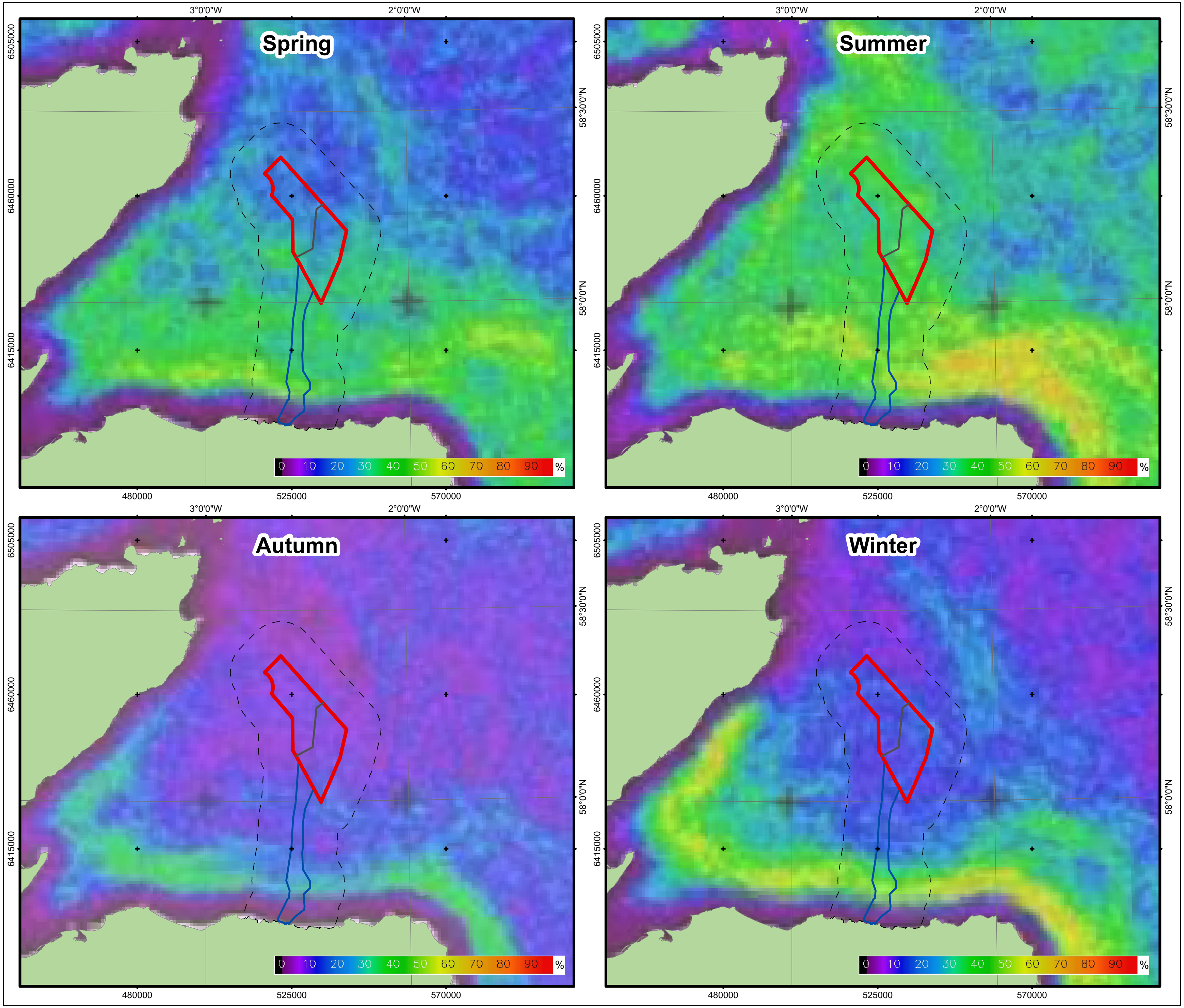
2.2.1.5 Within the Caledonia OWF (i.e., Array Area), the stratification is mainly due to temperature-related density differences between warmer surface waters and cooler deeper waters. Data from the Moray East OWF shows that this typically forms a weak thermocline (where temperature changes rapidly with depth) between 10 to 15m of water depth which is immediately adjacent to the west of the Caledonia OWF, showing that there is no significant freshwater/salinity contribution to observed stratified waters (MORL, 2012[5]). In spring and summer, the additional stratification generated by summer warming and less frequent storm events generates additional surface thermal fronts that extend beyond the coastal zone. These can overlap with the Caledonia OWF for approximately 40% of the time in summer (Miller *et al*., 2014[6]; Figure 2-1).

2.2.1.6 The project-specific benthic survey showed a thermocline present between 5 to 20m of water depth within the Caledonia OWF, with a stable temperature of 8 ± 0.3°C (see Volume 7B, Appendix 2-1: Marine and Coastal Processes Baseline Technical Report; Miller *et al*., 2014[6]; Gardline, 2023a[7]). Salinity is shown to have stable vertical profile within the Caledonia OWF, except at the station closest to the Caledonia OECC (ENV12, approximately 1km from the Caledonia OECC), which shows a halocline between 10 to 25m (Gardline, 2023a[7]). Furthermore, salinity, within the Caledonia OECC, shows a slight decrease at the surface, except for the station closest to the shore (ENV53, approximately 1.33km from the shore) (Gardline, 2023b[8]).

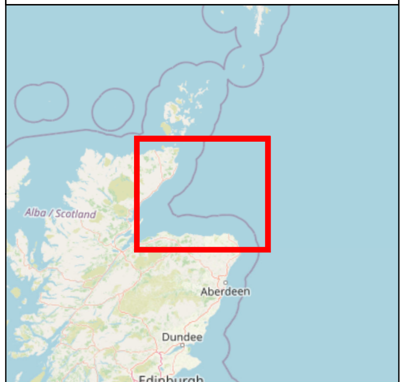
2.2.1.7 Data, averaged between 2014 and 2024, from E.U. Copernicus Marine Service Information (CMEMS) within the Proposed Development (Offshore), both Caledonia OWF (i.e., Array Area) and Caledonia OECC, correlates results from paragraphs 2.2.1.5 and 2.2.1.6 (CMEMS, 2025[9]). Data are provided in detail within Volume 8, Appendix 1: Marine and Coastal Processes Stratification Technical Note and can be summarised as follow:

- Within the Caledonia OWF, data, averaged between 2014 and 2024, from CMEMS show a difference between surface and bottom temperature between March and September of 3.5°C maximum, whereas salinity remains constant throughout the year with value of 34.45 ± 0.15PSU (CMEMS, 2025[9]);
- Stratification within the Caledonia OECC was shown to be of two types. Thermal stratification in the north and centre is present during spring and summer months with difference between surface and bottom temperature reaching a maximum of 5°C, whereas haline stratification occurs in the south of the Caledonia OECC with salinity varying from 33 PSU during winter to 34 PSU during summer (CMEMS, 2025[9]); and
- The variation of salinity along the Caledonia OECC is also an indicator of frontal feature between low salinity water, closer to the shore, and high salinity water further offshore.

2.2.1.8 The stratification occurring within the Moray Firth has been shown to directly influence the primary production, such as phytoplankton. For instance, in the Southern Trench Nature Conservation Marine Protected Area (NCMPA), a warm water plume event was correlated with high levels of phytoplankton, which in turn was correlated with an increase of prey species (e.g., sandeel), and the consequent increase of minke whales sighted per unit of survey effort (paragraph 2.5.1.2) (Tetley *et al*., 2008[4]).



Caledonia OWF
Offshore Export Cable Corridor
Caledonia North Site and Caledonia South Site Division Line
10km Zone of Influence



0 10 20 30 40 50 km

REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP
01	15/09/2025	Approved	EV	BB	DH

GEODETIC PARAMETERS
WGS 84 / UTM zone 30N (EPSG: 32630)

DRAWING TITLE
Figure 2-1: Comparison of Thermal Front Frequency for All Seasons (Miller et al., 2014)

STATUS	SCALE	
Approved	1:1,500,000	
DRAWING NUMBER	SHEET NO	REV
N/A	01 of 01	N/A

2.2.2 Primary Producers

2.2.2.1 This section provides a summary of the baseline provided in Volume 7B, Appendix 2-1: Marine and Coastal Processes- Baseline Technical Report, and wider evidence that is relevant to this Ecosystem Level Effects assessment.

2.2.2.2 Primary production underpins ocean ecosystems and contributes substantially to global oxygen and carbon cycles. Phytoplankton are primary producers, accounting for approximately half of the Earth's oxygen production and carbon fixation (Longhurst, 2007[10]). When the surface waters of the North Sea develop thermal stratification in the spring, the phytoplankton bloom depletes surface nutrients and their growth becomes limited by the lack of nutrients in the surface layer. The sub-surface chlorophyll maximum (SCM) typically develops between 20 to 40m below the surface and is sustained by a balance between sufficient sunlight from the surface and sufficient nutrient supply by turbulent mixing, which drives an upward flux across the thermocline. The SCM may account for up to 50% of annual primary production: this is all the production by photoautotrophs (organisms that can photosynthesise and produce organic compounds) in the euphotic zone (the upper layer of a body of water that receives enough sunlight for photosynthesis to occur) in seasonally stratified seas (Hickman *et al*., 2012[11]).

2.2.2.3 In winter, the water column in the North Sea, and the Moray Firth, is typically well-mixed, leading to a uniform vertical distribution of chemical tracers such as nutrients and oxygen, from the surface to the deep waters. Under these conditions, the increase in turbulence kinetic energy (TKE) (the energy in the swirling, chaotic motion of water or air) has a minimal effect on the vertical nutrient profiles. With the onset of thermal stratification and increased light availability in spring, phytoplankton begin to grow, reproduce and consume nutrients, depleting nitrate and other essential nutrients from the surface layer. As warming progresses into summer, stratification in the surface waters increases, separating the nutrient-rich deeper waters from the surface, thereby limiting nutrient replenishment. By July, nitrate reaches limiting concentrations at the surface. In autumn, the breakdown of stratification allows nutrients to be resupplied to the surface and the water column becomes well-mixed again by October.

2.2.2.4 The introduction of anthropogenic structures into seasonally stratified waters can disrupt natural conditions, artificially increasing the mixing of these waters (Bailey *et al*., 2014[12]). Such changes may increase nutrient availability to the SCM and consequently increase annual primary production, potentially influencing the wider marine ecosystem.

2.2.2.5 Chlorophyll-a (Chl-a), a photosynthetic pigment, is commonly used as a proxy for biological productivity. In the context of this report, it represents primary production, the lowest trophic level. During winter, Chl-a concentrations are low due to reduced light and lower temperatures, which limit biological activity. In spring, phytoplankton blooms lead to a surge in productivity in the North Sea, as nutrient concentrations are still abundant in sunlit surface waters. By summer, productivity declines as nutrient availability depletes, and surface Chl-a concentrations decrease. These seasonal trends, characterised by summer stratification and nitrate limitation, are typical of the wider North Sea. Under such conditions an SCM often forms. In more stratified conditions, the SCM tends to be more distinct, and there is a stronger nitricline (difference between surface and deep-water nitrate). An increase in Chl-a is usually observed in autumn as stratification breaks down and nutrients are mixed back into the surface layer, followed by another decline as temperatures drop and daylight hours decrease in October (Figure 2-2).

2.2.2.6 Nitrate is regarded as the primary limiting nutrient in the North Sea, showing the most significant seasonal decline, and typically becoming limiting to phytoplankton growth by May or June. While phosphate and silicate concentrations also decrease, they usually remain above concentrations considered limiting for phytoplankton (Figure 2-3). Chl-a concentrations are highest between April and September, although productivity tends to decline slightly in summer, as surface waters become increasingly stratified and isolated from the nutrient-rich deeper layers.

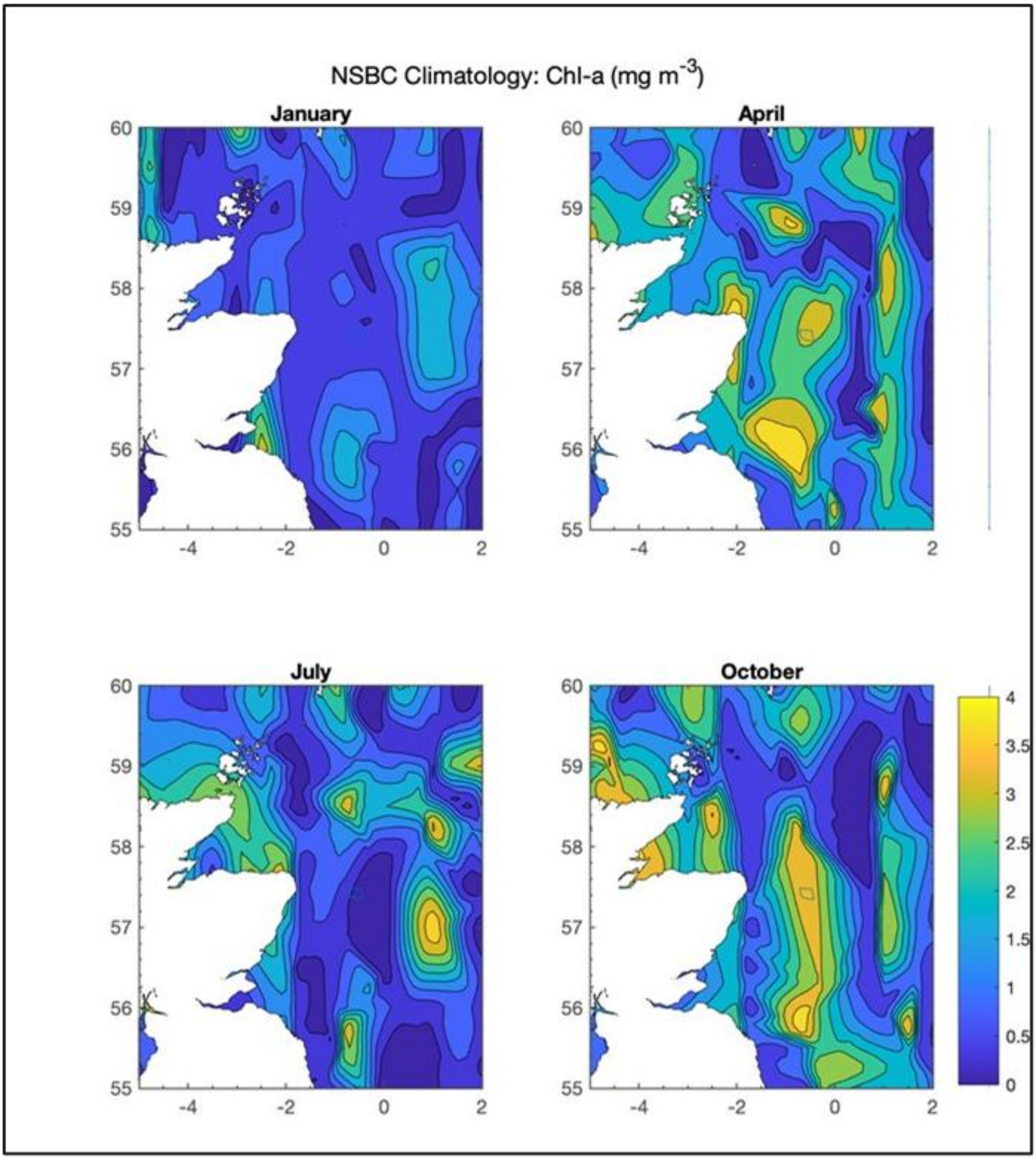


Figure 2-2: Maps of Chl-a (mg m^{-3}) concentration in winter, summer, spring and autumn, taken from the North Sea Biogeochemical Climatology (NSBC) (sourced from Hinrichs *et al.*, 2017[13]).

