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Volume 8 Additional Information

Appendix 1: Marine and Coastal Processes Stratification Technical Note

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OCEAN WINDS

Volume 8 Appendix 1: Marine and Coastal Processes Stratification Technical Note

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Acronyms and Abbreviations

BEIS	Department for Business, Energy and Industrial Strategy
CMEMS	Copernicus Marine Service Information
CTD	Conductivity, Temperature and Depth
EIAR	Environmental Impact Assessment Report
MD-LOT	Marine Directorate – Licensing Operations Team
MD-SEDD	Marine Directorate – Science Evidence Data and Digital
NCMPA	Nature Conservation Marine Protected Area
OECC	Offshore Export Cable Corridor
OWF	Offshore Wind Farm
PSU	Practical Salinity Unit
TKE	Turbulent Kinetic Energy

1 Introduction

1.1.1.1 This appendix aims to describe in detail the baseline water column processes, such as stratification and frontal features, present within the Proposed Development (Offshore). The Proposed Development (Offshore) includes the Caledonia Array Area (hereafter referred to as 'Caledonia Offshore Wind Farm (OWF)') and the Caledonia Offshore Export Cable Corridor (OECC). The available data specific to the Caledonia OWF and Caledonia OECC originate from E.U. Copernicus Marine Service Information (CMEMS) and are presented in the sections below.

1.1.1.2 The potential impacts of the Proposed Development (Offshore) on key marine and coastal processes receptors, including cumulative and inter-related effects, are detailed within the relevant Environmental Impact Assessment Report (EIAR) Chapters (Volumes 2, 3 and 4, Chapter 2: Marine and Coastal Processes) which were submitted to the Marine Directorate – Licensing Operations Team (MD-LOT) as part of the offshore consent applications for Caledonia North and Caledonia South in November 2024. Following the submission of the applications, a formal consultation period was held, during which statutory consultees and the public were invited to provide feedback.

1.1.1.3 During this period, concerns were raised by Marine Directorate – Science Evidence Data and Digital (MD-SEDD) relating to the potential for impacts on stratification as a result of the Proposed Development (Offshore). Subsequently, this appendix has been produced to address these concerns, drawing on current literature to establish a baseline of the physical environment relevant to stratification and provides an impact assessment.

