Hornsea Project Four

Professor Mike Elliot's Marine Processes Report Review

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1 Introduction and Background

1.1.1.1 Ørsted's Hornsea Four Offshore Wind Farm project (Hornsea Four) submitted an Environmental Statement (ES) and Habitat Regulations Assessment (HRA) to The Planning Inspectorate in support of an application for Development Consents in September 2021.

1.1.1.2 Natural England (NE) and The Marine Management Organisation (MMO), in their Relevant Representations to the Hornsea Four Development Consent Order (DCO) application, raised a number of concerns on the Marine Geology, Oceanography and Physical Processes baseline and assessment. This report addresses those concerns according to the main features of the area and some aspects of the development. The response here is arranged according to the dominant receptors as well as elements of the operation, its construction, operation and decommissioning, as well as the structure and functioning of the area.

2 General Comments

2.1.1.1 It is of note that NE makes many requests for more information and also raises specific points whereas the MMO comments are mostly just indicating that more information is required – hence more emphasis is placed in this report on the very detailed NE comments. Cross-referencing the comments from the MMO and NE with the extensive material provided by the developers and their consultants has proved difficult but this reviewer gets the impression that the NE and MMO were not cross referencing the material in the different documents, e.g. the sediment information in the marine ecology report and that in the physical aspects report.

2.2 RAMP

2.2.1.1 The environmental consequences of the Ramp focusses on the sediment dynamics and the interference to the coastal currents and long-shore movement. The beaches along the eroding Holderness coastline are of mixed clayey-sand and are relatively poor faunally due to the constant input and export of sediments.

2.2.1.2 The NE queried whether 36 months is sufficient for the area to stabilise once the shore ramp is in place. This is considered to be sufficient as shown by other similar developments, including creating coffer dams for pipelines (e.g. at Dimlington near Spurn Point and the brine discharge work for the Atwick and Aldbrough solute mining developments) and Mappleton shore protection. The ramp will act as a groyne to trap sediment on the upstream (northern) side but once filled in the sediment will resume transport. After the removal of the ramp, the area will then have to regain equilibrium and enable the trapped sediment to migrate thereby allowing the shore to regain its original profile (unless there are benefits to the community of leaving it in place).

2.2.1.3 There is evidence from Mappleton regarding the amount of time required to create a new equilibrium, but this only shows structures being put in place rather than those removed. There may be further evidence from the placement and removal of the coffer dam at Aldbrough for the gas caverns (reference the source from SSE if publicly available). NE raises the potential impacts of this beach access ramp to cliff stability. Based on other hard engineering works along this coast (Boyes et al., 2016), it is expected that there will be additional coastal erosion on the down-current side of the ramp and so the ramp must be placed to account for this, i.e. with only farmland at risk of erosion.

2.3 RECEPTORS

2.3.1.1 In several places, Natural England considers the list of Marine Process Receptors to be incomplete but the list is given in the reports and it is not clear why the list is considered incomplete unless it is only the omission of the Silver Pit (see below). Unlike many discussions elsewhere, in the NE response, a receptor is a site or a feature but not necessarily equivalent to a conservation objective, i.e. the geological or ecological attribute for which an area was designated. In some cases, the receptor is a natural geomorphological feature (such as the Holderness cliffs) but can also be a statutory designation (e.g. MCZ) or a licenced area (e.g. the dredged material disposal ground for Bridlington Harbour). This distinction can create confusion, for example in carrying out an HRA.

2.3.1.2 It is agreed that there are a number of designated site receptors which may be influenced by impacts in the Export Cable Corridor (ECC) either directly or indirectly as a result of impacts to other marine process receptors. These therefore need to be considered. These include: Holderness Inshore MCZ, Holderness Offshore MCZ, Flamborough and Filey Coast SPA, Flamborough SSSI, Humber Estuary SAC, SPA, SSSI and Ramsar, Greater Wash SPA, Southern North Sea SAC. The potential for indirect impacts to the Holderness Coast from the ECC should also be explored. These relate to the whole site whereas it is better to determine the effects on the features for which those sites were designated (the conservation objectives) which are mostly structural features. Hence there is the need to consider the processes as well as the structure. As some of these are to the north of the site then it is acknowledged that the effects will be lessened due to the southerly residual currents. Some of these sites are many km from the development but one questions what distance would NE regard as being appropriate – the whole of the southern North Sea? The Leewarden judgement regarding SAC protection queried the distance from a protected site that could be deemed to be influenced by a development. Once questions whether this is a proportionate response and were the same criteria used for developments elsewhere in the North Sea?

2.3.1.3 NE disagree that the rates of cliff erosion and patterns of longshore drift along the Holderness Coast are the primary environmental interest sensitive to potential changes in wave energy transmission due to Hornsea Four. They consider the form and function of Smithic Bank are equally important since the sandbank protects the coastal hinterland, including the town of Bridlington and that lowering of Smithic Bank due to HP4 related project impacts could have a significant impact on longshore sediment transport. It is agreed here that both receptors have high environmental value. Given the position and distance offshore plus the residual currents southwards then the Holderness coastline is important but also the Smithic Bank, because of its importance to Flamborough Head birds, and the Flamborough-Helgoland Front and its branches.

2.3.1.4 The presence of the structures may interfere with oceanographic processes, both residual and wind-induced currents and wave systems. NE say they cannot rule out potential adverse effects to sensitive receptors and designated sites downwind of these areas (e.g. Holderness Offshore MCZ, Holderness Coast, Smithic Bank), until this has been assessed over the lifetime of the project. However, Section 4.8.3.17 in the Technical Report estimates up to 10% wave height reduction effects on the leeward side of the array. NE suggests that without a consideration of these effects over the lifetime of the project, they cannot understand the spatial extent and potential impacts of the wave shadow effect on downwind receptors. However, the lee has been quantified in the reports using modelling and shown not to reach either the coast or the Smithic Bank. While effects from westerly and SW winds may be negligible, easterlies and North easterlies, which have the greatest fetch may create a greater lee but again, this does not reach the Smithic Bank or the Holderness coastline, as shown by modelling in the absence of empirical research given that short time similar structures have been in place.