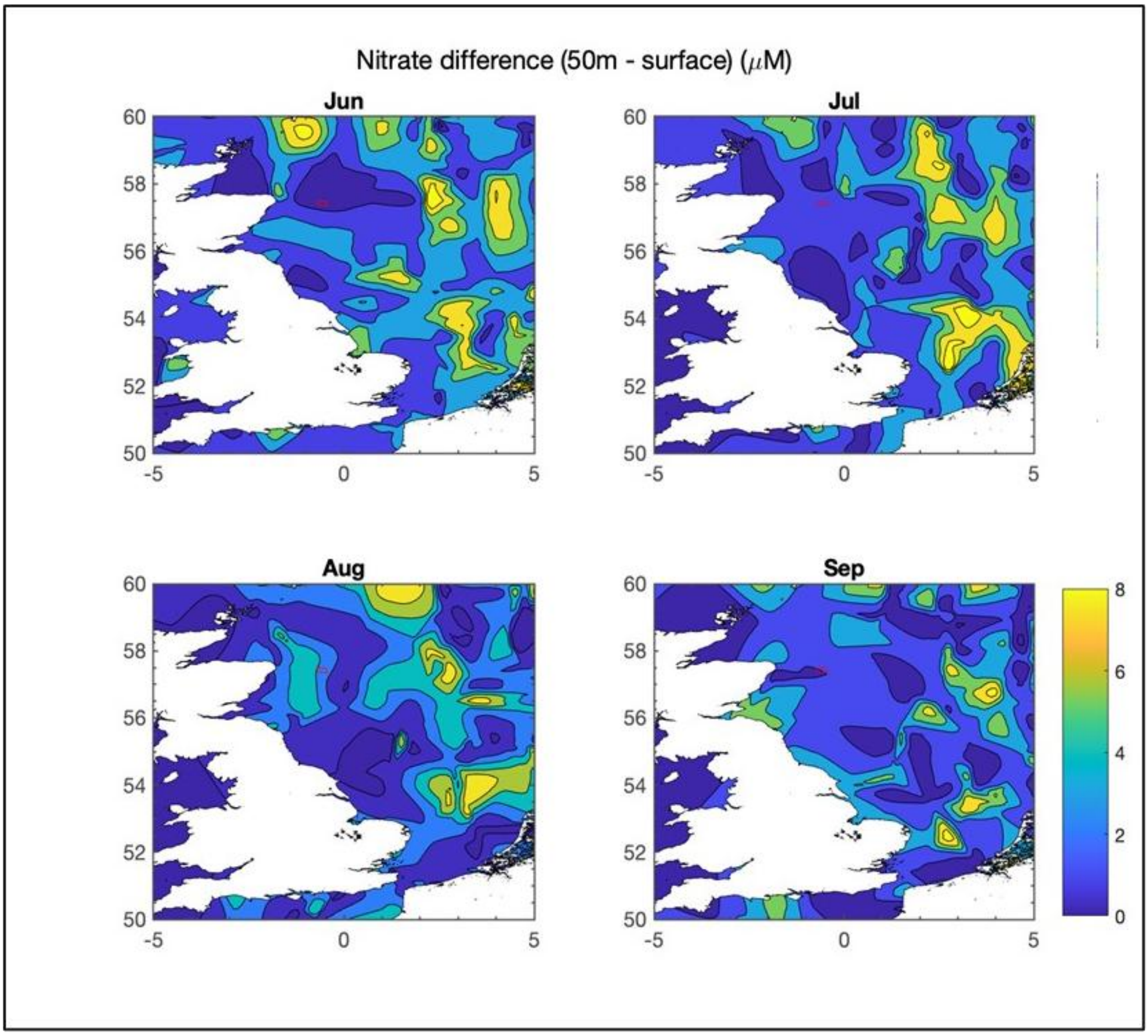


Figure 2-3: Maps of the difference between nitrate at 50m and nitrate at the surface, an indicator of the degree of stratification and nutrient limitation to surface phytoplankton (sourced from Hinrichs *et al.*, 2017[13]).

2.3 Prey Species

2.3.1.1 This section provides a summary of the baseline provided in Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology, Volume 2, Chapter 5: Fish and Shellfish Ecology and Volume 7B Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report and wider evidence that is relevant to this Ecosystem Level Effects assessment.

2.3.1.2 Prey species are fundamental to the marine ecosystem. Such species include invertebrates such as copepods and krill, as well as forage fish, including Atlantic herring, hereafter referred to as 'herring' (*Clupea harengus*), sandeel (*Ammodytidae* spp.), Atlantic mackerel (*Scomber scombrus*), hereafter referred to as 'mackerel', and sprat (*Sprattus sprattus*). They form the foundation of the diet for many higher trophic level predators, including larger fish and crustaceans, seabirds and marine mammals. These prey species play a key role in transferring energy from some of the lowest to the highest trophic levels within the ecosystem and contribute to nutrient recycling through the consumption of detritus. Forage fish, are particularly important prey items for top marine predators including elasmobranchs, seabirds and cetaceans, while small planktivorous species (those that eat plankton) serve as important links between zooplankton and higher trophic levels (Frederiksen *et al*., 2006[14]). As a result, their populations are influenced by both top-down factors such as predation, and bottom-up factors such as ocean climate variability and plankton availability. In recent years, populations of these prey species have fluctuated in response to various anthropogenic pressures, including climate change, habitat degradation and fishing pressure.

2.3.1.3 Copepods and krill (crustacea) are key components of the North Sea zooplankton community and serve as a vital food source for forage fish. Their abundance and distribution have been significantly affected by rising sea temperatures, which have led to shifts in the composition of zooplankton communities. For instance, populations of cold-water copepod species, such as *Calanus finmarchicus*, have declined, while warmer-water species, like *Calanus helgolandicus*, have become more prevalent (Beaugrand *et al*., 2003[15]). These shifts can affect the availability of nutritious prey for fish larvae, leading to potential bottlenecks in fish population dynamics.

2.3.1.4 As detailed in Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology, the study area is defined by the following spatial scales:

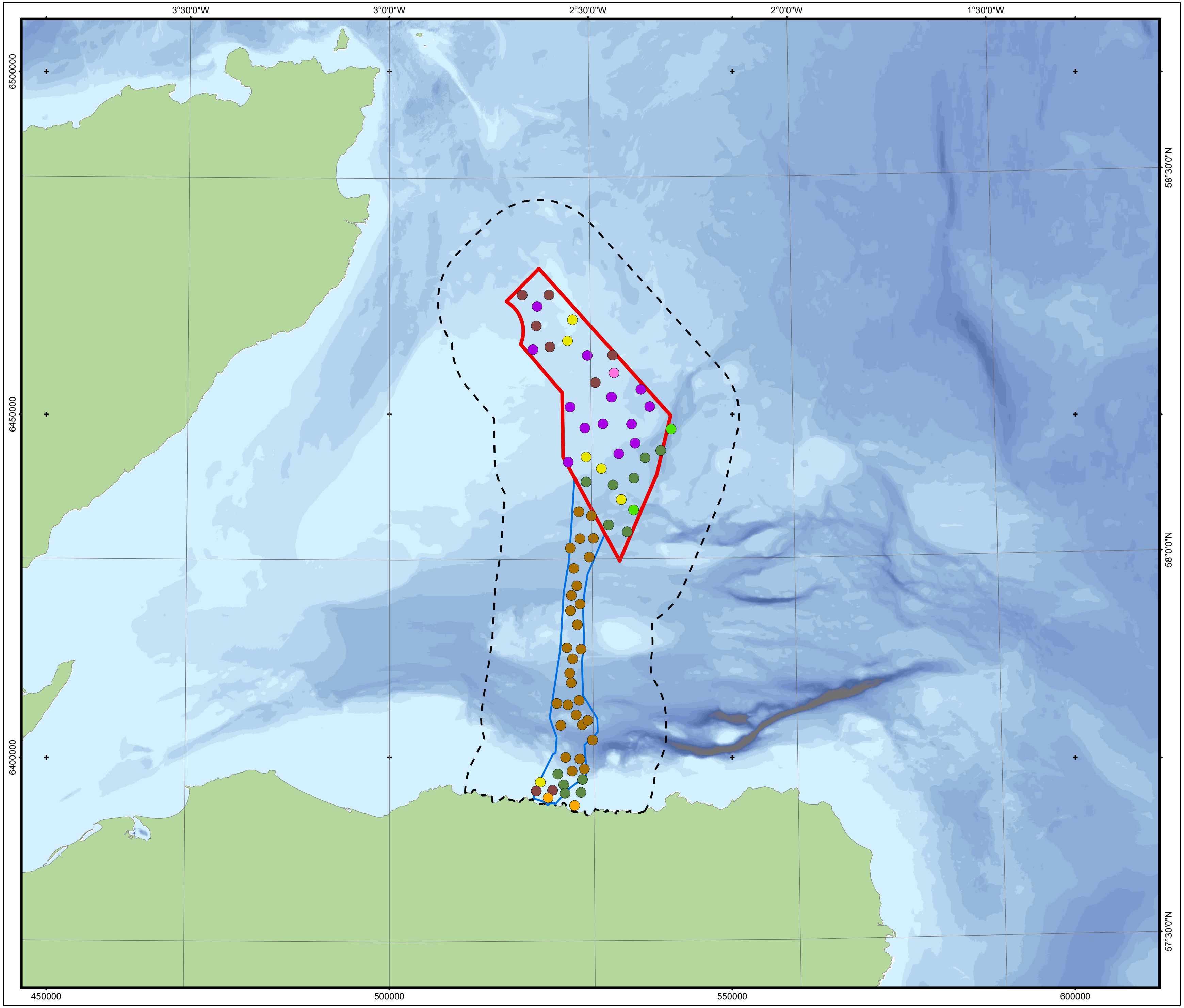
- The footprint of the Proposed Development (Offshore), which consists of the Caledonia OWF and Caledonia OECC, within which the offshore infrastructure will be installed, and the intertidal area along the coast which takes into account the potential OECC Landfall Site locations; and

- The benthic subtidal and intertidal ecology study area, which has been established using a 10km buffer around the Caledonia OWF and Caledonia OECC. This 10km buffer encompasses the area over which suspended sediment might travel following disturbance, based on the maximum distance suspended sediments will travel in one tidal excursion on a mean spring tide.

2.3.1.5 Benthic species are foundational to the structure and function of marine ecosystems, influencing everything from nutrient cycling to habitat formation and food web dynamics (Snelgrove, 1999[16]). A total of 2,075 individuals representing 242 taxa were recorded from 34 grab samples across the Caledonia OWF. The benthic subtidal community was predominantly composed of Annelida (Polychaeta), which accounted for the majority (51%) of the recorded taxa, followed by Arthropoda (Malacostraca) (20%), Mollusca (19%) and Echinodermata (4%). The 'Others' category, represented by Annelida (Clitellata, Sipuncula), Arthropoda (Pycnogonida), Chaetognatha, Cnidaria (Anthozoa), Foraminifera, Hemichordata, Nemertea, Phoronida and Platyhelminthes, comprised 6% of recorded taxa. Pea urchin (*Echinocyamus pusillus*), polychaete worm (*Lumbrineris aniara*) and bivalve mollusc genera *Abra* were observed frequently across the Caledonia OWF. The presence of *E. pusillus*, *Alba* spp. and *L. aniara* were reflected in the recordings of the biotopes '*Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in Atlantic circalittoral coarse sand or gravel' and '*Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand' which were widespread across the Caledonia OWF (Figure 2-4).

2.3.1.6 Full descriptions of the site-specific surveys, and sample analyses, are presented within the following:

- Volume 7B, Appendices 4-1: Environmental Baseline Report (Array Area);
- Volume 7B, Appendices 4-2: Environmental Baseline Report (Offshore Export Cable Corridor);
- Volume 7B, Appendices 4-3: Habitat Assessment Report (Array Area);
- Volume 7B, Appendices 4-4: Habitat Assessment Report (Offshore Export Cable Corridor); and
- Volume 7B, Appendices 4-5: Intertidal Survey Report.