2 Frontal Systems and Stratification

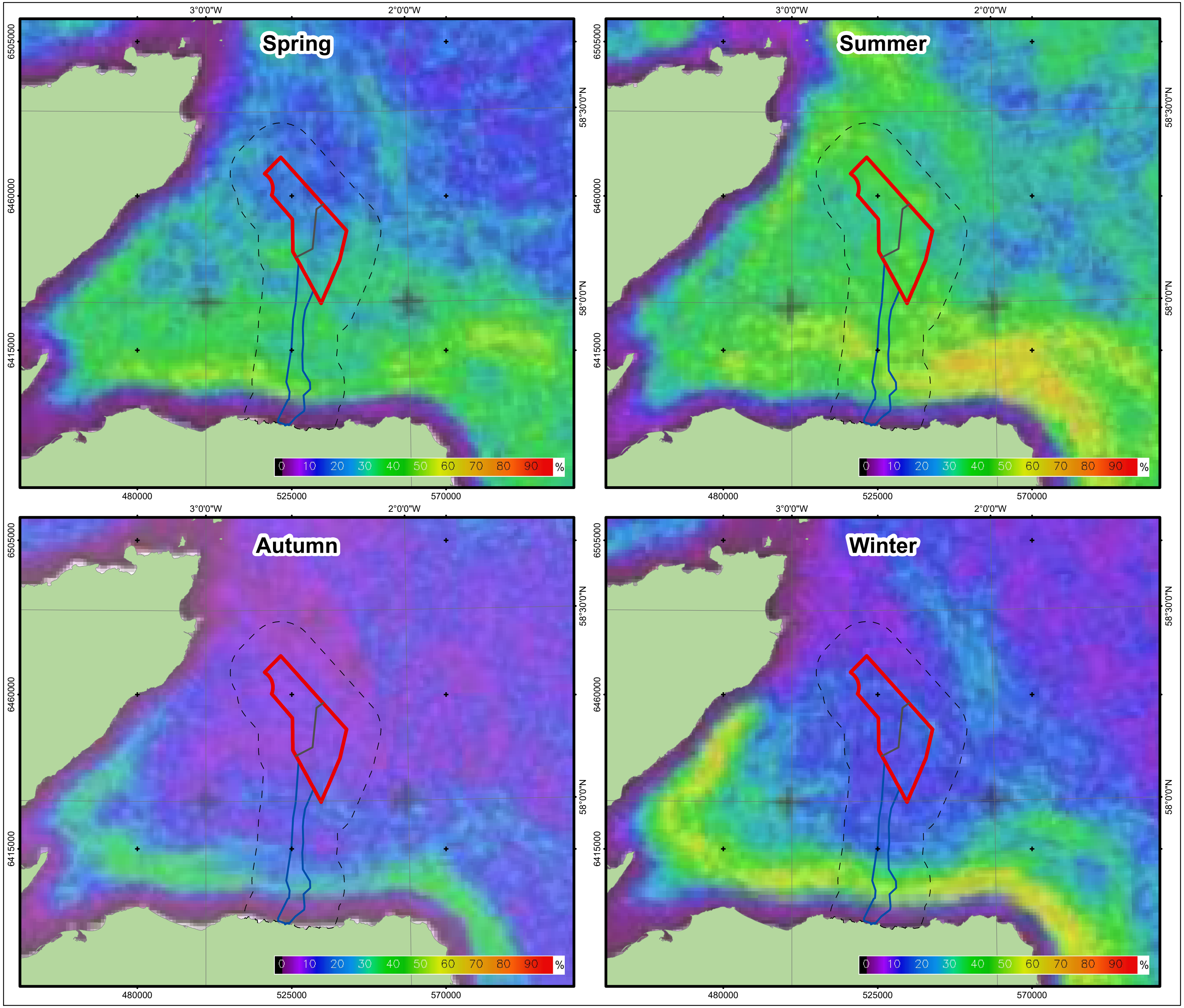
2.1 Regional Overview

2.1.1.1 Stratification is a hydrodynamic feature characterised by vertical density gradients over relatively short distances within the water column and is related to the distribution of seawater temperature and salinity. Regional stratification in the North Sea is primarily influenced by water depth, tidal current strength, proximity to the shelf edge (which facilitates exchange with oceanic waters), and the presence of fresher, nearshore water (Huthnance, 1991[1]).

2.1.1.2 In winter and autumn, stratification in the North Sea only occurs in coastal areas affected by freshwater input, where salinity drives the process, such as along the southern coast of the Moray Firth (Figure 2–1; Miller *et al*., 2014[2]). Elsewhere, the water column remains uniform from surface to seabed (Huthnance, 1991[1]; Connor *et al*., 2006[3]; Miller *et al*., 2014[2]). The onset of stratification in spring occurs when the surface warms through solar heating without being assimilated by stirring into underlying waters.

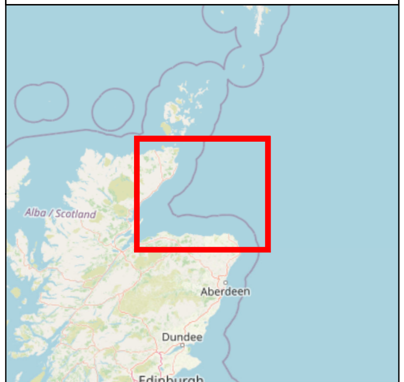
2.1.1.3 Connor *et al*. (2006[3]) classified the Moray Firth as a Region of Freshwater Influence, being weakly stratified during autumn, winter and spring, and stratified during the summer. Naturally occurring stratification occurs within the Moray Firth due to seasonal heating of the upper water column and vertical fronts are also observed along the south coast of the Moray Firth between regions of slight freshwater influence coming from the inner Moray Firth (Adams and Martin, 1986[4]; Miller *et al*., 2014[2]).

2.1.1.4 Frontal zones mark boundaries between water masses, including tidally mixed and stratified areas, and are numerous on the European continental shelf (Department for Business, Energy and Industrial Strategy (BEIS), 2022[5]). Fronts play an important role in enabling the circulation and transport of nutrients and heat, and frequently reoccurring fronts (e.g., spatially and/or seasonally) are widely recognised as supporting enhanced biological activity (NatureScot, 2025[6]).



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

Service Layer Credits: © OpenStreetMap (and) contributors, CC-BY-SA



0 10 20 30 40 50 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 2-1: 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

2.1.1.5 Frequent thermal fronts are present along the southern coast of the Moray Firth. The front is present throughout the year, however, it occurs more often during summer (60%) than during autumn (30%) (Figure 2–1; Miller *et al*., 2014[2]). In winter, the frontal system is well developed along the southern coast of the Moray Firth, with occurrence between 50 to 60% and it can extend approximately 18km from the coast (Figure 2–1; Miller *et al*., 2014[2]). The high occurrence of the front during winter is explained by the increased input of freshwater, which circulates eastward parallel to the southern coastline of the Moray Firth. In spring, the front can be observed up to approximately 50km from the southern coast of the Moray Firth, which is the consequence of low rainfall coupled with an increase in temperature, bringing the front offshore (Figure 2–1; Hill *et al*., 2008[7]; Miller *et al*., 2014[2]). It is noted that the Southern Trench Nature Conservation Marine Protected Area (NCMPA), for which the Caledonia OECC overlaps, is designate to protect biodiversity features, including fronts (NatureScot, 2025[6]).