2.3.1.5 In addition, it is questionable whether the erosion of Holderness coast is caused primarily by wave action or is mostly due to slumping (Boyes et al., 2016) – the latter has been assumed to be the case in numerous studies. If, however, the array does reduce erosion then locally this may be welcomed by society even if that reduces sediment input to the Humber and further south. It is accepted that sediment from the Holderness coast enters the sediment pool to the south, in the Humber Estuary, the Wash and areas in between.

2.4 MAXIMUM DESIGN SCENARIO

2.4.1.1 It is emphasised that there is the need to determine what scenarios are probable and possible and while many repercussions could occur, there is the need to determine what actually will occur. Many changes are possible but unlikely and furthermore there is the acknowledged difficulty of making predictions in a highly variable environment. Similarly, it is accepted that highly variable systems are both more resilient (i.e. a greater capability to recover) and also can absorb changes, what has been termed 'environmental homeostasis (Elliott and Quintino, 2007, 2019). Many of NE comments question the assumptions made but it is emphasised that this is necessary in any field of risk assessment and management given that the scientific understanding is uncertain and data complete. As shown in many marine areas, it is often possible to define the structure of the system (the features at one time) whereas defining, understanding and interrogating the functioning (the rate processes) may either be prohibitively expensive and/or take an inordinate amount of time.

2.4.1.2 The footprint of the development has been modelled but this could be given more clarity, for example by separating the activity-, pressures- and effects-footprints (see Elliott et al., 2020). In this case, the activity-footprint in only where the human action occurs whereas the pressures-footprint show the mechanism creating change on the natural and social systems. These pressures in turn lead to the effects-footprints on both the natural and the societal components including human welfare. Despite this, the allowable amount (or zone) of impact' is an acknowledged aspect in EIA but in many cases it can only be refined after construction and operation with empirical data and direct, rather than modelled evidence or evidence from comparable cases. This is a conundrum common in many EIA – that impacts can only be verified and validated with empirical evidence which can only be acquired following construction and operation (and even decommissioning).

2.4.1.3 NE request the need to indicate the mitigation hierarchy has been followed (the mitigation hierarchy consists of four steps in order – Avoid, then Minimise, then Restore impacted areas and finally Offset any impacts that remain). However, the last of these, to offset, is regarded more as a compensation mechanism than a mitigation one and whereas compensation of habitat may be more or less successful in coastal and estuarine areas, it is rarely effective offshore (Elliott et al., 202b). The mitigation methods appear to be indicated where possible. It is emphasised that the MDS is allowing for the scientific uncertainty and again can only be refined after more empirical evidence after construction and operation.

2.5 SMITHIC BANK

2.5.1.1 The Smithic Bank is a well-regarded geomorphological feature often associated with a conical headland. However, there may be a similar sandbank to the north of the conical headland – gyres created by the north-south tidal and residual currents enable the sandbanks to be created. Literature suggests that in the case of Flamborough Head, the north-south currents are much more important than any east-west ones in creating the sandbanks. Hence the offshore influence of the turbine array is less important. In the case of Flamborough Head, the sandbanks in turn develop the sandeel populations which feed the seabirds (as long as they have a suitable roost site). Hence it is acknowledged that protecting the north-south current patterns is needed to ensure the sandbanks remain. It is of note that Figure 45 shows the shadow from the array clearing the coast and the Smithic bank.

2.5.1.2 It is suggested (Vol. A5 Annex 1.1 Marine Processes Technical Report) that Smithic Bank is formed from sediments from the north, Filey Bay, and Bridlington Beach whereas NE seem to assume it receives its sediments from the Holderness Cliffs. This is less likely as it is of note that the Bank is composed of well-sorted sands whereas the cliffs are glacial clays. Given the residual currents and sand transport southward then interfering with the southern edge of the bank is less harmful that further north; rock protection is likely to be required with a mobile sandbank and could act as a groyne, again until the equilibrium is regained and sand then bypasses the groyne. There is the need to quantify how much the bank would be lowered, i.e. the footprint of the cable route, but NE have to acknowledge that this is in the context of a mobile sandbank.

2.5.1.3 The reports identify Smithic Bank as a local sediment store for material supplied through cliff erosion and so NE indicate Smithic Bank should be considered a receptor of the landfall works. But again it is suggested that the Smithic Bank has a different type of sediment from the cliffs and if it stored cliff material then it would be finer; furthermore, the bank appears outside the line of sediment migration along the Holderness coast (as observed from the shore). In addition, Smithic Bank is to the north of the main Holderness eroding cliffs and so while it may get ebb tide material, it is unlikely to get the dominant material.

2.5.1.4 Coastal counter-currents also need to be considered where there is a dominant north-south current and southerly residual current. However, this is an anomaly if the ebb current tidal excursion is greater than the flood current one, as suggested in the reports (Figure 18). Figure 1.15 gives the spring tide tidal ellipses but the area is adjacent to the array rather than being inshore adjacent to the coast. Berthot and Pattiaratchi (2006) indicate the mechanisms regarding similar conical headland gyres and sediment build up – as long as the headland is there and the dominant currents present then the sandbank will build up. On a finer scale, the erosion-deposition currents on a daily, lunar and seasonal basis have not been shown.