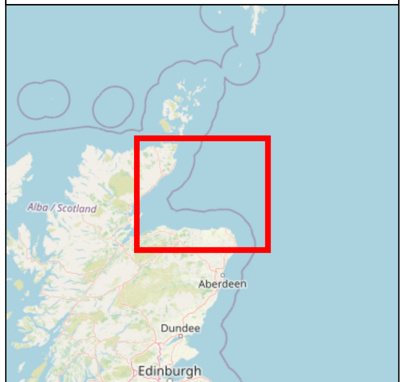
Caledonia OWF
Offshore Export Cable Corridor
10km Benthic Ecology Study Area

Depth (m)

- 0 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150
- 150 - 160
- 160 - 170
- 170 - 180
- 180 - 190
- 190 - 200
- >200

Biotope Code

- MD521
- MC3212
- MD4211
- MC5211
- MD5212
- MB5233
- MC6216
- MD6219



0 5 10 15 20 25 km

REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP
01	15/09/2025	Approved	EV	BB	DH

CALEDONIA Offshore Wind Farm

GoBe APEM Group

GEODETIC PARAMETERS
WGS 84 / UTM zone 30N (EPSG: 32630)

DRAWING TITLE
Figure 2-4: Biotope Classification

STATUS: Approved
SCALE: 1:750,000
DRAWING NUMBER: N/A
SHEET NO: 01 of 01
REV: N/A

2.3.1.7 Fish are typically highly mobile and have a wide range (as detailed in Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report and Volume 2, Chapter 5: Fish and Shellfish Ecology), and consequently, the study area is considered at different spatial scales; these spatial scales consist of:

- The footprint of the Proposed Development (Offshore) (the area within which offshore infrastructure will be installed (i.e., the Caledonia OWF and Caledonia OECC)), and the intertidal landfall area;
- A sedimentary study area (i.e., the area within which suspended sediment might travel following disturbance, based on the maximum spring tidal excursion). This consists of a 10km buffer around the Caledonia OWF and Caledonia OECC; and
- An Underwater Noise (UWN) study area (i.e., the area within which potential subsea noise impact ranges are predicted to occur as a result of activities relating to the installation of infrastructure). This consists of a 70km buffer around the Caledonia OWF.

2.3.1.8 The characterisation of the species found within the study area was defined by drawing upon site-specific surveys that were undertaken for the Proposed Development (Offshore) and in support of various OWFs in the vicinity, as well as wider information from publicly available sources (Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report).

2.3.1.9 Environmental DNA (eDNA) samples taken across the Caledonia OWF and the Caledonia OECC determined a total of 26 fish classes and a combined 137 Operational Taxonomic Units (OTUs), including key prey species such as herring (*C. harengus*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Norway pout (*Trisopterus esmarkii*), mackerel (*S. scombrus*) and sprat (*S. sprattus*) (see Volume 7B, Appendix 4-1 Environmental Baseline Report (Array Area) and Volume 7B, Appendix 4-2 Environmental Baseline Report (Offshore Export Cable Corridor).

2.3.1.10 The wider spawning and nursery sites identified within and in proximity to the Proposed Development (Offshore), as well as spawning timings, are presented in Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report, and are summarised below, along with the most recent International Council for the Exploration of the Sea (ICES) advice on stock health and catch limits.

2.3.1.11 Herring are an important prey species for other fish, marine mammals and birds within the North Sea food-web. Herring are demersal spawners, that lay their eggs onto or into seabed sediments. They also exhibit substrate dependency and show a high preference for coarse grounds and high energy environments when selecting spawning grounds. There are two large herring stock spawning grounds that run along much of the east coast of Scotland and extend offshore. The Buchan stock spawning ground (as defined by Coull *et al*., 1998[17]) overlaps with the south of the UWN study area, and the

Orkney/Shetland herring spawning ground interacts with the north of the UWN study area. The Buchan and Shetland herring stocks typically spawn off the northeast Scottish and Shetland coasts between August and September. As detailed in Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report, the Caledonia OWF and Caledonia OECC, as opposed to the wider study area, do not have a direct overlap with herring spawning ground.

2.3.1.12 North Sea herring stocks remain above safe biological limits (ICES, 2025a[18]): this means that the population size of North Sea herring has been deemed by ICES to be healthy enough to avoid risks of collapse or long-term damage. However, fishing pressure on stocks in the Greater North Sea exceeds the level that allows the population to be fished sustainably, with low recruitment estimated for 2025, and the population of breeding fish showing a decline. As a result, catch limits for North Sea herring have been set for 2025 (ICES, 2024b[19]) and 2026 (ICES, 2025a[18]), reflecting a cautious approach to ensure the stock remains within safe biological limits. Further, ICES advise that no activities on spawning habitats should be allowed (i.e., no human actions or interventions that could potentially affect spawning habitats) unless the effects of these activities have been assessed and shown not to be detrimental (ICES, 2025a[18]). This restriction is in recognition of the sensitivity of herring to habitat disturbance, on account of their substrate-dependent spawning behaviours (De Groot, 1980[20]; Maucorps, 1969[21]; Lacoste *et al*., 2001[22]; Parrish *et al*., 1959[23]; Blaxter, 1985[24]).

2.3.1.13 Sandeel are an important trophic link in the North Sea food chain, between zooplankton and sandeel predators (including piscivorous fish, most seabirds and mammals). As many marine predators rely on sandeel, which are vulnerable to changes in habitat, sandeel are of increasing conservation interest, and as such are listed as a: Species of Principal Importance in the United Kingdom (UK); Nationally Important Marine Feature in the UK (Hirst *et al*., 2012[25]) and a Scottish Priority Marine Feature (PMF). Sandeel typically spawn during the winter months, with peak spawning usually occurring from late November to January. Areas of "high" Central Western North Sea sandeel stock (ICES, 2022[26]) spawning potential overlap with the north of the Caledonia OWF, with the rest of the Caledonia OWF and Caledonia OECC being classified as either "medium" or "low". There is a patchy distribution of suitable sandeel habitat across the study area, with a large proportion of "preferred" sediment across the Caledonia OWF and Caledonia OECC.

2.3.1.14 Sandeel populations have fluctuated significantly over the past few decades (MacDonald *et al*., 2019[27]). Sandeel are highly sensitive to changes in water temperature and habitat conditions, and warming sea temperatures have contributed to declines in their abundance in some areas. In response to these pressures, ICES (2025b[28]) recommend avoiding any activity that could lead to the degradation of sandeel habitats. Since March 2024, the fishing of sandeel in all Scottish waters has been prohibited. Prior to this prohibition, sandeel held a significant position as a target species for Scottish fishing vessels. Sandeel landings by Scottish vessels experienced notable fluctuations, with quantities often surpassing 100,000 tonnes annually during the early 2000s, reaching a peak of over 150,000 tonnes in 2002 (Marine Scotland, 2023[29]). However, in the late 2000s and 2010s, landings dwindled, averaging around 50,000-70,000 tonnes per year (Marine Scotland, 2023[29]). The recent decline in sandeel populations has had significant repercussions on reliant species, contributing to declines in seabird populations and impacting the overall marine ecosystem's health (Marine Scotland, 2023[29]).

2.3.1.15 Mackerel are a migratory pelagic species and have spawning grounds which interact with the study area and which extend over much of the North Sea (Coull *et al*., 1998[17]). Mackerel are broadcast spawners, releasing buoyant eggs that drift with ocean currents (Russell, 1976[30]) and spawn from May to July, with peak activity in early summer (Coull *et al*., 1998[17]). Adults undertake seasonal migrations: overwintering in deeper Atlantic waters to the west of the British Isles and moving into the North Sea during warmer months to feed and spawn (Jansen *et al*., 2012[31]). The North Sea mackerel stock has a healthy breeding population, with the spawning stock biomass (SSB) above all critical levels. However, fishing pressure is above the level corresponding to maximum sustainable yield (as advised by ICES) and continued catches above this level may carry a risk of the stock declining over time (ICES, 2024c[32]).

2.3.1.16 Sprat are a pelagic species and have spawning grounds which interact with the study area, and which extend over much of the North Sea (Coull *et al*., 1998[17]). Spawning generally occurs from December to April, with some regional variability (Coull *et al*., 1998[17]). Given their short lifespan (typically 3–5 years) and rapid reproductive turnover, sprat populations are highly variable and responsive to both environmental change and fishing pressure (Petitgas *et al*., 2010[33]). The North Sea sprat stock has a healthy breeding population, well above all thresholds that ICES use to determine this, though recruitment in 2023 was below average. This low recruitment is anticipated to reduce spawning-stock biomass by mid-2025, though it is still expected to stay at safe levels (ICES, 2025c[34]).

2.3.1.17 There have been substantial changes in the communities of prey species in the northeast Atlantic over the past few decades, particularly in the North Sea, as a result of a number of factors including climate change and fishing activities (Blanchard *et al*., 2012[35]; Gordó -Vilesca *et al*., 2024[36]). These communities consist of species that have complex interactions with one another and the natural environment. Fish and shellfish populations are subject to natural variations in population size and distributions, largely as a result of year-to-year variation in recruitment success. Population trends are further influenced by broad-scale climatic and hydrological variations, as well as anthropogenic impacts such as climate change and overfishing (see Section 4).

2.4 Seabirds

2.4.1.1 This section provides a summary of the baseline provided in Volume 2, Chapter 6: Offshore Ornithology, and wider evidence that is relevant to this ecosystem level effects assessment.

2.4.1.2 Seabirds play a crucial role in marine ecosystems and are widely regarded as indicators of overall ecosystem health (Wanless *et al*., 1998[37]). They can provide early signals of shifts in oceanographic conditions, pollution levels, and changes in fish populations (Barrett *et al*., 2007[38]; Romero *et al*., 2021[39]). For example, seabird tissues can be analysed to monitor pollutant bioaccumulation, while their responses to environmental stress, such as reduced reproductive effort, breeding success, or survival can offer further insights (Mallory *et al*., 2010[40]). Changes in prey availability are often mirrored in seabird population trends (Parsons *et al*., 2008[41]). Species like guillemot, razorbill, kittiwake, and puffin (Wanless *et al*., 1998[37]), which rely on sandeel as prey, serve as effective indicators of broader ecosystem health, as population declines have been linked to reduced sandeel abundance in key foraging areas (Parsons *et al*., 2008[41]). Consequently, the breeding productivity of these species can reflect sandeel availability for other predators, including cetaceans (Parsons *et al*., 2008[41]). Similarly, the diet composition of chicks in species such as gannets, which feed on herring, can reveal patterns in the abundance and distribution of juvenile herring (Overholtz and Link, 2007[42]; Scopel *et al*., 2017[43]).

2.4.1.3 When preferred prey becomes scarce, seabirds may switch to consuming alternative prey species. However, such dietary shifts can negatively impact chick growth and survival due to variations in prey energy content and availability (Barrett *et al*., 2007[38]; Kowalczyk *et al*., 2013[44]; Watanuki *et al*., 2022[45]). Abrupt changes in diet, particularly among generalist or opportunistic species, can therefore act as indicators of broader pelagic ecosystem health (Romero *et al*., 2021[39]). For example, Romero *et al*. (2021[39]) analysed regurgitated food from Cory's shearwaters (*Calonectris borealis*) on the Selvagens Islands in the Northeast Atlantic and observed a shift in diet from Atlantic chub mackerel (*Scomber colias*) to longspine snipefish (*Macroramphosus scolopax*). This change reflected alterations in pelagic fish communities, potentially influenced by factors such as fisheries management and/or the North Atlantic Oscillation.

2.4.1.4 Key anthropogenic pressures driving variation in seabird population sizes and distribution are considered to be climate change, prey availability, bycatch (entanglement in fishing gear), Invasive Non-Native Species (INNS), and pollution (Dias *et al*., 2019[46]; Mitchell *et al*., 2020[47]; Royal Haskoning DHV, 2019[48]), with collision risk and distributional responses due to OWFs highlighted as emerging threats (Dias *et al*., 2019[46]; Mitchell *et al*., 2020[47]).

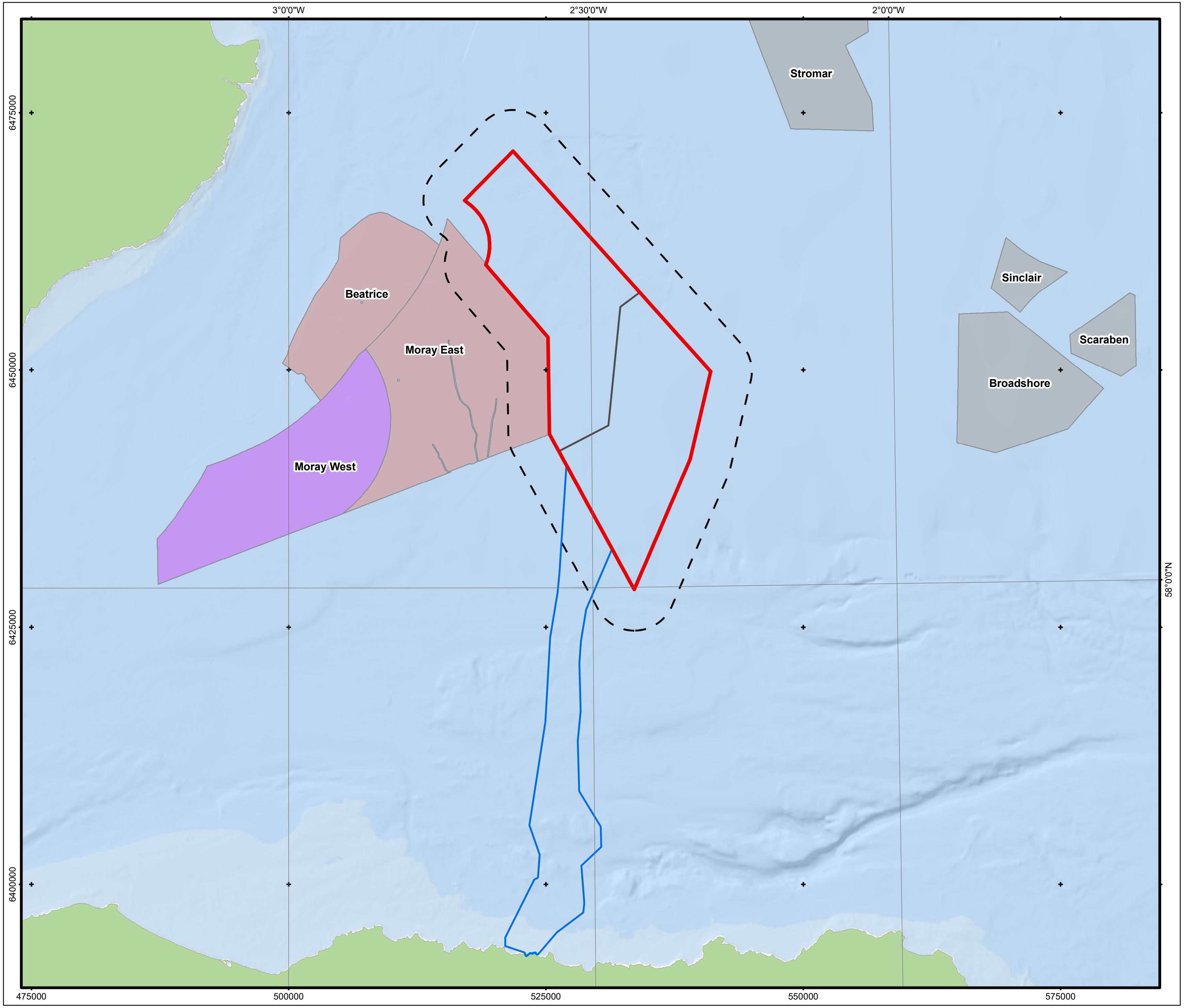
2.4.1.5 The following study areas have been used to inform the Offshore Ornithology baseline:

- Offshore Ornithology regional study area, defined by the area within which potential impacts to breeding seabirds could occur;
- Offshore Ornithology study area, which encompasses the Caledonia OWF, plus a 4km buffer (Figure 2-5); and
- Intertidal Ornithology study area, which encompasses the intertidal area between MHWS tides extending out to 1.5km seaward of MHWS, covering the whole of the intertidal area.

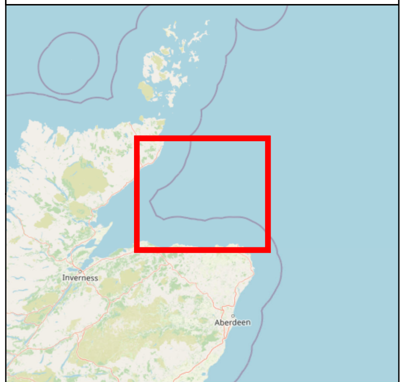
2.4.1.6 A programme of 24 Digital Aerial Surveys (DAS) were undertaken monthly between May 2021 and April 2023 inclusive. The survey area included the Caledonia OWF plus a 4km buffer, covering an area of approximately 884km^2.

2.4.1.7 From the surveys, a list of ornithological receptors was collected that featured both seabirds and intertidal species, such as waders and wildfowl. The list of species identified can be found in Table 2-1.

2.4.1.8 The species focussed on in this report are gannet, kittiwake, guillemot and puffin as these species have been identified for compensation following the conclusions of the RIAA (Caledonia North RIAA (Parts 1-4) and Caledonia South RIAA (Parts 1-4)).



- Caledonia OWF
- Offshore Export Cable Corridor
- Caledonia North Site and Caledonia South Site Division Line
- Aerial Survey Area
- Operational Wind Farm
- Wind Farm Under Construction
- Wind Farm in Concept/Early Planning



0 5 10 15 20 km

REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP
01	15/09/2025	Approved	EV	BB	DH

GEODETIC PARAMETERS
WGS 84 / UTM zone 30N (EPSG: 32630)

DRAWING TITLE

Figure 2-5: Offshore Ornithology Study Area

STATUS
Approved

SCALE
1:500,000

DRAWING NUMBER
N/A

SHEET NO
01 of 01

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N/A

Table 2-1: List of seabird species identified by DAS.

Species	Latin Name
Arctic skua	*Stercorarius parasiticus*
Arctic tern	*Sterna paradisaea*
Black guillemot	*Cepphus grylle*
Common guillemot	*Uria aalge*
Common gull	*Larus canus*
Common tern	*Sterna hirundo*
Fulmar	*Fulmarus glacialis*
Gannet	*Morus bassanus*
Great black-backed gull	*Larus marinus*
Great northern diver	*Gavia immer*
Great skua	*Stercorarius skua*
Herring gull	*Larus argentatus*
Kittiwake	*Rissa tridactyla*
Lesser black-backed gull	*Larus fuscus*
Mallard	*Anas platyrhynchos*
Manx shearwater	*Puffinus puffinus*
Pink-footed goose	*Anser brachyrhynchus*
Puffin	*Fratercula arctica*
Razorbill	*Alca torda*
Red-throated diver	*Gavia stellata*
Sooty shearwater	*Ardenna grisea*

2.4.1.9 Gannets were observed in all months of the year, with a total of 1,093 gannets recorded in 23 of 24 baseline surveys. They were most abundant in the breeding season (mid-March to September). In terms of population trends, between the Seabird 2000 census (1998-2002) and the recent Seabirds Count census (2015-2021), gannet populations have increased by 38% in Britain and Ireland (Burnell *et al*., 2023[49]). Scotland's most important gannetry is the Bass Rock in the Firth of Forth, which is the world's largest colony with 75,259 Apparently Occupied Sites (AOS) and was increasing as of the 2013-2014 census (Murray *et al*., 2014[50]). However, as outlined further in Section 4.7, gannet were severely impacted by the 2021-2022 Highly Pathogenic Avian Influenza (HPAI) outbreak, with a significant short-term decline in population numbers, breeding success and survival on the Bass Rock (Lane *et al*., 2023[51]). RSPB colony counts reported that the total number of gannet across all sites surveyed in 2023 declined by 25% compared to the pre-HPAI count for these colonies though the extent to which HPAI has contributed to these declines remains uncertain (Tremlett *et al*., 2024[52]).

2.4.1.10 Kittiwake were recorded in all months of the year and in every baseline survey, with a total of 5,366 individuals recorded. Kittiwake were the most abundant during the breeding season (April to August). The Seabirds Count census (2015-2021) reported approximately 121,082 Apparently Occupied Nests (AON) in Scotland, a decline of 57% AON since the Seabird 2000 census (1998-2002) (Burnell *et al*., 2023[49]), with declines in numbers of this species a continuation of a global decline which has been occurring for decades. At Buchan Ness to Collieston Coast Special Protection Area (SPA), located in Aberdeenshire, an increase in breeding kittiwake numbers of 20% between 2022 and 2023 was reported. There was no obvious pattern to changes in abundance. It is important to note that counts undertaken in 2023 were undertaken prior to the further 2023 HPAI outbreak, so any changes due to HPAI events since 2023 are not captured in the most recently available data.

2.4.1.11 Guillemots were recorded in all months of the year and in every baseline survey, with a total of 20,137 individuals recorded. Highest abundances were recorded during the breeding season (April to mid-August). Between the Seabird 2000 census (1998-2002) and the Seabirds Count census (2015-2021), there has been a decline of approximately 31% of breeding individuals in Scotland (Burnell *et al*., 2023[49]). Around the Moray Firth, a 6% decrease in breeding guillemot numbers at the East Caithness Cliffs SPA (home to Scotland's largest breeding guillemot population) were observed between the Seabird 2000 census (1998-2002) and the Seabirds Count census (2015-2021), and the population of the Buchan Ness to Collieston Coast SPA remained stable over the same period. The RSPB colony counts following the first outbreak of HPAI found that the total number of guillemots estimated to be breeding across all sites surveyed in 2023 decreased by 6% compared to the pre-HPAI baseline count for these colonies, but evidence linking these declines directly to HPAI rather than other pressures that could lead to reduced colony size is lacking. (Tremlett *et al*., 2024[52]).

2.4.1.12 A total of 2,054 puffins were recorded during both years of baseline surveys, with birds observed in 22 of 24 surveys. Puffins were most abundant during the breeding season (April to mid-August, with birds attending colonies from mid-March onwards). Census date from Seabirds Count (2015-2021) indicates a 32% decline in puffin numbers since the Seabird 2000 Census (1998-2002) (Burnell *et al*., 2023[49]). Puffin populations are also declining in the Moray Firth (Burnell *et al*., 2023[49]). Puffin was not included in the RSPB HPAI surveys, since the species is thought to have incurred relatively low mortality due to HPAI (Tremlett *et al*., 2024[52]).

2.5 Marine Mammals

2.5.1.1 This section provides a summary of the baseline provided in Volume 2, Chapter 7: Marine Mammals and wider evidence that is relevant to this ecosystem level effects assessment.

2.5.1.2 Marine mammals are typically considered generalist feeders and are not dependent on a single prey species (Evans and Hinter, 2013[53]). Most species can likely supplement their diet with other suitable species, if required, which enhances their resilience in the face of changing prey availability. However, minke whales show a marked preference for sandeels, especially within the Southern Trench NCMPA (NatureScot, 2020[54]).

2.5.1.3 As marine mammals are typically highly mobile and wide-ranging, the study area is considered at two spatial scales:

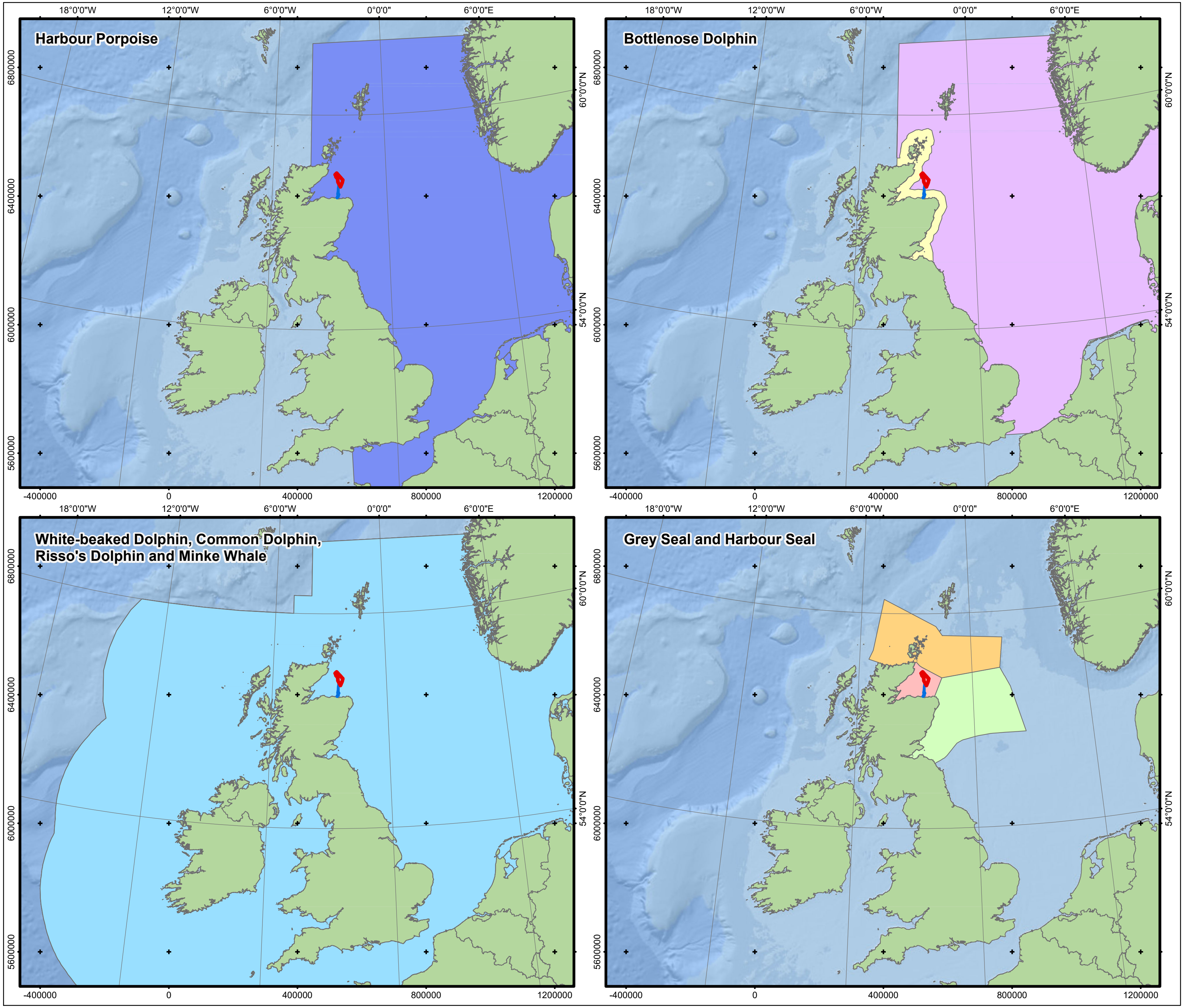
- The local scale study area, which covers the Caledonia OWF plus a 4km buffer, is the survey area for the site-specific DAS conducted by the Proposed Development (Offshore) to provide an indication of the local densities of each species; and
- The regional scale study area, using the Management Units (MUs) defined by the Inter Agency Marine Mammal Working Group (IAMMWG, 2023[55]) and the Seal Management Units (SMUs) defined by the Special Committee on Seals (SCOS, 2023[56]) (Figure 2-6).

2.5.1.4 The site-specific baseline characterisation for the Caledonia OWF consisted of 24 monthly DAS conducted from May 2021 to April 2023, encompassing the Caledonia OWF plus a 4km buffer.