2.2 Stratification within the Caledonia OWF

2.2.1.1 Data from CMEMS within the Caledonia Offshore Wind Farm (OWF) (i.e., Array Area), averaged between 2014 and 2024, show a difference between surface and bottom temperature between March and September, which corresponds to spring and summer seasons when the surface waters become warmer (Figure 2–2; CMEMS, 2025[8]) . The highest difference is observed between May and July, with values reaching up 3°C and 3.5°C in the north and the south of the Caledonia OWF, respectively (CMEMS, 2025[8]). Results from CMEMS (2025[8]) confirmed the conclusions made by Miller *et al*. (2014[2]) with a higher occurrence of thermal front frequency during spring and summer (Figure 2–2). Furthermore, Miller *et al*. (2014[2]) showed a higher occurrence of thermal front within the south of the Caledonia OWF (30% and 50% in spring and summer, respectively) than the north (20% and 45% in spring and summer, respectively), which can be explained by the gap of 0.5°C between the north and south data from CMEMS (2025[8]) leading to stronger stratification in the southern section of the Caledonia OWF (Figure 2–1 and Figure 2–2).

2.2.1.2 A project-specific benthic survey, including water sampling between March and June 2023, was carried out within the Caledonia OWF (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)). The Conductivity, Temperature and Depth (CTD) profiles showed that two stations are well-mixed, whereas the others (i.e., 33 stations) presented a thermocline between 5 and 20m, with the temperature being stable beyond the thermocline (i.e., 8 ± 0.3°C). These results highlight that the Caledonia OWF is not entirely stratified at the same time and that some spatial variation exist, which is not represented by CMEMS data.

2.2.1.3 The mixed layer water depth data are correlated with the difference of temperature between the north and the south of the Caledonia OWF (Figure 2–2; CMEMS, 2025[8]). Figure 2–2 shows that the thermocline can reach 5m between May and July; however, the water column remains well mixed during autumn and winter, which corroborates Miller *et al*. (2014) observations showing a low frequency of thermal front (less than 10%) during these seasons (CMEMS, 2025[8]).

2.2.1.4 The bathymetry shown by CMEMS (2025[8]) do not correspond to the data from EMODnet (2024[9]). CMEMS data showed a water depth comprised between 40 to 45m, whereas EMODnet shows water depth of 55m and 63m in the north and the south of the Caledonia OWF, respectively (EMODnet, 2024[9]; CMEMS, 2025[8]). As water depth plays a role in the stratification, the data collected from CMEMS may present some uncertainties.

2.2.1.5 The salinity within the north of the Caledonia OWF remains constant throughout the year with value of 34.55 ± 0.05PSU (Practical Salinity Unit), whereas the south of the Caledonia OWF shows a higher variation from 34.5PSU in summer to 34.3PSU during winter (Figure 2–2; CMEMS, 2025[8]). These results showed that the stratification of the south of the Caledonia OWF could also be influenced by freshwater input, which in turn induced a stronger stratification with higher frequency of occurrence (Figure 2–1; Miller *et al*., 2014[2]). Salinity profiles recorded within the Caledonia OWF showed the same trend with a constant salinity through the water column except in the south of the Caledonia OWF (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)).