2.5.1.5 NE are concerned that moderate elevation changes to the sandbank through construction/decommissioning (and maintenance) activities, and alterations to the sediment transport processes nearby due to the presence of the Dogger Bank A&B Cable Crossing, might modify the Holderness shoreline response to storm waves, and the Holderness shoreline morphology over the lifetime of the project/installed infrastructure. Hence, of course direct and indirect effects on nearby designated sites and those further afield need to be carefully considered. All of this is possible but is it probable? This would require removal of the sandbank which is unlikely given the mechanisms for its formation (conical headland, sediment supply from the north etc). In addition, the sandbank is seaward of the Bridlington beaches rather than the main part of the Holderness cliffs which extend further south.

2.5.1.6 While in relation to the sensitivity of the Holderness Coastline, NE suggests that potential scenarios should be modelled to allow assessment of the potential impacts again taking account of the potential impact of climate change. This suggests the sediment supply on to Smithic bank comes from the Holderness Cliffs when in fact it either may or is likely to come from the Filey Bay and the northern area. The complexity of sediments and current patterns north of Flamborough Head but including the gyre in Filey bay are shown by Cutts et al. (2000) which shows the currents changing direction with the tidal state and the gyre reversing under certain conditions and depending on spring or neap tides. Furthermore, Filey beach is known to change in height considerably with storms, on occasion the beach dropping to expose the foundations of the seawall.

2.5.1.7 NE welcomes that the Dogger Bank cable crossing will be positioned east of Smithic Bank and seaward of the 20m depth contour but they wish it demonstrated that this location is sufficiently seaward as to avoid alterations to the local wave/current regime, sediment transport regime and morphology of the sandbank. The final positions of the various cable crossings need to be considered as a set. In particular, NE would be concerned if a 2km length of cable re-burial/de-burial occurred across Smithic Bank, potentially up to 7 times through the lifetime of the project and hence there is the need to fully assess the potential impacts of the cable installation across the project lifetime and to bring forward mitigation where needed. It is emphasised here that NE need to consider the operational width for that 2 km and hence the number of hectares occupied as a proportion of the whole bank. It is noted that Table 22 (Volume 5, Annex 1.1.) presents an extremely valuable estimation of the amounts of area occupied by the suite of developments in the area; while these are regarded as best-guess estimates which may change once construction has been completed, they are likely to give the appropriate order or magnitude. It is accepted that mitigation for the cable in situ is not possible and compensation is not suitable for offshore structures (see Elliott et al., 2020b).

2.5.1.8 It is difficult to determine the precise concerns of MMO and NE regarding the influence of the various cable crossings on the bank and whether they are concerned about the lowering or the raising of the bank. They will appreciate that the height of the bank is in equilibrium with the prevailing currents and so will adjust by accreting or eroding if artificially lowered or raised respectively. NE are concerned that the Hornsea 4/Dogger Bank A&B Cable Crossing is still not situated in sufficiently deep water as to avoid significantly reducing water depths and, dissipating storm wave energy, at a location just seaward of Smithic Bank. Hence, as with other comments, it is not clear what is the concern – that the area will be made shallower and hence will dissipate wave energy reaching the shore or it will not be made shallower, i.e. as is, and so will not dissipate wave energy.

2.5.1.9 The NE concern about the potential placement of any cable protection across Smithic Bank as this could lead to a reduction in water depth within the water column, and potentially lead to local scour and the formation of a barrier to sediment transport. Significantly altering the profile of the sandbank could have a significant impact on longshore drift, and in turn, could result in impacts to features much further afield. However, this is an assumption on the part of NE and it is emphasised that the use of the term 'significantly' needs quantifying – do they mean detectable, notable, statistical? This seems to imply both scour and accretion at the same place. It is acknowledged that as with all mobile sand banks, changes to Smithic Bank are occurring constantly but with regard to a human activity, a signal to noise ratio probably cannot be modelled.

2.5.1.10 Finally, NE queries the statement that 'On the outer (easterly) flank, sandwave asymmetry is with the flood tide, moving sands to the south-west onto the bank…'. The study suggests the flood tide along the eastern edge of the Smithic Bank and the ebb tide currents along the western edge creates this gyre. There is the need to clarify their confusion and determine whether it is a stronger flood and weaker ebb that creates the asymmetry.

2.6 FLAMBOROUGH-HELGOLAND FRONT

2.6.1.1 The position and dynamics of the Flamborough-Helgoland Front are particularly complex and comments from the respondents appear to suggest they regard it as a single, linear feature. Earlier studies, such as Nihoul (1980) suggests that it starts parallel to the western North Sea coast and then deviates more towards the mid-Netherlands area but others indicate the bifurcation round Dogger Bank. Researchers accept the importance of the Flamborough Front and that there are hydrographic differences either side but there is the need to demonstrate if biological productivity differs across or in the vicinity and whether it is the Front itself or the presence of the conical headland that drives the rich food for the seabirds. The presence of the gyres and the two sandbanks north and south of the headland create the sediment conditions for seabirds feeding feeding on sandeels together with the availability and suitability of roost sites create the benefits of the area and productivity on its own would not give the benefits.

2.6.1.2 Seasonal stratification occurs north of the Front but assessing the dynamic of this stratification and modelling it in relation to any introduced structures is particularly difficult; giving the turbulent footprint within a large natural turbulence field, as shown by the current and previous data, will be particularly uncertain and requires empirical evidence. Again, there is the need to exercise caution regarding the use of the term 'significant' and refer to a signal to noise ratio and assumption that the change can be detected. NE suggests a high potential that the Front will be disturbed but there is no strong evidence either way without ground truthing after the array is in place. Again it is emphasised that there is the need to quantify the activity-, pressures- and effects-footprints and determine whether the turbulence could affect the Front but this could only be done after construction unless superimposing the images from previous sites.

2.6.1.3 Carpenter et al. (2016) and Hill et al. (1993) show the complexity in the dynamics of tidal mixing fronts in the North Sea and hence the difficulty of not only describing and predicting their position and seasonal changes but also the difficulty of modelling any interference to the fronts.