2.5.1.5 The local scale study area provides an indication of the local densities of each species, whereas the regional scale study area encompasses a wider geographic context in terms of species presence and their estimated density and abundance. The regional study area for each species is:

- Harbour porpoise (*Phocoena phocoena*): North Sea MU;
- Bottlenose dolphin (*Tursiops truncatus*): Coastal East Scotland MU;
- Minke whale (*Balaenoptera acutorostrata*): Celtic and Greater North Sea MU;
- White-beaked dolphin (*Lagenorhynchus albirostris*): Celtic and Greater North Sea MU;
- Short-beaked common dolphin (*Delphinus delphis*): Celtic and Greater North Se MU;
- Risso's dolphin (*Grampus griseus*): Celtic and Greater North Se MU;
- Harbour seal (*Phoca vitulina*): East Scotland, Moray Firth and North Coast and Orkney SMUs; and
- Grey sea (*Halichoerus grypus*): East Scotland, Moray Firth and North Coast and Orkney SMUs.

2.5.1.6 In addition, humpback whales (*Megaptera noveangliae*) are assessed qualitatively but have no associated MU.



- Caledonia OWF
- Offshore Export Cable Corridor
- North Sea MU
- Celtic and Greater North Sea MU
- Greater North Sea MU
- Coastal East Scotland MU
- North Coast and Orkney SMU
- Moray Firth SMU
- East Scotland SMU

0 100 200 300 400 500 km

01	15/09/2025	Approved	EV	BB	DH
REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP

CALEDONIA Offshore Wind Farm

GoBe APEM Group

GEODETIC PARAMETERS
WGS 84 / UTM zone 30N (EPSG: 32630)

DRAWING TITLE
Figure 2-6: Marine Mammal Regional Scale Study Area Including the Marine Mammal MUs

STATUS	SCALE	
Approved	1:16,000,000	
DRAWING NUMBER	SHEET NO	REV
N/A	01 of 01	N/A

2.5.1.7 The key marine mammal species that were determined to be common in the local study area and considered for quantitative assessment within Volume 2, Chapter 7: Marine Mammals were as follows:

- Harbour porpoise: a total of 141 individuals were recorded in the local study area during both years of site-specific DAS, with a peak abundance in June 2022 (2-year average density estimate (corrected) was 0.09/km^2);
- Bottlenose dolphin: a total of two individuals were recorded in the local study area in May 2022 (2-year un-corrected relative density estimate was 0.002/km^2);
- White-beaked dolphin: a total of 64 individuals were recorded in the local study area during both years of site-specific DAS, with a peak abundance in September 2022 (2-year un-corrected relative density estimate was 0.02/km^2);
- Common dolphin: a total of 39 individuals were recorded in the local study area in October 2022 (2-year un-corrected relative density estimate was 0.01/km^2);
- Risso’s dolphin: a total of seven individuals were recorded in the local study area during the second year of site-specific DAS in August and September 2022 (2-year un-corrected relative density estimate was 0.002/km^2);
- Minke whale: a total of 12 individuals were recorded in the local study area during both years of site-specific DAS, with a peak abundance in July 2021 (2-year average un-corrected relative density estimate was 0.003/km^2);
- Humpback whale: not recorded in the local study area during site-specific DAS;
- Harbour seal: not recorded in the local study area during site-specific DAS; and
- Grey seal: a total of 26 individuals were recorded in the local study area during both years of site-specific DAS, with a peak abundance in October 2022 (2-year average density was 0.01/km^2).

2.6 Megafauna

2.6.1.1 This section provides a summary of the baseline provided in Volume 2, Chapter 5: Fish and Shellfish Ecology and Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report and wider evidence that is relevant to this ecosystem level effects assessment.

2.6.1.2 Marine megafauna are defined as all large organisms (body mass >45kg) inhabiting the coastal and open oceans. Basking sharks (*Cetorhinus maximus*) migrate from the western English Channel in spring to west Scottish waters, where they spend the summer and early autumn before moving offshore in winter. Basking shark sightings have occurred infrequently in the study area and across the Moray Firth (Scottish Government, 2022[57]). Basking sharks are the largest fish in the North Atlantic, reaching up to 12m in length.

2.6.1.3 In view of the high level of mobility and wide distribution range of basking sharks, the basking shark study area is defined by the Proposed Development (Offshore) footprint (including the Caledonia OWF and the Caledonia OECC) within the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Region II: Greater North Sea (OSPAR, 2024[58]). Basking sharks, unlike marine mammals do not currently have distinct MU established for monitoring and management of population in the seas surrounding the UK.

2.6.1.4 The site-specific baseline characterisation of the basking shark study area for the Caledonia OWF consisted of 24 monthly DAS, from May 2021 to April 2023. Analysis of DAS data collected identified one basking shark in November 2022, located within the southern section of the Caledonia OWF.

2.6.1.5 Basking sharks visit Scottish waters largely from spring to autumn to feed and breed (Fugro, 2021[59]). The shark species migrates from the western English Channel in spring to seas off the west of Scotland, where they spend the summer and early autumn before moving offshore between November and March (Sims *et al*., 2003[60]; Solandt and Chassin, 2013[61]). They are seasonal visitors to Scottish seas and are recorded in higher numbers around the western isles of Scotland (Witt *et al*., 2016[62]; 2019[63]). Sightings have also been recorded in the Moray Firth (Witt *et al*., 2012[64]; NatureScot, 2020[65]); however, to a much lesser extent compared to the west coast (Paxton *et al*., 2014[66]; Witt *et al*., 2016[62]).

2.7 Elasmobranchs

2.7.1.1 This section provides a summary of the baseline provided in Volume 2, Chapter 5: Fish and Shellfish Ecology and Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report and wider evidence that is relevant to this ecosystem level effects assessment.

2.7.1.2 When defining the baseline for elasmobranch species (with the exception of basking shark), the study areas as defined for the fish and shellfish baseline are applicable (see paragraph 2.3.1.1 where these are defined).

2.7.1.3 Elasmobranch species that have the potential to occur within the study area are predominantly demersal, including various skates such as the common skate (*Dipturus batis*), flapper skate (*Dipturus intermedius*), spotted ray (*Raja montagui*), cuckoo ray (*Leucoraja naevus*) (Coull *et al*., 1998[17]; Ellis *et al*., 2010[67]; 2012[68]). Benthopelagic and pelagic shark species are also likely to be present, including the starry smoothhound (*Mustelus asterias*), porbeagle shark (*Lamna nasus*), tope shark (*Galeorhius galeus*), spurdog (*Squalus acanthias*), blue shark (*Prionace glauca*), and lesser spotted dogfish (*Scyliorhinus canicula*). Most of these species are likely to pass through the area rather than being resident, given their extensive ranges (Coull *et al*., 1998[17]; Ellis *et al*., 2010[67]; 2012[68]). The baseline for elasmobranchs also includes low intensity nursery grounds for spotted ray, spurdog and tope shark.

3 Ecosystem Level Impacts from the Proposed Development (Offshore)

3.1 Overview

3.1.1.1 This section provides a summary of the ecosystem level impacts that may arise from the presence of the Proposed Development (Offshore). This section draws on the information provided in the relevant EIAR Chapters and is structured through a 'bottom-up' approach beginning with physical processes and its role in primary production at the base of the marine ecosystem, before moving into the higher trophic levels (prey species, seabirds and marine mammals and megafauna).

3.2 Stratification and Primary Producers

3.2.1.1 The Design Envelope of the Proposed Development (Offshore) includes both bottom-fixed and floating foundations (details in Volume 1, Chapter 3: Proposed Development Description (Offshore)), which increase the complexity of assessment, as different foundations have different impacts, in strength and scale, due to their shape and interaction with hydrodynamics (i.e., tide and waves). An evident lack of data available to quantitatively understand the impact of floating foundations on the water column structure presents some limitations in undertaking a detailed assessment. Consequently, the assessment methodology presented here is based on a qualitative approach.

3.2.1.2 As tidal currents travel through an array area, the individual foundations generate a turbulent wake within which vertical mixing can be enhanced above ambient levels and directly impact seasonally stratified water passing in close proximity. This increase in turbulence has the potential to enhance vertical mixing and to contribute to a local reduction in the strength of vertical stratification (Carpenter *et al*., 2016[69]; Cazenave *et al*., 2016[70]; Dorrell *et al*., 2022[71]). Beyond this, the wake effect dissipates such that background flow conditions are restored.

3.2.1.3 In addition to the potential for direct disturbance of the water column by wind farm infrastructure, it has also been suggested that atmospheric wakes associated with wind turbines have the potential to affect sea surface currents, altering the temperature and salinity distribution in areas of wind farm operation (Christiansen *et al.,* 2022a[72]).

3.2.1.4 Structures within the water column can influence water column mixing by generating turbulent wakes and modifying near-surface wind speeds (Christiansen *et al*., 2022a[72]). Christiansen *et al.* (2022b[73]) showed that wind speed can reduce by a maximum of 2.5%, but on average the changes are observed between 1-2%. A reduction of wind speed led to a reduction of surface currents in order of 0.0025m/s (Christiansen *et al.*, 2022b[73]). The changes induced by the infrastructures can enhance stratification by reducing the wind stress and associated turbulence within the surface mixed layer. OWFs are shown to induce counteracting processes, namely the reduction of wind stress and mixing at the surface on the one hand, and the generation of turbulence within the water column on the other (Christiansen *et al.*, 2022b[73]). These alterations may, in turn, impact nutrient availability to the SCM, potentially affecting overall annual primary production with cascade effects on prey species (Section 3.3), seabirds (Section 3.4) and marine mammals (Section 3.5) (Carpenter *et al*., 2016[69]; Slavik *et al*., 2018[74]).

3.2.1.5 Existing research does provide insights into the impacts of bottom-fixed WTG foundations on stratified waters. Collectively, these studies suggest that OWFs can alter local stratification through turbulence generated by the turbines, though the magnitude and importance of these effects vary. Floeter *et al*. (2017[75]) and Schultze *et al*. (2020[76]) reported observable weakening of stratification near turbine foundations, with impacts extending beyond the immediate area. However, Floeter *et al*. (2017[75]) also noted the difficulty in distinguishing between changes caused by infrastructure and those due to natural topographic features. Hammar *et al*. (2010[77]) found that hydrographic changes predicted in the Baltic Sea due to OWFs were minor relative to natural variability. Similarly, Cazenave *et al*. (2016[70]) observed limited local impacts on stratification in a regional-scale hydrodynamic model. Carpenter *et al*. (2016[69]) concluded that while some weakening of stratification may occur, significant large-scale changes in the North Sea are unlikely under current levels of OWF deployment, with more substantial cumulative effects only expected if turbine coverage becomes extensive.

3.2.1.6 Stratification exhibits a natural variability concerning its formation, stabilisation and deterioration (Chen *et al*., 2022[78]). As presented in paragraphs 2.2.1.6 and 2.2.1.7, the thermocline within the Caledonia OWF varied in depth through time and in strength. For comparison, *in situ* data taken within Muir Mhòr OWF array area showed the same results with a thermocline present at both 70m and 15m within the same month (Muir Mhòr, 2024[79]), making it challenging to accurately evaluate the temporal impact of WTGs infrastructure. Despite, the oceanographic conditions being different between Muir Mhòr and Caledonia OWFs, this observation demonstrates that the impact of foundations, both bottom-fixed and floating, of the Proposed Development (Offshore), will be intermittent even within periods of stratification.

3.2.1.7 Ongoing studies have been commissioned to reduce the knowledge gap and include those within the Offshore Wind Evidence and Change programme which are currently investigating the interaction of floating offshore infrastructure and vertical stratification (such as ECOWind and

ECOFLOW). Of note is that the results are not yet available. Further, there is currently no publicly available literature which indicates a modification of stratification and frontal feature of the Southern Trench NCMPA, despite the presence of fully commissioned fixed bottom OWFs (Moray East OWF and Beatrice OWF) within the Moray Firth.

3.2.1.8 As detailed in section 2.2 of this report, and Volume 7B, Appendix 2-1: Marine and Coastal Processes: Baseline Technical Report, the Caledonia OWF is seasonally stratified, with the water column typically stratified in spring and summer and mixed in autumn and winter (paragraph 2.2.3). While foundations (fixed and floating) may cause minor, highly localised reductions in stratification, only a small portion of water will interact with infrastructure, limiting the extent of mixing. Full mixing would require repeated passes of the same water body through the area, which is unlikely due to tidal currents. Wake effects from the Proposed Development (Offshore) are expected to be minimal and unlikely to affect distant features like the Southern Trench NCMPA front. Overall, any impacts on water column stratification, and subsequently primary production are expected to be localised and limited to the near-field[i].

3.3 Prey Species

3.3.1.1 This section provides a summary of the conclusions of Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology and Volume 2, Chapter 5: Fish and Shellfish Ecology, and ecosystem level impacts that may arise from the Proposed Development (Offshore). The impacts to prey species are most linked with increased Suspended Sediment Concentrations (SSCs) and associated sediment deposition, UWN and habitat loss and disturbance. All of the potential impacts from the Proposed Development (Offshore) result in either a minor or negligible impact (which are not significant in EIA terms) to the key receptors.

Herring

3.3.1.2 Herring are substrate dependent, demersal spawners, making them highly sensitive to any disturbance to, or loss of suitable spawning habitats (Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report). Furthermore, herring possess a swim bladder that is involved in hearing and making them highly sensitive to UWN. The Buchan and Orkney/Shetland herring spawning stocks therefore have the potential to be affected by the Proposed Development (Offshore). Considering the broadscale distribution of herring spawning habitat across the wider North

[i] Near-field includes the Proposed Development (Offshore) (i.e., Caledonia OWF, Caledonia OECC and Landfall Site), whereas the far-field comprises coastal and seabed areas outside the near-field areas, also called Zone of Influence.

Sea (as detailed fully in Volume 2, Chapter 5: Fish and Shellfish Ecology), and the localised nature of any habitat disturbance events, any interaction of the Proposed Development (Offshore) with these spawning substrates is minimal. It is subsequently anticipated that disturbance to, or loss of, herring spawning habitat arising from the Proposed Development (Offshore) will not significantly impact herring populations in the region. Volume 2, Chapter 5: Fish and Shellfish Ecology also concluded no significant effects from UWN or increases in SSC and subsequent sediment deposition on herring. Consequently, it is not likely that there will be an ecosystem level effect through a change in fish population dynamics which would have the potential to disrupt the wider marine ecosystem.