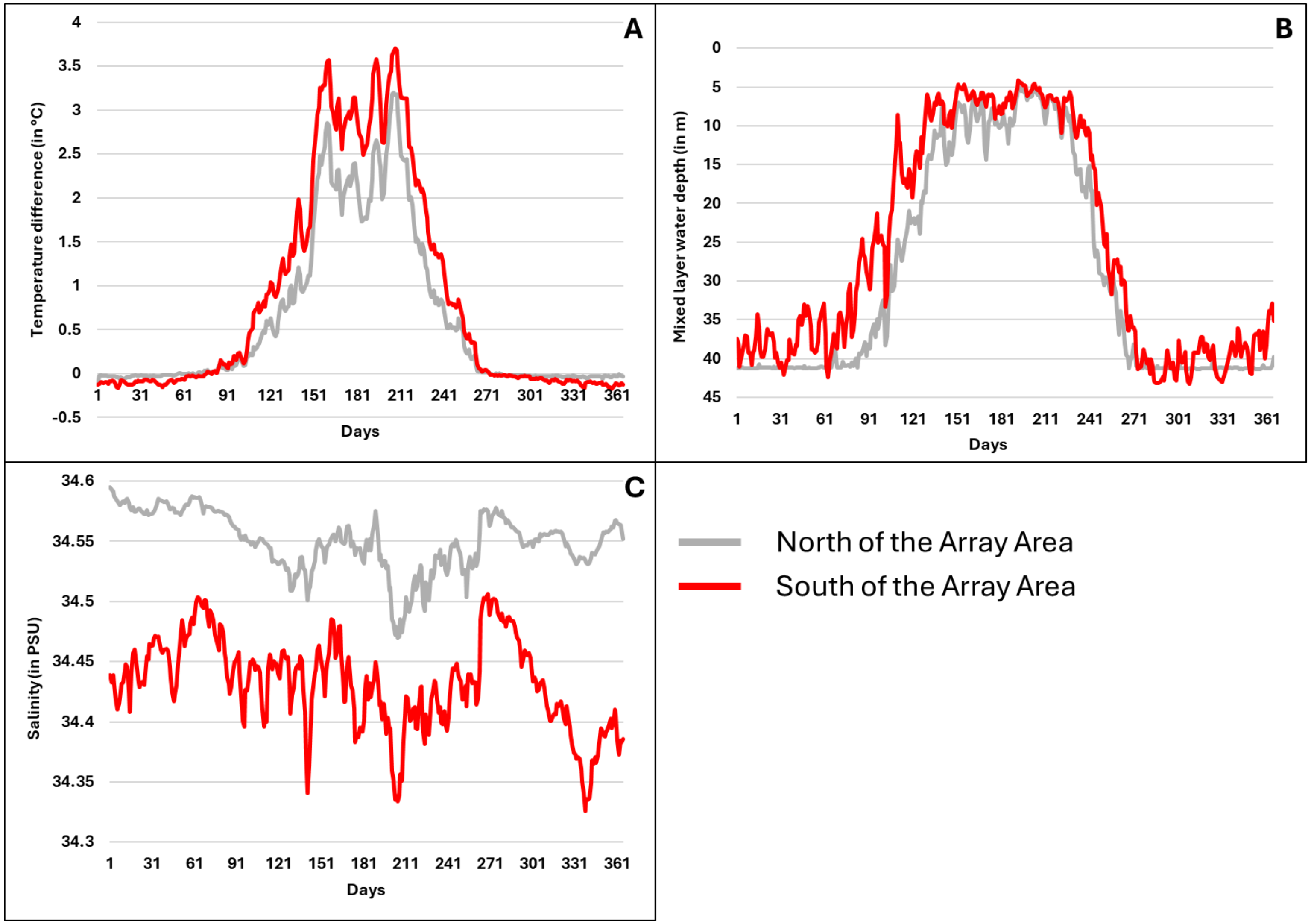


Figure 2–2: Stratification within the Caledonia OWF represented by the difference between surface and bottom temperature (in °C) (Panel A); the water depth of thermocline (in m) (Panel B) and the salinity (in PSU) (Panel C). All data were averaged between 2014 and 2024.

2.3 Stratification within the Caledonia OECC

2.3.1.1 Data from CMEMS, averaged between 2014 and 2024, show that the difference between surface and bottom temperature is highest during spring and summer as observed within the Caledonia OWF (paragraph 2.2.1.1; Figure 2–3; CMEMS, 2025[8]). However, data suggest a variation of the difference between surface and bottom temperature along the Caledonia OECC (Figure 2–3; CMEMS, 2025[8]). The south of the OECC shows the lowest difference between surface and bottom temperature of maximum 2°C, whereas the north and the centre of the OECC show results reaching up 4°C and 5°C respectively (Figure 2–3; CMEMS, 2025[8]).

2.3.1.2 These results suggest a stronger thermal stratification in the north and the centre of the Caledonia OECC than in the south, which is correlated by the mixed layer water depth data (Figure 2–3; CMEMS, 2025[8]). In the south of the Caledonia OECC, the thermocline remains at 10m during autumn and winter with a slight decrease (approximately 5m) during spring and summer. In the north and centre of the OECC, the thermocline shows the same trend as within the Caledonia OWF. As mentioned for the Caledonia OWF (paragraph 2.2.1.3), the water depths differ between CMEMS and EMODnet, consequently the results of mixed layer water depth could be different *in situ* than presented in Figure 2–3 (EMODnet, 2024[9]; CMEMS, 2025[8]).

2.3.1.3 Miller *et al*. (2014[2]) showed that the water column to the south of the OECC is likely to be stratified all year long, with varying frequency from 30% (lowest) in Autumn to 60% (highest) in Summer. Consequently, the stratification in the south of the OECC cannot only be explained be thermal difference between surface and bottom temperature.

2.3.1.4 Salinity data along the OECC showed variation amongst the locations (Figure 2–3; CMEMS, 2025[8]). In the north of the OECC, salinity remains constant throughout the year with value 34.55 ± 0.05PSU (Figure 2–3; CMEMS, 2025[8]). However, data taken in the south of the OECC show an increase of salinity from 33PSU during Winter to 34 PSU during summer, this variation is the origin of stratified waters in the south of the OECC, which occurs due to the increase of freshwater input starting in autumn until spring.

2.3.1.5 The data collected along the OECC show that salinity remains constant through the water column for all stations (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)), which does not align with the results from CMEMS (2025[8]).