2.6.1.4 It is therefore reiterated that the importance of the Flamborough-Helgoland front to primary productivity in the North Sea has long been agreed, even though there are few measurements of the primary productivity at small scales near the front. It is agreed that it is vital to understand the potential impacts of the HP4 alone, and in-combination with other plans and projects. There is no doubt that this is an important feature but there is limited evidence for the direct productivity elements and the increased productivity needs to be further demonstrated and the potential impact of an OWF to stop the nutrient flows needs to be confirmed. Hence, although such a change is unlikely, especially over large temporal and spatial scales, it will be difficult to refute the NE question that "Turbulent wakes are not expected to interact with the Flamborough Front." and "The magnitude of impact has been assessed as 'negligible' for this effect" without empirical data which can only be obtained after construction.

2.6.1.5 The Flamborough Front is located close to/overlaps the HP4 array (and HP2 and HP1) and hence the importance of the Front to primary productivity (and in turn secondary productivity), requires a better understanding of the potential impacts of the project alone (and in-combination). This has been raised many times – the behaviour of the front is poorly understood as is its means of formation and the mechanisms for nutrient delivery and primary production. As the content of nutrients in the area will not change, even if there are minor changes in concentration, and the light regime stays the same then it is not easy to see how the primary production will change. This is the subject of proposals to the EcoWind programme and will provide evidence if funded.

2.6.1.6 Given their concerns, NE consider that the sensitivity of the Flamborough Front should be considered High until further evidence to the contrary has been provided. Again, modelling does not appear to be sufficient to show the small-scale changes given that the potential effects depend on the amount of the Front which could be affected. Hill et al. (1993) suggest the front has three parts (a western arm parallel to the shore), an NE arm going towards the Dogger Bank and a shorter SE arm going past the Silver Pit – the northern part of H4 could be in a break in the front; the front could be 50-70 km wide from north to south but modelling may not be capable of determining if it will be disturbed, hence the need for empirical evidence.

2.6.1.7 NE require further schematics showing the Flamborough Front position throughout the year to indicate the potential impacts. It is noted that the position of the Front in figures 36 and 37 (Vol 5 Annex 1.1) differs from that in other maps (e.g. Hill et al. 1993) which shows it to be a more diffuse and fragmented feature. These figures suggest that the Front does go through the H2 development – this needs confirming and whether there is any more empirical evidence from the arrays affecting the Front.

2.6.1.8 The current patterns and resulting sediment dynamics around conical headlands, such as Flamborough Head, are particularly difficult to observe and therefore model (e.g. https://nora.nerc.ac.uk/id/eprint/10521/1/CircNORA.pdf). NE suggest that the potential extent of overlap with the Flamborough Front needs to be clarified. The figures give the sequence for the seasonal changes to the front but the line of the Front is coherently in one place – if the earlier papers (Hill et al., 1993) showing the front occupying a 50-75 km band are correct then it has the potential to envelop various structures but it is suggested that its large size makes it more resistant and resilient. Timko et al. (2019) also show the width of the Front and the direction not as discrete a feature as suggested by the respondents. These aspects need to be considered especially as the figures probably give a simplified impression of the front.

2.7 DECOMMISSIONING

2.7.1.1 The topic of decommissioning has rightly been raised by the developer and respondents. The role of marine structures and their behaviour in relation to the prevailing physical and biological features is increasingly being addressed. This is especially in order to determine the repercussions of removing the structures and perhaps disturbing a new equilibrium formed during the lifespan of the structure (e.g. the current and previous INSITE projects and McLean et al., 2022, Elliott and Birchenough, 2022; Burdon et al 2018a). This creates a large new area for discussion, in that a new equilibrium would be formed during the life span of the OWF so that again this will be disturbed on decommissioning. The current reassessment of the OSPAR 98/3 requirement regarding the full or partial removal of marine structures is considering the lack of empirical evidence on times for creating and recreating an equilibrium of bed conditions and whether removing structures extends and increases environmental change and perhaps damage, especially given the energy required to remove structures.

2.7.1.2 While removing the turbine structure will be easily accomplished, removing and rock armouring around it and especially removing buried and protected cables will create further bed changes, especially as that introduced hard substratum adjacent to sandy beds has benefits particularly for lobsters and other crevice dwellers. The persistence of structures after operation is currently being considered by the INSITE Synthesis project but a case-specific approach will be needed. The danger of exposure of cables will require post-decommissioning monitoring (either formal or informal monitoring) and exposed cables could then be removed with minimal environmental damage whereas cables that remain buried would be left in-situ to avoid further disturbance.

2.7.1.3 Hence, NE are correct in suggesting that as infrastructure is left in place then the long-term impacts beyond decommissioning need to be considered. This should include the new equilibrium that would have been created around the introduced bed structures and the potential for greater damage should the bed structures be removed, if this was possible it would not be possible without damaging the seabed. Recent studies on pipelines have shown that once established and depending on the type of cable protection used, removing mattresses and rock armouring is both costly and environmentally damaging.

2.7.1.4 Despite the above, there is potential for buried infrastructure to become exposed beyond the operational lifespan of the project. Hence the monitoring of the structure has to be continued but this is a grey area of remaining liability after the operational phases of structures (see Blanet 2020).

2.7.1.5 In conclusion here, NE are correct in suggesting that as the rock berms are expected to remain in situ, their impacts beyond the operational lifetime of the project need to be assessed in the context of any receptors which could be affected by their persistence. Decommissioning is still being considered for all structures with a debate regarding whether an area which has reached an equilibrium should have the structures left as otherwise removal would cause more damage. In addition, the energy and fuel use in decommissioning is a material concern and hence a balance between the local environmental changes and damage and a contribution to global climate change.