Sandeel

3.3.1.3 Sandeel are a demersal species that rely on specific sediment types for spawning, making them particularly susceptible to disturbance from construction activities (as detailed in Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report). A post-construction monitoring study at the Beatrice OWF showed that sandeel abundance either remained stable or increased between 2014 and 2020, despite offshore construction beginning in April 2017 (BOWL, 2021[80]). The study found no evidence that construction negatively affected the local sandeel population. Similarly, short and long-term monitoring studies at the Horns Rev OWF in the Baltic Sea, Denmark, found no significant adverse effects on sandeel populations from wind farm construction and operation (van Deurs *et al*., 2012[81]). Additionally, the sandeel populations were observed to recover quickly following construction, suggesting that a similar recovery can be expected for the Proposed Development (Offshore) after construction activities have finished. Notably, Jensen *et al*. (2011[82]) reported that sandeel populations mix over distances of up to 28km, indicating that some recovery of adult populations will occur with adults recolonising appropriate sandy substrates from nearby unaffected habitats. Recovery may also occur through the recolonisation of larvae into suitable sandy sediments, as sandeel larvae are likely dispersed throughout the surrounding waters of the Proposed Development (Offshore) during the spring months following their winter/spring spawning (Ellis *et al*., 2012[68]). This suggests the view that long-term ecosystem impacts resulting from changes in sandeel population dynamics due to the Proposed Development (Offshore) are unlikely.

Mackerel

3.3.1.4 Mackerel are a migratory pelagic species and have spawning grounds which interact with the study area, as well as extending over much of the North Sea (Coull *et al*., 1998[17]) (Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report). Mackerel are not reliant on substrate for spawning and other aspects of their life history and can temporarily flee an area thus avoiding impacts. Furthermore, mackerel spawning grounds have a relatively short life cycle and mature quickly. They are highly fecund and produce large numbers of eggs annually, which allows their populations to recover quickly.

3.3.1.5 Several studies have investigated the potential effects OWF developments on mackerel (Mavraki *et al*., 2020[83]; Van Hoey *et al*., 2021[84]). Mackerel are often found near OWFs, especially during spring and summer, feeding primarily on zooplankton. The increased biodiversity and availability of shelter around OWFs, known as the "reef effect", may attract mackerel to these areas, however, research indicates that while mackerel do interact with OWFs, their feeding behaviour is largely unaffected.

3.3.1.6 The impacts from the Proposed Development (Offshore) therefore are not likely to have an impact on mackerel stocks and ultimately their role in the marine ecosystem, with all impacts expected to be temporary in nature, and populations being able to fully recover.

Sprat

3.3.1.7 Sprat are a pelagic species and have spawning grounds which interact with the study area, as well as extending over much of the North Sea (Coull *et al*., 1998[17]) (Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report).

3.3.1.8 Sprat are not reliant on substrates for spawning or other aspects of their life history and can temporarily flee an area, avoiding impacts. Furthermore, sprat spawning grounds are widespread across the North Sea, they have short life cycles and mature quickly. They are highly fecund and produce large numbers of eggs annually, which allows their populations to recover quickly. Therefore, the impacts from the Proposed Development (Offshore) are not likely to have an impact on sprat stocks and ultimately their role in the marine ecosystem, with all impacts expected to be temporary in nature, with sprat populations being able to fully recover.

Other Fish Prey Species

3.3.1.9 Many other prey species that are found in the vicinity of the Proposed Development (Offshore), including pelagic spawners such as cod and whiting, are less reliant on substrate for spawning and other aspects of their life history and can temporarily flee an area avoiding impacts. There are many prey species with spawning/nursery grounds in the vicinity of the Proposed Development (Offshore) including migratory species (as detailed in Volume 7B, Appendix 5-1: Fish and Shellfish Ecology Technical Baseline Report), yet the impacts associated with the Proposed Development (Offshore) to these receptors are not likely to result in a negative ecosystem level effect due to the minor-negligible significance of impacts, with all impacts expected to be temporary nature and being able to fully recover.

Cumulative Effects

3.3.1.10 Cumulative effects assessments for fish and shellfish ecology and benthic subtidal and intertidal ecology are detailed in Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology, Volume 2, Chapter 5: Fish and Shellfish Ecology, which consider the wider potential impacts beyond the Proposed Development (Offshore).

3.3.1.11 The conclusions of the cumulative effects assessments for mortality, injury and behavioural changes resulting from UWN arising from construction activity on fish and shellfish were:

- Group 1, Group 2, Group 3, and eggs and larvae: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Shellfish: **Low** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.3.1.12 The conclusions of the cumulative effects assessments for temporary increase in suspended sediment and sediment deposition on fish and shellfish and all benthic receptors were:

- All fish and shellfish and all benthic receptors: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.3.1.13 The conclusions of the cumulative effects assessments for short term habitat loss and disturbance on fish and shellfish:

- All fish and shellfish receptors: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.3.1.14 The conclusions of the cumulative effects assessments for long term habitat loss on fish and shellfish:

- All fish and shellfish receptors: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

In-Combination Effects

3.3.1.15 It is recognised that the impacts to receptors alone from the Proposed Development (Offshore) and cumulatively do not provide a holistic approach to assessing the impacts to the marine ecosystem. With consideration to a holistic approach, an in-combination effects assessment has been carried out. This looks at the effects that may occur through the inter-relationship with another EIAR topic that may lead to different or greater environmental effects than in isolation. These include:

- Project lifetime effects: Assessment of the scope for effects that occur throughout more than one phase of the Proposed Development (Offshore) (construction, operation and decommissioning); to interact to potentially create a more significant effect on a receptor than if just assessed in isolation in these three key project stages (e.g., subsea noise effects from piling, operational WTGs, vessels and decommissioning); and
- Receptor-led effects: Assessment of the scope for all effects to interact, spatially and temporally, to create inter-related effects on a receptor. As an example, all effects on fish and shellfish ecology, such as UWN impacts, temporary habitat disturbance, long term habitat loss or temporary increases in SSC and deposition etc., may interact to produce a different, or greater effect on this receptor than when the effects are considered in isolation. Receptor-led effects might be short-term, temporary or transient effects, or incorporate longer term effects.

3.3.1.16 Project lifetime and receptor-led effects relating to Fish and Shellfish Ecology are presented in Table 3-1.

Table 3-1: In-combination effects on fish and shellfish receptors.

Project Phase	Nature of Inter-related Effect	Assessment Alone	Inter-related Effects Assessment
Project Lifetime Effects			
Construction, operation and decommissioning	Disturbance from UWN	Impacts were assessed as being not significant in the construction, operation and decommissioning phases.	The impacts of UWN during the construction and decommissioning phases are expected to be short-term and intermittent. Impacts from underwater noise during the operational phase will be long term but of a very localised extent and at very low levels. The interaction of these impacts across construction, O&M and decommissioning phases of the development is not predicted to result in an effect of any greater significance than those assessed in the individual project phases.
Construction and decommissioning	Increase in SSC and sediment deposition	Impacts were assessed as being not significant in the construction, and decommissioning phases.	The impacts of increased SSC and sediment deposition during the construction and decommissioning phases are expected to be short-term and intermittent, and of localised extent with any effects being reversible. The interaction of these impacts across construction and decommissioning phases of

Project Phase	Nature of Inter-related Effect	Assessment Alone	Inter-related Effects Assessment
			the development is not predicted to result in an effect of any greater significance than those assessed in the individual project phases.
Construction, operation and decommissioning	Habitat loss and disturbance, and increased SSC and deposition	Impacts were assessed as being not significant in the construction, operation and decommissioning phases.	The impacts of habitat loss and disturbance and increased SSC and deposition during the construction, operation and decommissioning phases are expected to be short-term and intermittent, and of localised extent. The interaction of these impacts across construction, operation and decommissioning phases of the development is not predicted to result in an effect of any greater significance than those assessed in the individual project phases.
Receptor-led Effects			
No spatial or temporal interaction between the effects assessed above is expected during the project lifetime.			

3.4 Seabirds

3.4.1.1 This section provides a summary of the conclusions of Volume 2, Chapter 6: Offshore Ornithology, and ecosystem level impacts that may arise from the Proposed Development (Offshore). Impacts to ornithological receptors are most linked to collision mortality and/or distributional responses (displacement, disturbance and barrier effects). All of the potential impacts from the Proposed Development (Offshore) result in a negligible effect for all species sensitive to OWF impacts and present within the study areas.

3.4.1.2 Seabird species consume a variety of prey, although key prey for many UK seabirds typically include herring, sprat, and sandeel. Changes in the populations of these prey species can potentially lead to distributional shifts in specialist seabird species (Daunt and Mitchell, 2013[85]). The sensitivity of offshore seabird populations to fluctuations in prey availability varies; however, most seabirds are not highly specialised foragers and are generally capable of exploiting a broad range of prey across different areas (Del Hoyo *et al.*, 1992[86]). An assessment of the potential for such distributional responses is provided in Volume 2, Chapter 6: Offshore Ornithology, which concludes no potential for significant effects.

3.4.1.3 Potential indirect effects resulting from changes in prey availability due to the Proposed Development (Offshore) are discussed in Section 3.3. This includes consideration of key prey species such as sandeel, herring, mackerel and sprat. As concluded in Section 3.3, the Proposed Development (Offshore) is not expected to result in any changes to prey communities, and therefore no indirect effects on ornithological features are anticipated.

Cumulative Effects

3.4.1.4 A cumulative effects assessment (considering any impacts of the Proposed Development (Offshore) combined with the impacts of other developments) for seabirds is detailed in Volume 2, Chapter 6: Offshore Ornithology.

3.4.1.5 The conclusions of the cumulative effects assessments for distributional responses on birds were:

- Kittiwake: **Low** sensitivity, **Negligible** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Guillemot, puffin and gannet: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.4.1.6 The conclusions of the cumulative effects assessments for collision risk were:

- Kittiwake and gannet: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.4.1.7 The conclusions of the cumulative effects assessments for combined distributional responses and collision risk were:

- Kittiwake and gannet: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

In-combination Effects

3.4.1.8 Project lifetime effects and receptor-led effects (as defined in paragraph 3.3.1.15) consider a holistic approach to assessing the impacts to the marine ecosystem.

3.4.1.9 Each phase of the Proposed Development (Offshore) may cause a range of effects on offshore ornithological receptors. The magnitude of these effects has been assessed individually, drawing from a wide evidence base that includes project-specific surveys and knowledge of the bird ecology within the North Sea.

3.4.1.10 Each effect has the potential to form an in-combination effects impacting seabird receptors and become a source for impacts upon receptors beyond those considered within the context of offshore ornithology.

3.4.1.11 How impacts to offshore ornithological receptors may form inter-relationships with other receptor groups and assessments of significance are provided below for indirect impacts through effects on habitats are prey in all phases of the Proposed Development (Offshore):

- Volume 2, Chapter 4: Benthic Subtidal and Intertidal Ecology due to habitat intersections at MHWS; and
- Volume 2, Chapter 5: Fish and Shellfish Ecology due to the potential indirect effects from potential changes in distribution and abundance of forage fish species.

3.4.1.12 As none of the offshore impacts on birds were assessed individually to have any greater than a minor adverse effect, it is considered highly unlikely that they will inter-relate to form an overall significant effect on offshore ornithology receptors.

3.5 Marine Mammals

3.5.1.1 This section provides the conclusions of Volume 2, Chapter 7: Marine Mammals, and ecosystem level impacts that may arise from the Proposed Development (Offshore).

3.5.1.2 Potential impacts to marine mammals from the Proposed Development (Offshore) include:

- Auditory injury and disturbance from UWN generated by pilling activities, UXO clearance and Geophysical surveys;
- Vessel collision and disturbance;
- Entanglement with mooring lines;
- Disturbance to haul out sites;
- Changes in water quality; and
- Long term displacement/habitat loss/barrier effects.

3.5.1.3 All identified impacts from the Proposed Development (Offshore) are assessed as resulting in negligible or minor effects for all species sensitive to OWF impacts and potentially present within the study areas.

3.5.1.4 Marine mammals rely on prey for survival, as such there is the potential for indirect effects to arise from impacts on prey species (such as herring, sandeel, mackerel and sprat) or on the habitats that support those prey species. A reduction in prey availability could increase the energy marine mammals expend in foraging due to the need for greater effort. However, most sensitive marine mammal species are generalist feeders that consume a range of prey types, which reduces the likelihood of increased energy demands. Additionally, all marine mammal receptors are highly mobile and capable of searching over large areas for food.

3.5.1.5 Indirect effects through prey species arising from the Proposed Development (Offshore) are discussed in Section 3.3, wherein any effect to forage fish (i.e., sandeel, herring, mackerel and sprat), crustaceans or primary producers will cause a level of change in the prey community that marine mammal species depend on. As concluded in Section 3.3, there is no potential for changes in prey communities predicted to arise from the Proposed Development (Offshore).

Cumulative Effects

3.5.1.6 A cumulative effects assessment is detailed in Volume 2, Chapter 7: Marine Mammals, which considers the wider impacts beyond the Proposed Development (Offshore).

3.5.1.7 The conclusions of the cumulative effects assessments for disturbance from piling during construction on marine mammals were:

- Harbour porpoise and bottlenose dolphin: **Low** sensitivity, **Medium** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**;
- White-beaked dolphin: **Low** sensitivity, **High** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**;
- Common dolphin, Risso's dolphin and grey seal: **Low** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Minke whale and harbour seal (worst-case[ii]): **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.8 The conclusions of the cumulative effects assessments for disturbance from vessels during construction on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, Risso's dolphin, humpback whale, harbour seal and grey seal: **Low** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Minke whale: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.9 The conclusions of the cumulative effects assessments for disturbance to haul-outs during construction on seals were:

- Harbour seal and grey seal (worst-case[iii]): **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

[ii] The worst-case scenario is informed by the source level and expected sound frequency and overlap with marine mammal hearing ranges.
[iii] The worst-case scenario is informed by the maximum number of vessels on site at any one time, location of the ports as well as the duration of construction.