2.3.1.6 The variation of salinity along the OECC is also an indicator of a frontal feature between low salinity water closer to the shore, and high salinity water. Previous studies show that frontal features can migrate intra- and interannually based on freshwater input, solar heating and a combination of both within the semi-enclosed Irish Sea (Hopkins and Polton, 2012[10]). However, the resolution of the data provided by CMEMS in relation to the Moray Firth does not allow for the conclusion of where the front is located with certainty and how it migrates through the year.

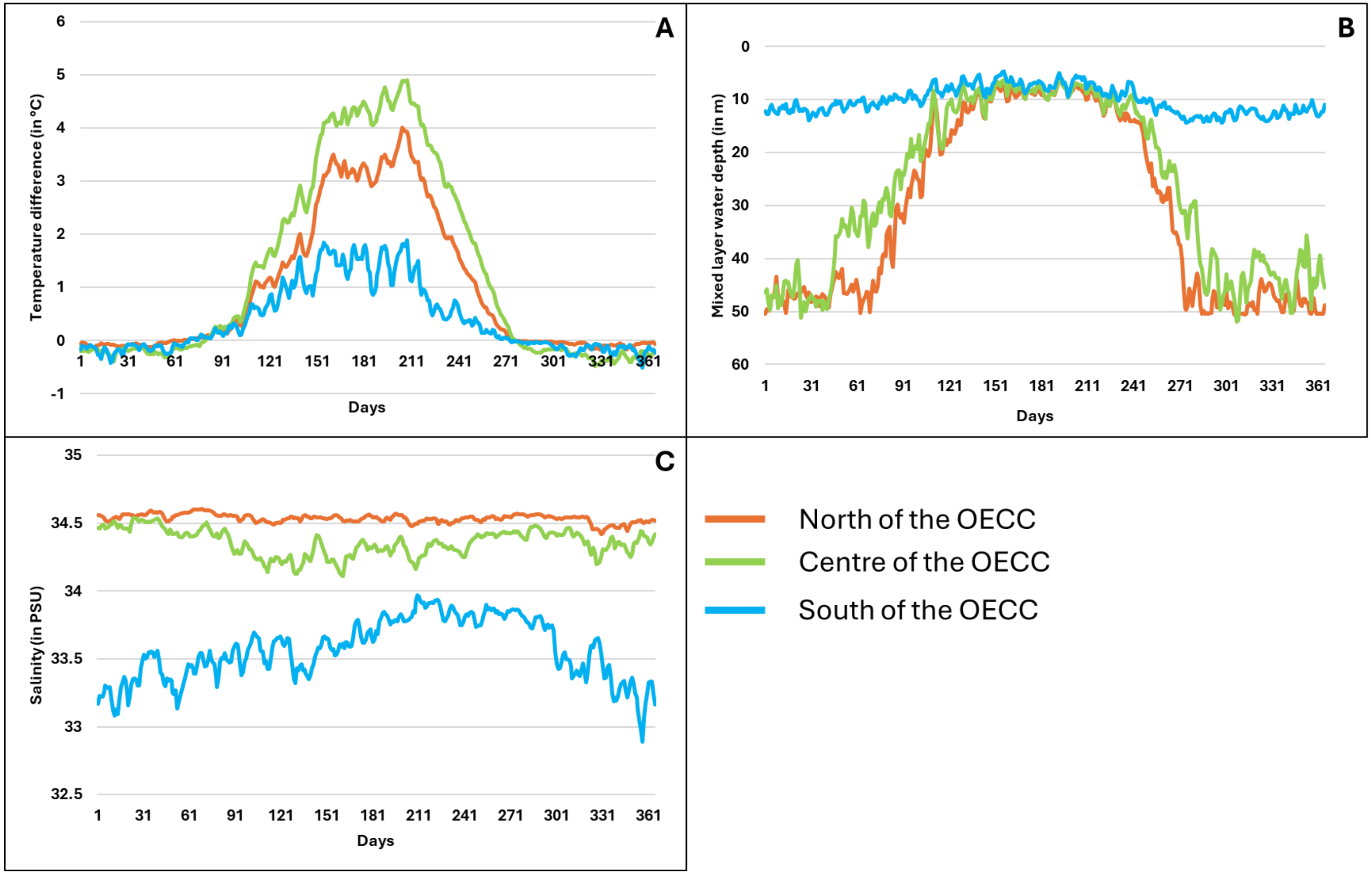


Figure 2–3: Stratification within the OECC represented by the difference between surface and bottom temperature (in °C) (Panel A); the water depth of thermocline (in m) (Panel B) and the salinity (in PSU) (Panel C). All data were averaged between 2014 and 2024. Data taken from the north, centre and south of the OECC are represented in yellow, green and blue respectively (CMEMS, 2025).

2.4 Impact Assessment

2.4.1 Overview

2.4.1.1 Based on the evidence of the seasonally stratified waters set out above and recommendations from MD-SEDD, an impact assessment of the Proposed Development (Offshore) on the modifications to water column structure and processes (mixing and stratification) has been carried out.