2.8 CLIMATE CHANGE

2.8.1.1 The respondents are correct in raising concerns regarding the influence of any development on climate change and its mitigation. Indeed, recent revisions to EIA procedures emphasise the need to determine the effects of the development of climate change adaptation and the effects of climate change on the structures (Lonsdale et al., 2017). In the current case, the predominant concerns are of sea level rise and increased storminess – see Burdon et al. (2018b) who present the possible effects of climate change on the Dogger Bank proposed development and vice versa but it is emphasised that this is conjecture until greater empirical evidence is achieved with structures in place. In the case of Hornsea Four, the modelled evidence suggest that the lee of the development will be restricted and will not reach the coastline of Smithic Bank. As indicated above, the dynamics of the Bank with the development is place are uncertain and unlikely to be clarified without greater empirical evidence which can only be gathered after the development has been constructed. It is expected, but still hypothesised, that while there will be a predicted increase in water depth above the bank with sea-level rise, the sandbank is in equilibrium with the existing depth and currents and so will adjust with increased water above it.

2.8.1.2 NE emphasise that the influence of climate change impacts (e.g. sea level rise) needs to be considered as required within paragraph 5.5.7 of NPS EN-1. These predictions are key to understanding the potential for infrastructure to become exposed throughout the project lifetime and the subsequent requirement for remedial works. However, while this is relevant for shore-based structures but less so for offshore structures.

2.8.1.3 The climate change repercussions of any development are highly uncertain although scenarios can be tested. For example, the scenarios for ICCP RCP 8.5. etc. can be used but these are projections and while may be satisfactory for testing physical and socio-ecological repercussions for large areas, they appear to be less effective for very small areas and individual developments. Further studies are required on these aspects.

2.8.1.4 Finally, while it is acknowledged that effects of climate change on the development and the effects of development on climate change adaptation need to be considered, there is a query regarding the legal position that renewable energy production is itself mitigation/compensation for global climate change (2020a).

2.9 BASELINE

2.9.1.1 The respondents acknowledge that the Marine Geology, Oceanography and Physical Processes chapter and technical report present a large amount of relevant information and evidence but they suggest that there are several gaps in the baseline characterisation including: an adequate description of the underlying geology, seabed sediments and dominant morphological features in the vicinity of, and within, the proposed project area; sufficient baseline characterisation and understanding of the Flamborough Front through and/in the vicinity to the HP4 array, coupled with an adequate assessment of the effects of the array on tidal flows, turbulent wakes, and mixing within the water column, and a detailed investigation of the geomorphology of Smithic Bank, its evolution, and the impact of the proposed development on its form and function.

2.9.1.2 NE also requires further data on the following: high-resolution geophysical survey data (due to be completed in 2021) to help eliminate uncertainties regarding scour equilibrium depth, sub-surface geology, bedform nature and distribution, sediment mobility; high resolution bathymetric surveys around Smithic Bank (e.g. swath bathymetry) and accompanying geotechnical surveys (including near the Dogger Bank A&B cable crossing and along the Holderness coastline); high-resolution bathymetric survey data for the offshore array and offshore export cable corridor (ECC), and the effects of the proposed foundation structures on turbulent wake-induced mixing, stratification, and, in turn, primary productivity in and around the Flamborough Front.

2.9.1.3 This is an extensive list of omissions but an examination of the available reports suggest that all of these aspects are covered within the limits of background knowledge and understanding and within the available time and resources. It is acknowledged here that under current environmental governance and management, while the respondents do not have to prove that the development will cause an impact, the developers have to prove that there will not be such an impact. It is emphasised that, scientifically, proving a negative is not possible especially as no matter how much information and how many data are provided then it is always the case that more can be requested. Filling the gaps in the above list relies on determining what is 'adequate', 'sufficient' and 'detailed' and whether the studies come under the 'nice to know' or 'need to know' category.

2.9.1.4 There is the need to check if these data are now available and the gaps filled subsequent to the earlier NE and MMO representations. It is suggested that some of these are available but others will be prohibitively expensive to collect especially as the signal to noise ratio is unlikely to be determined. For example, the effects of turbulent mixing on primary production would require many sampling stations, the inclusion of Eularian and Lagrangian current determination both laterally and vertically, as well as direct primary productivity measurements (perhaps carbon isotope or light and dark techniques together with water quality parameters).

2.10 EIA/HRA/MCZ

2.10.1.1 The respondents raised the question of whether the area of search for the impact assessment is sufficient but it is emphasised that in a highly dynamic area, and indeed in many marine situations, this is a subjective decision. For example, given the interlinked dynamics of the North Sea, and in particular the dominant, residual counter-clockwise current patterns, then any developments along the British east coast have the potential to affect anywhere to the SE of England and the eastern North Sea. Such potential effects are highly dependent on the dynamics of the physico-chemical processes (e.g. tidal excursion, storm surge behaviour, sediment mobility, nutrient dynamics, NAO repercussions), the movement of highly mobile species and the relationship between the activity-, pressures- and effects-footprints. Superimposed over this are what may be termed 'moving baselines', especially due to climate change and, in this area, isostatic rebound, and 'unbounded boundaries', for example the changes in the Hornsea Four areas being the result of not only near-field but far-field influences. In particular, is the difficulty of determining the influences at a turbine/gravity-base site, between these (given a putative separation of 1.5-1.8 km) within the array, between arrays and other developments, and between the developments and the other receptors and other features.

2.10.1.2 The respondents are critical in suggesting that the EIA is impact pathway-led rather than receptor-led but the reports show that both are considered. It is arguable that conservation management focusses on structure rather than processes but that the need for both is acknowledged and emphasised here. NE suggest that the result of this is that the overall impact to a given receptor as a result of Hornsea Four is not assessed but the available reports suggest that each receptor has been addressed, perhaps with the omission of the Silver Pit.