3.5.1.10 The conclusions of the cumulative effects assessments for disturbance from geophysical surveys during construction on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, Risso's dolphin, minke whale, humpback whale, harbour seal and grey seal: worst-case **Low** sensitivity, worst-case **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.11 The conclusions of the cumulative effects assessments for operational noise on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin and Risso's dolphin: **Negligible** sensitivity, **Medium** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Minke whale, humpback whale, harbour seal and grey seal: **Low** sensitivity, **Medium** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.12 The conclusions of the cumulative effects assessments for secondary entanglement during operation on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, Risso's dolphin, minke whale, humpback whale, harbour seal and grey seal: **High** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.13 The conclusions of the cumulative effects assessments for disturbance from vessels during operation on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, Risso's dolphin, humpback whale, harbour seal and grey seal: **Low** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**; and
- Minke whale: **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.5.1.14 The conclusions of the cumulative effects assessments for disturbance to haul-outs during operation on seals were:

- Harbour seal and grey seal (worst-case[iv]): **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

[iv] The worst-case scenario is informed by the maximum number of vessels within coastal areas at any one time, location of ports as well as the duration of operation and maintenance.

3.5.1.15 The conclusions of the cumulative effects assessments for disturbance from geophysical surveys during operation on marine mammals were:

- Harbour porpoise, bottlenose dolphin, white-beaked dolphin, common dolphin, Risso's dolphin, minke whale, humpback whale, harbour seal and grey seal: worst-case low sensitivity, worst-case low magnitude of cumulative impact. No significant cumulative effects in EIA terms.

In-combination Effects

3.5.1.16 Project lifetime effects and receptor-led effects (as defined in paragraph 3.3.1.15) consider a holistic approach to assessing the impacts to the marine ecosystem.

3.5.1.17 The likely in-combination effects arising from the Proposed Development (Offshore) on marine mammal receptors are as follows:

- Vessel collisions;
- Disturbance from vessels;
- Indirect impacts on marine mammals due to changes in prey availability;
- Changes in water quality; and
- Disturbance to haul-outs.

3.5.1.18 The effects of the impacts listed above have been assessed as negligible to minor significance and, therefore, not significant in EIA terms. Overall, no inter-relationships have been identified where an accumulation of residual impacts on marine mammal receptors and the relationship between those impacts gives rise to a need for additional mitigation beyond the embedded mitigation already considered.

3.6 Megafauna

3.6.1.1 This section provides a summary of the conclusions of Volume 2, Chapter 5: Fish and Shellfish Ecology and ecosystem level impacts that may arise from the Proposed Development (Offshore). The impacts to megafauna are most linked with increased SSCs and associated sediment deposition, UWN and habitat loss and disturbance. All of the potential impacts from the Proposed Development (Offshore) result in either a minor or negligible impact (which are not significant in EIA terms) for megafauna.

3.6.1.2 Megafauna (basking sharks) are dependent on prey for survival, and consequently there is the potential for indirect effects on megafauna to occur as a result of impacts on their prey species (such as copepods) or prey supporting habitats that support them. Changes to prey availability could increase the energy expenditure required for feeding through increased effort. The majority of sensitive marine mammal receptors are generalist feeders, feeding on a variety of prey species, thereby removing the requirement for additional energy expenditure. Furthermore, all megafauna receptors are highly mobile and search large areas for prey.

3.6.1.3 Prey species of basking sharks (copepods *C. helgolandicus* and *C. finmarchicus*) are typically present within wider Scottish waters and are not exclusive to the vicinity of the Proposed Development (Offshore), as basking sharks are highly mobile, it is reasonable to assume that they will be able to find nearby suitable habitat with sufficient and suitable prey resources.

Cumulative Effects

3.6.1.4 A cumulative effects assessment for basking sharks is detailed in Volume 2, Chapter 5: Marine Mammals, which considers the wider impacts beyond the Proposed Development (Offshore).

3.6.1.5 The conclusion of the cumulative effects assessment for disturbance from underwater noise arising from construction activity was:

- **Low** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.6.1.6 The conclusion of the cumulative effects assessment for disturbance from underwater noise arising from operational noise was:

- **Low** sensitivity, **Negligible** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.6.1.7 The conclusion of the cumulative effects assessment for risk of secondary entanglement was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.6.1.8 The conclusion of the cumulative effects assessment for cumulative impact from EMF was:

- **High** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

In-combination Effects

3.6.1.9 Project lifetime effects and receptor-led effects (as defined in paragraph 3.3.1.15) consider a holistic approach to assessing the impacts to the marine ecosystem. The potential in-combination effects on basking sharks are presented and assessed in Table 3-2.

Table 3-2: In-combination effects on basking sharks.

Potential Impact	Project Phase	In-combination Effects Assessment
Project lifetime effects		
Vessel collisions	Construction, operation and decommissioning	Both the potential impacts of vessel collisions and disturbance are anticipated to arise throughout all project phases. However, it is not likely that these impacts would interact across project phases to result inter-related effects of greater significance than those for each individual phase. With the adoption of VMP the impacts would more likely be maintained at a similar significance level (which is negligible and not significant in EIA terms) throughout the lifetime of the Proposed Development (Offshore).
Vessel disturbance	Construction, operation and decommissioning	
Indirect impacts on prey	Construction, operation and decommissioning	Indirect impacts on prey are estimated to arise throughout all key phases, but is not expected to result in an ongoing, additive loss of prey over the project lifetime. Rather there may be an initial and temporary decrease in prey availability during the construction phase followed by recovery of areas, leading to no large-scale and long-term loss of prey. The implementation of embedded mitigation will reduce the risk of significant effects on prey. Furthermore, due to the generalist nature of the basking shark diet, indirect prey species across the different phases are not anticipated to alter the population trajectory. Therefore, the significance of this interaction between the effect across different phases is not predicted to be higher than that for individual project phases, which is assessed as negligible and therefore not significant in EIA terms.
Changes in water quality	Construction, operation and decommissioning	The impacts of changes in water quality during the construction, operation and decommissioning phases are expected to be short-term and intermittent, reversible and of localised extent. The implementation of embedded mitigation will reduce any potential impacts of changes in water quality on basking sharks. The interaction of this impact across different key phases of Proposed Development (Offshore) is not anticipated to result in an effect of any greater significance than those assessed in the impact assessment.
Receptor-led Effects		
No spatial or temporal interaction between impacts assessed in the impact assessment is expected during the project lifetime.		

3.7 Elasmobranchs

3.7.1.1 This section provides a summary of the conclusions of Volume 2, Chapter 5: Fish and Shellfish Ecology and ecosystem level impacts that may arise from the Proposed Development (Offshore).

3.7.1.2 Potential impacts to elasmobranchs from the Proposed Development (Offshore) include SSC and associated sediment deposition, UWN and habitat loss and disturbance. All of the potential impacts from the Proposed Development (Offshore) result in either a minor or negligible impact (which are not significant in EIA terms) to the key elasmobranch receptors.

3.7.1.3 Elasmobranchs are carnivorous and dependent on prey for survival, and consequently there is the potential for indirect effects on them to occur as a result of impacts on their prey species (such as crustaceans, herring, sprat, sandeel and mackerel) or prey supporting habitats that support them. Changes to prey availability could increase the energy expenditure required for feeding through increased effort. Nonetheless, indirect effects through prey species arising from the Proposed Development (Offshore) are discussed in Section 3.3, wherein any effect to sandeel, herring, sprat, mackerel crustaceans or primary producers will cause a level of change in the prey community that elasmobranch species depend on. As concluded in Section 3.3, there is no potential for changes in prey communities predicted to arise from the Proposed Development (Offshore). Instead, as recognised in the PrePARED project (2024[87]), there could be an increase in fish aggregations from potential reef effects from infrastructure associated with the Proposed Development (Offshore) and therefore potential to increase the abundance of some elasmobranchs attracted to the food resource (Hermans *et al*., 2025[88]).

Cumulative Effects

3.7.1.4 The potential for cumulative impacts on elasmobranch species is detailed in Volume 2, Chapter 5: Fish and Shellfish Ecology.

3.7.1.5 The conclusion of the cumulative effects assessment for mortality, injury and behavioural changes resulting from UWN arising from construction activity on elasmobranchs was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.7.1.6 The conclusion of the cumulative effects assessment for temporary increases in SSC and sediment deposition on elasmobranchs was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.7.1.7 The conclusion of the cumulative effects assessment for short term habitat loss and disturbance on elasmobranchs was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.7.1.8 The conclusion of the cumulative effects assessment for long term habitat loss on elasmobranchs was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

3.7.1.9 The conclusion of the cumulative effects assessment for EMF effects on elasmobranchs was:

- **Medium** sensitivity, **Low** magnitude of cumulative impact. **No significant cumulative effects in EIA terms**.

In-combination effects

3.7.1.10 Project lifetime effects and receptor-led effects (as defined in paragraph 3.3.1.15) consider a holistic approach to assessing the impacts to the marine ecosystem. Project lifetime and receptor-led effects relating to elasmobranchs are the same as those for fish and shellfish which are presented in Table 3-1.

4 Changing Baselines and Future Change

4.1 Overview

4.1.1.1 This section outlines the major current and future anthropogenic-driven ecosystem level impacts on the key trophic levels of the marine ecosystem. This section investigates the role of known future pressures (climate change, commercial fisheries, OWF development, INNS, pollution and avian influenza) and how they may influence the marine ecosystem in future years.

4.2 Climate Change

4.2.1.1 Climate change can alter the stratification of the water column, which in turn affects nutrient cycling and the availability of nutrients for primary producers which are the foundation of the marine food web, and are responsible for generating the majority of organic matter through photosynthesis that supports marine life. In the northern North Sea, increasing sea surface temperatures can enhance water column stratification, reducing the mixing of nutrient-rich deeper waters within the upper photic zone, where phytoplankton require nutrients for growth (Lowe *et al*., 2009[89]). This reduced nutrient availability may lead to lower primary productivity, particularly affecting larger phytoplankton species, which have higher nutrient demands than smaller species. Consequently, overall phytoplankton biomass may decline, and the species composition may shift toward smaller, less productive taxa, further impacting food availability for higher trophic levels.

4.2.1.2 Climate change can affect environmental conditions in various ways, including increasing sea surface temperature. As sea temperatures rise, the composition of phytoplankton species in the North Sea is expected to shift. Warmer waters tend to favour smaller, fast-growing species such as flagellates, which are less energy-dense compared to larger diatoms that typically dominate the colder waters of the North Sea (McQuatters-Gollop *et al*., 2007[90]). This shift could have significant implications for higher trophic levels, as many zooplankton species preferentially feed on diatoms. A reduction in diatom abundance may result in lower-quality food sources for secondary producers, with potential consequences for the entire food web.

4.2.1.3 A further consequence of increased sea surface temperatures is the potential redistribution of fish species, with some extending their ranges into deeper, cooler waters (Poloczanska *et al*., 2013[91]). However, this shift can be limited by habitat availability, so species with specific habitat requirements, such as sandeel which exhibit preferences for coarse sandy sediments, may struggle to adapt. In fact, declines in sandeel recruitment in parts of the UK have been linked to rising sea temperatures (Heath *et al*., 2012[92]). Climate change may also affect critical life history events for fish and shellfish, including spawning periods and migration timings (Poloczanska *et al*., 2013[91]). Despite these observations, climate change impacts on marine fish populations are difficult to predict, and the evidence is not easy to interpret, and therefore it is difficult to make accurate estimations of the future baseline scenario for the entire lifetime of the Proposed Development (Offshore) (approximately 35 years).

4.2.1.4 Climate change is also expected to affect fish (including prey species) distribution and abundance, growth rates, recruitment, behaviour, survival and response to changes of other trophic levels (Prakash and Srivastava, 2019[93]). As noted above, a decline in primary productivity driven by climate change is already influencing higher trophic level dynamics and fish recruitment in the North Sea (Capuzzo *et al*., 2018[94]). Projected warming scenarios indicate regime shifts, such as changes in the predator-prey relationship between sandeels and copepods, potentially leading to further declines in sandeel recruitment (Regnier *et al*., 2019[95]). Additionally, increased sea surface temperatures in the North Sea may lead to an increase in the relative abundance of species associated with more southerly areas. For example, landings data for spawning herring and sardine (*Sardina* spp.) at ports in the English Channel showed that higher spawning herring landings were correlated with colder winters, while warm winters were associated with large catches of sardine (Alheit and Hagen, 1997[96]). This is supported by Edwards *et al*. (2013[97]) who highlighted that during warm phases, herring spawning in the English Channel declined and sardine catches rose substantially. In contrast, during cool phases, herring catches resurged while sardine decreased.

4.2.1.5 Such shifts in prey availability and quality, along with altered breeding times in response to warming seas, are causing seabirds to become de-synchronised from their prey, which is having a direct impact on seabird populations in the UK (Daunt and Mitchell, 2013[98]).

4.2.1.6 Current trends suggest that the northward shift of specific species (e.g., sandeels) and an increase in the abundance of typically warmer water species (e.g., sardines) are likely to continue in a warming climate, which may result in alterations to the existing marine baseline. However, considering the timescales of warming oceans and changes in distribution of species, it is likely that in the near to medium term this would result in changes in the relative abundances of species rather than broad changes in the community structure.

4.3 Commercial Fisheries

4.3.1.1 The North Sea is one of the world's most heavily fished marine regions and is experiencing significant ecosystem stress from commercial fishing activities (O'Leary *et al*., 2017[99]). A combination of heavily fished regional grounds, climate change and habitat destruction have already led to notable changes in biodiversity, fish stocks, and ecosystem dynamics (O'Leary *et al*., 2017). The extent of future impacts of fisheries on the North Sea marine ecosystem will largely depend on how fisheries respond to environmental changes, implement sustainable fishing practices, and respond to shifts in species distributions.