2.4.1.2 Modifications to the water column structure and mixing processes, such as the formation and duration of stratification and frontal features, may result in changes to the associated productivity (Sharples *et al.*, 2020[11]).

2.4.2 Conceptual Understanding of Change

2.4.2.1 Structures in the water column within both Caledonia North and Caledonia South have the potential to alter water column mixing through the generation of turbulent wakes and changes to near-surface wind speeds (Christiansen *et al.*, 2022[12]; Dorrell *et al.*, 2022[13]). The assessment methodology is based on a qualitative approach due to the evident lack of data available to understand quantitatively the impact of WTGs on water column structure within the study area.

2.4.2.2 A pronounced frontal feature is present along the Caledonia OECC between 10km and 25km from the southern coast of the Moray Firth, where a density gradient exists between the water originating from the North Atlantic (i.e., high salinity) entering the Moray Firth from the north-east and the freshwater input from the south-west of the inner Moray Firth (CMEMS, 2025[8]). Further, water column temperature data sourced from CMEMS suggests that both Caledonia North and Caledonia South are seasonally stratified as a result of surface water being heated during the spring and summer (CMEMS, 2025[8]).

2.4.2.3 As currents travel through an array area, the individual structures generate a turbulent wake. 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[14]; Dorrell *et al.*, 2022[22]). Beyond this, the wake effect dissipates such that background flow conditions are restored.

2.4.2.4 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.*, 2022[12]).

2.4.2.5 Whilst there have been no studies directly investigating the effects of floating WTG on stratified water and frontal systems, as proposed for Caledonia South, a suite of evidence exists regarding the potential impact of bottom-fixed WTG foundation, present in both Caledonia North and Caledonia South, upon stratified waters, as summarised in the following:

- Floeter *et al*. (2017[15]) performed CTD measurements on two OWFs in the German Bight, North Sea. Water transects through the wind farms revealed a consistent weakening of stratification near the centre of the wind farm arrays, with effects extending into the surrounding area by approximately half the diameter of an ambient tidal excursion. However, it was not possible to determine how much of the observed change was due to "infrastructure" turbulence from turbine foundations rather than natural marine processes (e.g., interplay between tidal currents and bottom topography);
- Field measurements were also taken by Schultze *et al*. (2020[16]) who measured the wake from an offshore monopile at the DanTysk wind farm, east of the North Sea (Northern Germany). The survey demonstrated that turbulence generated by monopile reduces the strength of stratification by a decrease of temperature of 0.2°C; with pre-monopile (baseline) conditions not fully observed at the survey limit - a distance of 300m from the (6m diameter) monopile;
- Hammar *et al*. (2010[17]) summarised the predicted hydrographic changes for three OWF sites located in the Baltic Sea. The study concluded that cumulative structure-induced variations did not exceed natural variations concerning turbulence and vertical mixing, with an increase of 1% predicted for the Skottarevet and Kriegers Falk and no effect for the Lillgrund Wind Park. The average tidal current for these OWFs is approximately 0.4m/s, which corresponds to the average current within both Caledonia North and South, i.e., 0.42m/s, measured by two FLiDAR buoys (Volume 7B, Appendix 2-1: Marine and Coastal Processes Baseline Technical Report);
- Cazenave *et al*. (2016[18]) presented a regional-scale 3D hydrodynamic model with a number of bottom-fixed WTGs. Results showed that the OWF foundations may have some limited influence on the local strength of stratification, but it does not suggest that naturally present stratification would be completely mixed by this process. In addition, the model considers mean flow at a typical spatial resolution of 10 to 20m in the horizontal plane, and more than several metres in the vertical plane. The elevation of turbulence intensity and turbulent mixing at smaller length scales in the narrow wake is important for the processes in question (Carpenter *et al*., 2016[14]), but is only generally parameterised, and not explicitly resolved by this model, which leads to some uncertainty in the results; and

- Carpenter *et al*. (2016[14]) used an idealised[i] numerical model to study the potential for large-scale change to the stratification of the German Bight region of the North Sea, in response to the presence of bottom-fixed WTGs. The study shows that stratification is only gradually broken down through hydrodynamic interaction with the OWF. The water column could be potentially fully mixed for a range of time between 100 to 500 days, only if the same body of initially stratified water is continually passed through the OWF. In reality, the same body of water repeatedly passes through the OWF due to tidal asymmetry and residual currents. As a result, mixing due to the foundations will only lead to some partial reduction in the strength of stratification in water that passes through the OWF. It was concluded that no large-scale changes to stratification of the North Sea are expected at the current levels of OWF construction, and extensive regions of the North Sea (i.e., length of 100km) would need to be covered in OWF for a significant impact on stratification to occur. The study also found that the results are sensitive to the assumed type (i.e., shape and size) of WTG (foundation) being assessed, and to the assumptions made about the evolution of the pycnocline thickness under enhanced mixing conditions.

2.4.2.6 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). It is of note that the results are not yet available.