2.10.1.3 NE are concerned that a receptor could be subject to a number of impacts that are deemed "not significant" in isolation, and yet the combined effects could have much greater significance. In marine management, cumulative effects assessment methods have not been agreed and require all 3 types of footprints to be quantified for all components of all activities and their resulting pressures and effects (Elliott et al., 2020; Lonsdale et al., 2020). This has not yet been attempted in any developments and there is the need to check if this can be done cost-effectively or whether there is sufficient information/data. Again, a central consideration in CEA are the spatial and temporal boundaries regarding what activities, pressures and effects are include, where and when.

2.10.1.4 For example, the plume created by construction would be expected to oscillate depending on the tidal state and strength and hence the material would assimilate into the coastal SSC. However, most material disturbed from the bed is relatively well-sorted sands with a low percentage silt and clay and hence it will settle quickly out of suspension. NE suggest that the assessment of the impact of sediment plumes due to cable trenching needs to be carried out here.

2.10.1.5 NE suggest that impacts on marine geology oceanography and physical process may give rise to impacts on intertidal and benthic ecology as well as impacts on individual species and so they would return to these aspects later as well as making comments on other parts of the ES – this gives an open-ended indication. If these were not included then there is the need to see why these are or are not included – were they included or scoped out, if scoped out then who indicated such? Previous studies indicate that the intertidal biota along the Holderness shoreline is extremely poor, attributed to the highly dynamic nature of the substratum which because of the erosion, appears to behave as a dredged-material disposal ground.

2.10.1.6 NE are also assuming that in order to clear sandwaves then the dredged material disposal will be at a site elsewhere and so locations for spoil disposal need to be identified so that their impact can be assessed. Such a monitoring would be usual but it will show the disposal site gets smothered and then recovers – the rate of recovery will be dependent on the timing of disposal in relation to benthic recruitment periods (Duarte et al., 2015). NE concludes that the impacts to receptors cannot be presumed to be of short-term duration but this questions the determination of timescales in a highly dynamic sedimentary area. For example, NE questions sediment re-joining the sediment pool in the area, being redistributed and migrating because of currents but this is what happens on the sea bed in sediment dominated systems (Duarte et al., 2015).

2.10.1.7 As in any EIA, the WCS should be considered hence the nature of plume spreading due to sand wave clearance in the nearshore. NE requires a schematic/map(s) showing the marine processes, their receptors, the maximum sediment plume concentration, extent, persistence and any associated bed level changes within the array and along the export cable corridor. It would be helpful for the developers to reinforce the plume modelling and the area covered – the ES in places gives the impression of smothering the bed but they should have given this as an area, a thickness and an indication of whether this can be tolerated by the benthos. Previous experience, studies and published and unpublished information shows that benthic organisms can withstand sediment coverage, including that from dredged material disposal and beneficial use literature, depending on the rates of input and the nature of the benthos; benthic species adapted to and living in sedimentary dynamic areas will be able to tolerate sediment smothering whereas more delicate species would not.

2.10.1.8 NE consider that the assessment of Magnitude and Impact appears to relate to the excavation of exit pits and not sand wave clearance and they do not agree with this assessment of magnitude (as negligible) and impact (as not significant) as not all receptors have been adequately considered (e.g. Holderness Offshore MCZ). They suggest that further mitigation may be required although they do not indicate what other mitigation would satisfy them. However, in an open sea situation, it is important to know what NE regards as mitigation – they will acknowledge that monitoring is not mitigation or a management response but only a way of determining if management responses are needed or are working.

2.10.1.9 NE repeat the statement that "During a neap tide the plume will be advected over a shorter distance (up to 6km) than a spring tide (up to 12km)…" – this is expected given the tidal dynamics. However, they omit the fact that the residual current is taken to be southward from Flamborough Head and so the tidal oscillation will move material southwards. NE agree that whilst sediment plumes due to seabed preparation for the HVAC booster stations and export cable installation are anticipated to be restricted to be within one tidal excursion distance, but they still regard as likely the potential for plumes to reach the Holderness Offshore MCZ and so require further information. However, the Holderness Offshore MCZ is within the north-south current patterns and the tidal oscillation will move the sediment and any increased SSC but this is taken to be N-S rather than E-W. The evidence for relative strength of the N-S and E-W current components need to be checked. Similarly, there is the need to interrogate the data for the benthic community at the MCZ to determine whether it is adapted to dynamic sedimentary conditions.

2.10.1.10 The respondents discuss the changes to the sand bank as the result of the development but they need to indicate the changes to sand banks under natural events such as storms. For example, Houthuys et al. (1994) suggest changes of up to 1.2 m can occur during storm conditions but there are many contributing variables. Hence, detecting any changes in the Smithic Bank due to natural variation and pressures against the 'signal of change due to the development can only be achieved after construction.

2.10.1.11 The evidence to show the MDS sediment releases for cable trenching in the inshore area west of Smithic Bank has also been raised. Particle size dependent plume modelling is needing to be checked to give confidence – the settling velocities could be estimated based on particle size and current strength.

2.10.1.12 NE suggest that the anticipated maximum scour footprint around each foundation option should be provided and they require monitoring scour development around a number of WTGs (GBS and monopile) and OSS in order to validate scour predictions in the ES. The scour footprint must be known from similar installations – again this could be given as an area and as a proportion of the whole area. Furthermore, NE query the comment that "All foundations are considered sufficiently separated to mitigate the chance of group scour." They suggest that group scour can extend beyond the influence of the foundation with large diameter structures such as GBS or jacket structures and, therefore, has a large cumulative environmental effect when taking into the whole Hornsea 4 array. NE require further information to support this assertion and the separation distance should be stated. This is an engineering point – the scour protection needs to be sufficient to stop scour and there should be no overlap between foundations. It is suggested here that the putative 1.5-1.8 km between foundations would be sufficient to avoid overlapping scour but this is a design and engineering point to eb elaborated by the developers, perhaps once construction is confirmed (see Volume A4, Annex 3.2: Selection and Refinement of the Offshore Infrastructure).