4.3.1.2 Although fisheries management has improved under the European Union's (EU's) Common Fisheries Policy (CFP), the recovery of key commercial species such as cod, haddock, and herring has been slow, with some populations remaining at critically low levels. As fishing continues in the future, there is the risk of further depletion of already vulnerable stocks, which has the potential to trigger broader consequences on marine ecosystems. Overfishing diminishes the reproductive capacity of fish populations, impeding their ability to recover and maintain sustainable levels (Engelhard *et al*., 2014[100]).

4.3.1.3 Species declines due to overfishing not only threaten biodiversity but also disrupt the stability of the food web. When key predators like cod are removed, the balance between predator and prey populations is disrupted. For instance, overfishing of cod has been linked to population increases in their prey species, such as small fish and invertebrates (Heath *et al*., 2014[101]). These trophic cascades can lead to unexpected shifts in ecosystem structure and reduce resilience to other pressures, including climate change and pollution. Moreover, changes in fish populations can influence other marine life, such as seabirds and marine mammals, which rely on fish stocks for food. A decline in prey availability can lead to reduced reproductive success and survival rates for these higher trophic levels, exacerbating the effects of fisheries on the broader ecosystem (Huse *et al*., 2002[102]). Bycatch can also impact the wider ecosystem through the removal of non-target prey species or the accidental capture of marine mammals, seabirds and other predatory species which are vital to maintaining ecological balance (Kelleher, 2005[103]).

4.3.1.4 Sandeel are an important prey species in the North Sea. Recent legislation prohibits commercial sandeel (lesser and Raitt's sandeel) fishing in Scottish waters (announced by the Scottish Government in January 2024, which came into force in March 2024). The ban aims to benefit wildlife (such as marine mammals, seabirds, and predatory fish) that rely on sandeel as a vital component of their diet. The ban is intended to bolster the broader marine ecosystem and to enhance resilience among vulnerable species, particularly considering the challenges posed by climate change and warming seas (Coull *et al*., 1998[17]). This closure complements earlier measures, such as the closure of Sandeel Management Area 4 in 2000 to reduce bycatch of cod and haddock, and the negative subsequent impacts on seabird food supply. These evolving regulations changes are expected to influence the future baseline of the area, potentially reshaping fishing practices, ecosystem dynamics, and species interactions.

4.3.1.5 The long-term health of the North Sea marine ecosystem will depend on how effectively fisheries adapt to environmental changes and implement both established and innovative sustainable practices. Effective management, ecosystem-based approaches, and enforcement of regulations can help to mitigate the negative impacts of fisheries on the marine ecosystem. A coordinated, long-term approach that considers both ecological and socio-economic factors is essential to ensure the sustainability of commercial fishing and the marine ecosystem.

4.4 Offshore Wind Developments

4.4.1.1 Offshore wind developments will play a key role in achieving net zero targets. As demand for renewable energy continues to rise, so too does the need for a long-term, holistic approach to managing this critical resource. The UK's offshore wind market is one of the largest and most successful in the world, with more than 50 wind farms at various stages of development around the coastline, generating enough renewable energy to supply approximately half of all UK homes.

4.4.1.2 The UK's current offshore wind development pipeline currently totals around 95 GW, with a government ambition to decarbonise the power system by 2030, including increasing offshore wind capacity in the same timeframe (The Crown Estate, 2024[104]). With Offshore Wind Leasing Round 5 expected to progress to an auction (Invitation to Tender Stage 2) in Spring 2025 and the emergence of Offshore Wind Leasing Round 6, the expansion of OWFs in UK waters is set to continue (The Crown Estate, 2024[104]).

4.4.1.3 As offshore wind capacity grows, the marine environment may experience a range of both positive and negative effects at population, community, and ecosystem levels. These impacts may result from the introduction of new habitat (hard substrata from development infrastructure), effects from construction activities and alterations to physical processes (van der Molen *et al*., 2014[105]; Cazenave *et al*., 2016[70]; Zijl *et al*., 2021[106]). Whilst negative cumulative impacts could arise from this growing industry, it is worth noting that research projects such as PrePARED are beginning to explore ecosystem-level responses, which will be essential for understanding impacts across all trophic levels.

4.4.1.4 The increasing number of OWFs may also deliver indirect benefits to marine ecosystems. For instance, OWFs often create de facto fisheries exclusion zones, where activities such as trawling and dredging are restricted or prohibited. As a result, the presence of wind farms can facilitate the recovery of overexploited species (Püts *et al*., 2023[107]). In such areas, prey species like forage fish may increase in abundance, which in turn supports higher trophic levels such as seabirds and marine mammals, contributing to the overall stability of the marine ecosystem. However, there is also the risk that fishing pressure may simply be displaced to other areas, meaning that the net impact of OWFs (positive or negative), on fish populations is uncertain.

4.5 Invasive Non-Native Species (INNS)

4.5.1.1 INNS can have numerous environmental, economic and social impacts. Direct ecological impacts such include resource competition (i.e., for food and space), predation, and disease (Gallardo *et al*., 2015[108]; Tsirintanis *et al*., 2022[109]). It is important to note that indirect impacts can also occur, such as changes in nutrient levels, ecosystem functioning or trophic cascades, which can have knock-on effects on ecological communities (Gallardo *et al*., 2015[108]; Dimitriadis, 2021[110]). Identifying what receptors are likely to be impacted by marine INNS, and the impacts themselves, are therefore challenging to identify.

4.5.1.2 Numbers, and consequently impacts, of INNS across the world are predicted to rise because of increased trade traffic and new trade routes (Hulme, 2021[111]), and climate change (Rahel and Olden, 2008[112]). Climate change will also alter the distribution and abundance of INNS, leading to changes in their impacts over spatial scales (Hellmann *et al*., 2008[113]; Rahel and Olden, 2008[112]; Pyšek *et al*., 2020[114]). Furthermore, climate change is expected to create novel climates (the emergence of future climatic conditions not found at present) (Williams *et al*., 2007[115]; Garcia *et al*., 2014[116]) that are predicted to result in communities that are compositionally unlike any found today (Williams and Jackson, 2007[117]). This makes future impacts of INNS difficult to predict.

4.5.1.3 As the marine environment becomes more developed, there is a heightened risk of marine INNS being introduced and establishing in new locations. The increased vessel traffic associated with marine developments such as OWFs can elevate the risk of INNS introductions, since INNS can be transported on vessels in ballast water or attached to hulls (Hewitt *et al*. 2009[118]). Furthermore, the addition of artificial hard substrates into the marine environment, which is a suitable attachment substrate for numerous INNS (Ruiz *et al*. 2009[119]), can increase habitat availability. As more and more artificial hard substrate is added to the marine environment, there is also the potential to cause a 'stepping-stone effect' (e.g., De Mesel *et al*. 2015[120]), whereby INNS can extend their distribution further than they could previously by spreading from one developed area to another. It should be noted that there is a widespread presence of marine INNS across the North Sea.

4.5.1.4 Marine INNS are already well-established in Scottish waters, including but not limited to: wireweed (*Sargassum muticum*), green seafingers (*Codium fragile* subsp. *tomentosoides*), red algae (*Dasysiphonia japonica*), acorn barnacle (*Austrominius modestus*), Japanese skeleton shrimp (*Caprella mutica*), leathery sea squirt (*Styela clava*), orange tipped sea squirt (*Corella eumyota*) and orange ripple bryozoan (*Schizoporella japonica*) (NatureScot, 2025[121]). Site-specific surveys for the Proposed Development (Offshore) recorded species of the Styelidae family (a family of ascidian tunicates to which the leathery sea quirt belongs) in sediment eDNA analysis in the Caledonia OECC, although identification was not carried out to species level.

4.5.1.5 Predation by invasive terrestrial mammal species poses a serious threat to seabird colonies, particularly those on islands (Ellis *et al*., 2007[122]; Brooke *et al*., 2018[123]). Species such as brown and black rats (*Rattus norvegicus*, *Rattus rattus*), feral cats (*Felis catus*), and mustelids such as American mink (*Neovison visonare*) are known to predate seabird eggs, chicks, and adults (Latorre *et al*., 2013[124]; Craik, 1997[125]; Ratcliffe *et al*., 2010[126]). Feral cats, which are capable of preying on larger birds, are particularly harmful to seabird populations and have been shown to contribute to the rapid decline of seabirds on isolated islands (Ratcliffe *et al*., 2010[126]), for example. Rats, however, are considered the most significant threat, impacting 75 seabird species across 61 islands studied globally (Jones *et al*., 2008[127]). In the UK, rat predation has been directly linked to seabird population declines on Lundy Island, as evidenced by comparisons with seabird numbers on the rat free islands of Skomer and Skokholm (RSPB England, 2021[128]). Rats and mustelids are excellent swimmers and can easily reach nearshore islands, while other mammalian predators may be unintentionally introduced by humans, often via boats (Biosecurity for Life, 2024[129]).

4.5.1.6 Tree mallow (*Malva arborea*) is a species of mallow native to western Europe and the Mediterranean. This biannual plant is native to the southwest of the UK but has been introduced by humans to a wide range of coastal sites in Scotland, including in the Firth of Forth (van der Wal, 2006[130]). The entrances of puffin burrows on Craigleith island provide the moist and fertile soil needed for tree mallow to germinate and grow, as it is difficult for seedlings to establish themselves in dense grass swards (van der Wal, 2006[130]). As tree mallow grows, it prevents puffins from accessing their burrows to nest and as such, puffin populations have declined following the introduction of tree mallow on Craigleith (van der Wal, 2006[130]). The SOS Puffin Project, led by the Scottish Seabird Centre, is actively managing tree mallow on Craigleith and nearby islands such as Fidra and The Lamb, where puffin populations are also at risk (Scottish Seabird Centre, 2024[131]).

4.6 Pollution

4.6.1.1 Pollution in the marine environment can affect organisms across all levels of the marine ecosystem. Heavy metals such as mercury, lead, and cadmium have entered the North Sea primarily through industrial discharges and land-based runoff. These contaminants can bioaccumulate in marine organisms, leading to toxicity and disruption of food webs. For instance, concentrations of mercury, cadmium and lead in mussels and fish in the North Sea are above background levels (OSPAR, 2016[132]).

4.6.1.2 Persistent organic pollutants (POPs), such as polychlorinated biphenyl (PCB) and dichlorodiphenyltrichloroethane (DDT), are long-lasting contaminants that can remain in the marine environment for decades. These pollutants accumulate in marine organisms, posing risks to their health, particularly in terms of reproduction and immune function. For example, POPs can accumulate in the fatty tissues of marine mammals leading to reproductive problems and impaired immune systems (Reckendorf *et al*., 2023[133]).

4.6.1.3 Marine litter consists of persistent, manufactured, and processed materials introduced into the ocean, with plastics and discarded fishing gear being the most prevalent types (UN Environment Programme, 2021[134]). Between 2016 and 2020, plastic production in Europe increased by almost 10% (Plastics Europe, 2021[135]), a proportion of which is likely to end up in the marine environment as plastic waste. Marine species, including mammals and seabirds, often ingest or become entangled in plastic debris, which can result in injury or death (Good *et al*., 2010[136]; Roman *et al*., 2019[137]; Zantis *et al*., 2021[138]). The impacts to the marine ecosystem from plastic pollution are likely to be further exacerbated by the effects of climate change due to increased degradation and fragmentation of plastics through heat degradation and increases storm activity (Deng *et al*., 2021[139]).

4.7 Avian Influenza

4.7.1.1 The most recent outbreak of HPAI emerged in 2020 in the form of HPAI H5N1 clade 2.3.4.4b virus. Initially detected in gulls and gannets, early impacts on bird populations were relatively minimal (Falchieri *et al*. 2022[140]). However, by spring 2022, the outbreak had spread widely among marine and coastal bird species. Gannet colonies experienced a decline of 25% in the UK between 2022 and 2023 (Tremlett *et al*., 2024[52]). HPAI spreads among birds via bodily fluids such as saliva, secretion, and faeces (Charostad *et al*., 2023[141]). The virus can also be transmitted through organic materials like soil and nesting materials and can remain inactive in freshwater at low temperatures for several months, as such increasing the risk of waterborne transmission to aquatic birds (NatureScot, 2024b[142]). Migratory birds are considered a major pathway for the geographic spread of the virus, with its introduction to the UK likely occurring through established migration routes (NatureScot, 2024b[142]).

4.7.1.2 Whilst the virus does not appear to be well adapted to mammals, several cases involving mammals have been reported in the UK, including infections in seals, foxes, and otters (NatureScot, 2023c[143]). Internationally, more than 300 seals have died from HPAI in eastern North America, while over 20,000 sea lions and thousands of elephant seals have been lost in South America (Whittle, 2024[144]). Additionally, evidence of the virus has been found in common dolphin, harbour porpoise, bottlenose dolphin and white-sided dolphin (Leguia *et al*., 2023[145]; Thorsson *et al*., 2023[146]; Murawski *et al*., 2024[147]). HPAI has also been associated with unusual mortality events of harbour and grey seals (Puryear *et al*., 2024[148]). Cases of mammal-to-mammal transmission reported in Spain, Peru, and the Caspian Sea have raised concerns over the virus's potential to spread more broadly across species (NatureScot, 2023c[143]).

5 Conclusions

5.1.1.1 This assessment highlights that the Proposed Development (Offshore) is unlikely to result in significant negative ecosystem level effects. However, there are potential positive ecological benefits that could arise. As detailed within this report, there is potential for OWFs to enhance local biodiversity, support prey species populations (including commercially important species), and contribute to the overall productivity of marine ecosystems.

5.1.1.2 The North Sea is a region that is facing increasing anthropogenic-driven pressure in the future which will require well informed and strategic management, to mitigate against ecosystem level impacts. OWFs may provide some local ecosystem benefits, and will also help tackle the broader impacts of climate change which will indirectly benefit marine ecosystems, for which the Proposed Development (Offshore) will make a significant contribution.

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