2.4.2.7 Wind strength is also a parameter which can affect stratification by increasing the turbulence within the water column (Dorell *et al*., 2022[22]). A reduction of wind stress between 5 and 25% was observed downwind of OWFs at, approximately 5km for wind exceeding 10m/s (Siedersleben, 2019[19]; Lampert *et al*., 2020[20]). A detailed hydrodynamic model with multiple OWFs in operation showed the emergence of large-scale attenuation in the wind forcing resulting in an enhancement of stratification strength in particular during the decline of the period of summer stratification (Christiansen *et al*., 2022[12]).

[i] Carpenter *et al.* (2016[14]) did not take into account the residual flow into account, which means that the same body of water passes through the array area leading to a cumulative impact of stratification.

Magnitude of Impact

2.4.2.8 Where an obstruction is introduced to a flow, complex three-dimensional interaction creates a localised narrow wake with reduced time-mean current speed and increased turbulence intensity. The most pronounced changes to the flow regime occur immediately around, but primarily downstream of, the obstruction, within approximately three times the length scale of the obstacle. This corresponds to 42m for each individual bottom-fixed WTG (14m length) and 309m for each individual floating WTG (103m length) (Wu and Ouyang, 2020[21]). Consequently, there is not expected to be a cumulative impact between the foundation within Caledonia North and Caledonia South, as the minimum spacing between WTGs is defined as 944m.

2.4.2.9 Observations from Floeter *et al*. (2017[15]) are based on OWFs with a density of turbines (1.35 turbines/km^2 and 1.9 turbines/km^2) lower than the Proposed Development (Offshore) (3 turbines/km^2), which suggests that the combined impact of multiple foundations upon vertical mixing will be higher within Caledonia North and Caledonia South. However, based on Hammar *et al*. (2010[17]), the increase of turbulent mixing should be around 2%.

2.4.2.10 The Caledonia OWF is located within waters defined as seasonally stratified, with the water column expected to be stratified for more than 120 days throughout the year, mostly during spring and summer, and fully mixed the rest of the year (CMEMS, 2025[8]). When stratification is present, it is possible that both bottom-fixed and floating foundations, and associated mooring lines and anchors, within the Caledonia OWF may cause some very minor and highly localised decreases in the strength of water column stratification. However, it is considered that only a small proportion of water passing through the Caledonia OWF will actually interact with WTG infrastructure, causing only partial and localised mixing of any stratification.

2.4.2.11 Numerous repeat passes through the Caledonia North Site and Caledonia South Site of the same water body would be needed for an initially stratified water column to become fully mixed (Carpenter *et al*., 2016[14]). This is unlikely to happen, due to displacement of the water body out of the Caledonia OWF over shorter time periods by residual tidal currents. It is therefore extremely unlikely that water which is stratified entering the Caledonia OWF will become fully mixed.

2.4.2.12 To summarise, WTG foundations can create turbulence, which can both reduce (tidal wakes, paragraph 2.4.2.7) or enhance (atmospheric wakes, paragraph 2.4.2.9) the strength of stratification. These two opposing modifications are interconnected, potentially occurring simultaneously. At this time, there is only limited opportunity to evaluate accurately the resulting impact on stratification and frontal system due to the lack of data. However, based on available evidence, impacts on water column processes associated with the Proposed Development (Offshore) are anticipated to be permanent during the lifetime of the Proposed Development, and restricted to the near-field. The magnitude of impact is therefore considered to be **Low**.

Sensitivity of Receptor

2.4.2.13 The sensitivity of the following receptors have been considered in the assessment of modifications to water column structure and processes (mixing and stratification):

- Seasonally stratified waters; and
- Nationally designated site: Southern Trench NCMPA.

2.4.2.14 Based on the observations above (paragraph 2.4.2.13 *et seq.*), areas of undesignated waters are likely to be sensitive to changes with a moderate to low capacity to accommodate the proposed form of change, this receptor's sensitivity has been assessed as **Medium**.

2.4.2.15 The fronts present in the Southern Trench NCMPA is located at its closest approximately 10km from the Caledonia OWF and consequently may be sensitive to changes with a moderate to low capacity to accommodate the proposed form of change. Due to its designated status, this receptor's sensitivity has been assessed as **High**.

Significance of Effect

2.4.2.16 The significance of effect determined for each receptor, based on Table 2–10 in Volume 2, Chapter 2: Marine and Coastal Processes, is summarised in Table 2-1. For all receptors, the overall effect of the Proposed Development (Offshore) on water column structure and processes (mixing and stratification) during the operation and maintenance phase is considered to be **Minor** and **Not Significant in EIA terms**.

Table 2-1: Significance of effect of modifications to water column structure and processes (mixing and stratification) for all receptors.