2.10.1.13 NE keep iterating the importance of the potential impacts on all sensitive receptors being fully assessed. This is agreed but it should include the positive as well as negative effects. For example, the value of rock protection in creating habitat surface area, crevices, etc has been commented on many times. Having a rock armouring next to bare sand creates ideal lobster habitat – it would be worthwhile to indicate how much more suitable lobster habitat will be created for the greater benefit of the crustaceans.

2.11 HRA – INFORMATION TO INFORM IT

2.11.1.1 The Likely Significant Effect is questioned by the developer – given the residual currents from North to South and the array is east of Flamborough Head then the potential for Flamborough Head being affected is lessened. The Head is in a sedimentary area, a conical headland and exposed to sediments but obviously a non-accreting area as shown by the chalk features. NE need to focus on the conservation features – the habitat chalk roost and breeding area, food supply for the birds, etc. The development is unlikely to affect the hard structure but the sand eels need to be maintained; this will occur as long as the sand is there of the right type. Surveys done in the 1990s by IECS could be re-examined to would show how stable the area is for benthos and sandeels and whether there have been changes in intervening years.

2.11.1.2 In some areas, the respondents are asking for 'certainty' in determining the changes but this is rarely, if ever, possible in dynamic areas and even 'beyond reasonable doubt' is subjective – this relies on defining the accepted degree of change, the signal to noise ratio, etc. It is questioned whether the respondents have defined the acceptable degree of change given that in places, their narrative appears to require no change. While this would be ideal, it is highly unlikely for the area. Again, it is emphasised that while NE does not have to demonstrate an effect, the developer has to demonstrate no effect – scientifically demonstrating a negative effect is very difficult if not impossible and for each aspect the developer addresses, NE can ask for greater detail. For example, there may be no detectable impact on a community but what on the physiology of an individual organism.

2.11.1.3 With regard to the recovery of the system after construction, NE query whether associated habitats will recover in the short-term (up to 2 years), and consider that there is very little evidence to support this assumption. However, there is an increasing body of literature on restoration and this includes the time scales for example, Duarte et al. (2015), Borja et al. (2010), Thrush et al. (2021) and Gray and Elliott (2009) all discuss the recovery of seabed features. These works suggest that recovery from sediment disturbance takes 18-48 months depending on type of benthos, season etc. The timing of the sediment disturbance in relation to the recruitment times also influences the speed of recovery.

2.12 MCZ ASSESSMENT

2.12.1.1 The conservation objectives are all determined on the structural characteristics which of course depend on functioning. The MCZ sites in this area were both decided with a knowledge current and some proposed activities and their features reflect the characteristics of the area. NE are concerned that potential impacts to physical process attributes have not been adequately assessed and that for habitat features this includes: Supporting processes – energy exposure, sediment movement and hydrodynamic regime, and for the Spurn Head Geological feature of Holderness Inshore MCZ this includes: the extent of supporting geomorphological processes and associated sediments; sediment transport pathways and connectivity to wider environment, and extent and distribution. However, it is suggested here that these are covered to a lesser or greater extent and within the reasonable spatial and temporal scales appropriate to characterising the area and within the constraints of current knowledge and understanding.

2.12.1.2 The respondents ask for additional measures to be carried out to avoid/reduce/mitigate potential impacts but, as indicated above and in Elliott et al. (2020b), mitigation may be short term measures and compensation, in the mitigation hierarchy, is often unattainable.

2.13 CUMULATIVE IMPACTS

2.13.1.1 It is acknowledged that the proposed Endurance storage facility overlaps the northern part of the HP4 array, and the pipeline will need to be crossed by the HP4 offshore ECC, hence, if that development was operational then there may be cumulative impacts which should be considered. NE emphasise that this should include the cumulative impact of O&M activities as well as additional wake effects if infrastructure is placed within or adjacent to the Hornsea Four array. The Endurance site is described in Gluyas and Bagudu (2020) which also shows the underlying hard geology of the area. NE ask for such information but the relevance of the request is not explained. With regard to the effects of the brine discharge from the Endurance development, it is of note that the Holderness coast has a long history of coastal brine discharges for gas storage caverns (at Aldbrough and Atwick) and the brine discharge effects investigated in detail. As the development Endurance is only proposed then it is difficult to consider its effects further.

2.13.1.2 The attenuation of wave energy through any structure is of interest and it is indicated here that wave energy transmission through the Hornsea 1 array undergoes no detectable reduction due to the monopile foundations now installed. The ES considers that this "…outcome is also expected to remain true for Hornsea Project Two based on a similar final design which greatly alleviates the case of potential cumulative impacts with Hornsea 4". NE require evidence to support this assumption but perhaps Hornsea 2 will provide the empirical evidence that NE are asking for throughout the report. The empirical evidence for Hornsea 4 can only be obtained by the development in place.

2.13.1.3 Accordingly, NE have concerns regarding the potential impacts on wave energy transmission over the lifetime of not only Hornsea 4, but also when combined with Hornsea 1 and Hornsea 2, and advise that this should be fully investigated. Again, it is difficult to investigate this without the structures in place. Numerical models are probably not capable but a physical model, if one could be produced, may give an indication of the consequences of the cumulative influences.