Receptor	Sensitivity	Magnitude of Impact	Significance of Effect
Seasonally stratified waters	Medium	Low	Minor
Southern Trench NCMPA	High	Low	Minor

3 Limitations

3.1.1.1 The bathymetry used for the mixed layer water depth data (Figure 2–2 and Figure 2–3) does not coincide with the high-resolution bathymetry from EMODnet (2024[9]) (Table 3-1). As the water depth has been shown to influence stratification, the results from CMEMS might not accurately represent the marine processes occurring within the Proposed Development (Offshore). The thermocline is shown to vary significantly, between 5 and 20m, from CTD profiles data, which is not the case from CMEMS data.

Table 3-1: Water depth difference between EMODnet (2024[9]) and CMEMS (2025[8]).

Locations	Water Depth from EMODnet (m)	Water Depth from CMEMS (m)
Caledonia North Site (Centre)	54.59	40
Caledonia South Site (Centre)	62.84	40
Northern part of OECC	106.00	50
Centre of OECC	74.08	50
Southern part of OECC	61.48	50

3.1.1.2 CMEMS data used a coarse grid resolution (7km x 7km), which is considered not accurate for water depths less than 10m, such as the Landfall Site, and consequently it was not presented within this appendix to avoid misinterpretation. In addition, the coarse grid does not present the stratification at a fine scale as presented by the CTD profiles in Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area).

3.1.1.3 The resolution of the CMEMS grid does not clearly present the position of the front and its migration from intra- and inter-annual perspectives. For example, the stratification appears to vary within the Caledonia OWF, with stations showing a fully-mixed water column whilst others demonstrating the presence of a thermocline. In addition, the survey-specific data were collected sequentially and stations were not repeated. Consequently, the lack of data does not allow for the conclusion of the potential changes in stratification temporally.

3.1.1.4 The limitations presented above (paragraph 3.1.1.1 *et seq.*) are associated with knowledge gaps, which are essential parameters to characterise stratification and frontal features:

- Despite the CMEMS data showing the presence of thermocline during spring and summer, other data presume that stratification is not occurring 100% of the time during these seasons (Miller *et al.*, 2014[2]). It is difficult to conclude precisely (i.e., on a daily scale) on the temporal presence of the stratification and associated fronts;
- Hopkins and Polton (2012[10]) showed that the front migrates in the Irish Sea with displacements ranging from 5 to 35km. The same phenomenon is expected to happen within the study area, however the data from CMEMS do not allow to conclude where the front is located through time; and
- Stratification is often correlated with a decrease in Turbulent Kinetic Energy (TKE)[ii] (Dorrell *et al.*, 2012[22]). However, the exact efficiency with which the TKE generated by turbine structures leads to mixing and nutrient fluxes in the summer thermocline is unknown (SAMS Enterprise, 2024[23]). To date, no data exists concerning the strength of stratification within the study area and the TKE associated to dissipate it.

3.1.1.5 The assessment and characterisation of complex marine physical processes, such as stratification and frontal features, requires years of study at micro-, meso- and regional scale. The Applicant considers this would be more suited to strategic monitoring through programmes like Offshore Wind Evidence & Change and/or ScotMER.

[ii] TKE is the mean kinetic energy per unit mass associated with eddies in turbulent flow.

4 Conclusions

4.1.1.1 In summary, the results showed the presence of seasonal stratification, and associated fronts, within the Proposed Development (Offshore). This stratification is the consequence of solar heating during spring and summer resulting in a difference between surface and bottom water temperature. The OECC presents a haline stratification in the southern part (i.e., closer to the shore), whereas the north and the centre of the OECC presents a thermal stratification. The difference of salinity variation throughout the year along the OECC lead to the conclusion that a frontal feature exists between 10km and 25km from the shore.

4.1.1.2 CMEMS data has proposed a high-level overview of the marine processes occurring within the Proposed Development (Offshore). The data used in this report inherently includes some uncertainties and associated knowledge gaps (Section 2.4), which does not fully characterise the stratification within the study area.

4.1.1.3 As part of MD-SEDD’s representation, it was noted that the consent applications do not provide any assessment, or make a formal impact classification, with regards to potential impact on stratification and water column processes, while acknowledging there is considerable uncertainty in this field. The data used to characterise the stratification and frontal features in this appendix present some uncertainties, which do not represent accurately the *in situ* baseline of the area of interest. However, it is considered that data collection should be realised on a strategic level to understand the functioning (e.g., strength of stratification, temporal variation and spatial variation) of such marine processes (as well as nutrients and chlorophyll-a concentrations) in order to provide solid basis for future assessments.

4.1.1.4 As requested by MD-SEDD, the impact of the Proposed Development (Offshore) on the modifications to the water column structure and processes (mixing and stratification) has been assessed in Section 2.4.

4.1.1.5 Additional data collection pre- and post-construction (as indicated by MD-SEDD) is not considered proportionate for the Proposed Development (Offshore) and the Applicant considers this would be more suited to strategic research/monitoring programmes (e.g., Offshore Wind Evidence & Change or ScotMER).

References

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