2.13.1.4 Again, NE indicate that the cumulative impacts of the Hornsea Four Dogger Bank A&B, and the Scotland to England Green Link 2 cables (and their protection) should be considered over the long-term (i.e. lifespan of the crossing). There is the need to check the cumulative effects but these will be very difficult to predict. At present there is no accepted and fully quantitative method of CEA (e.g. Lonsdale et al., 2020).

2.13.1.5 NE suggest that the uncertainties prevent them from concluding that the magnitude of impacts will be negligible to minor, nor that the significance of the effects on Smithic Bank, the Holderness Coast, and other sensitive receptors, will be slight for the project alone, and in-combination. However, based on the evidence, and in comparison to other developments, there appears to be a comprehensive presentation of the potential effects of the development. As is the case in presenting such information, there is caution in superimposing of shapes on a large scale map which distorts the sizes and give the impression of areas larger than in reality, e.g. cables the thickness of pens/pixel definition.

2.14 PHYSICAL, BIOLOGICAL PROCESSES/STUDIES

2.14.1.1 NE do not consider that either the Holderness Inshore MCZ or Holderness Offshore MCZ have been considered, but the reports indicate that they remain as marine processes receptors. This is surprising given that the MCZ were discussed in detail in Volume A5 Annex 2.3 MCZ Assessment and in the Section 2.11 Chapter 2 of the Benthic and Intertidal Ecology report. As emphasised above, the development has the potential for an impact but it is necessary to consider what is possible, probably and unlikely. If this is not the case then it would be difficult sanctioning any activities at sea.

2.14.1.2 NE repeat that Gravity Base Structures (GBS) as a maximum design scenario was introduced following the Section 42 consultation on the PEIR and that instead of this refining the application, it has the opposite effect and in NE words, have 'substantially increased' the significance of impacts for marine geology, oceanography and physical process receptors and therefore introduced an additional element of risk associated with this project. The developer's approach appears in line with other environmental assessments and there evidence from elsewhere, for example the use of GBS in Belgian waters.

2.14.1.3 The developer reports refer to the Outer Silver Pit as a geological feature adjacent to the array but NE suggest it should have been considered a potential receptor. It would be of interest to include it in case it is an accreting area and to check what type of feature it is. Given its position, it may receive any disturbed material via west to east transport patterns and the action of the Flamborough Front but again one questions whether material would settle in the Silver Pit if the bathymetry is in an equilibrium with the prevailing hydrography. The area as a whole can be examined regarding accreting and eroding areas and also the erosion-deposition cycles on scales from weekly, tidally, monthly, at the equinox and seasonally. However, this will indicate the inherent variability of the area against which the signal of effect can be judged.

2.14.1.4 In relation to the Smithic Bank and sand waves, given that most sandbanks are mobile then these sand waves will develop but their migration may be interfered with by the construction. That migration will be impeded until a new equilibrium is created for the sandbanks to be remobilised.

2.14.1.5 The Holderness cliffs and erosion are raised by the respondents but the logic of the concerns needs to be checked. The erosion here is created mostly due to the nature of the cliff and its slumping from saturation rather than sea level rise. However, increasing storminess may be more of a concern and the OWF may indeed lead to a sheltering of the coast as it absorbs energy from northerly and north-easterly wind and waves. Despite this, the evidence does indicate that the lee of the array from north-easterly and easterly winds does not extend as far as the cliffs of Smithic Bank. If the interference of waves is of concern then see McTiernan and Sharman (2020) for the joint use of OWF and wave power devices.

2.14.1.6 NE request the operational details of the anticipated timing of infrastructure exposure due to seabed lowering or sediment erosion and remediation plans. It would be of benefit to emphasise the actual area affected by seabed lowering and give how many metres over how many hectares. However, again it is emphasised that NE should remember that the bed will be in equilibrium with the hydrographic patterns and the new equilibrium.

2.14.1.7 NE keep mentioning that the underlying geology is not known; however, the underlying geology must be known at least for areas where piling is contemplated. This is given in other studies – see Endurance study (reference above). Furthermore, NE often refer to uncertainties in the use of terms, for example they are unclear what are these seismic units but apparently it refers to a given type of stratum which can be discriminated.

2.14.1.8 The complexity of the Holderness coastline, its intertidal sediment dynamics and the difficulties of modelling the changes have been shown in several publications. For example, in an intensive study at nearby Spurn Point by Foote (1994), the intertidal and near shore sediment movement and its relationship to current patterns showed a complex and difficult to model interaction.

2.14.1.9 The NE are concerned that the levels of suspended solids disturbed by the development or the turbulence created by the structures. However, they should acknowledge what may be termed the repercussions of the stress-subsidy theory (Elliott and Quintino, 2007, 2019; Gray and Elliott 2009) which emphasises that conditions are only stressful if an organism are not suited to them; in cases where organisms are adapted then they gain a benefit with the absence of organisms which are not tolerant. Hence, as an example, Allen (2003) indicates the nature of the inshore benthic community being adapted to the constant erosion and deposition linked to the cliffs and inshore area.

2.14.1.10 The sediments and benthos of this area are regarded to be both patchy and dynamic and the infauna showed characteristics similar to dredged material disposal sites sue to the constant transport, accretion and erosion of sediments (Allen, 2003). The impact assessment has to acknowledge that these features make the detection of change against natural variability difficult.

2.15 OPERATIONAL ASPECTS

2.15.1.1 Natural England notes and welcomes the applicant's efforts to refine the maximum design scenario for the use of GBF down to 110 foundations. However, they indicate that there is limited context provided (i.e. the location of these 110) and therefore it is difficult to refine down the worst-case scenario for the impact assessments. It is suggested here that presumably there are operation constraints which can only be resolved during building.

2.15.1.2 NE suggests that the potential impacts of vessels and equipment in the construction/decommissioning and operational phases of the project should also be considered. For example, there is potential for jack-up vessels or vessels with several anchors to hold station to cause indentations on the seabed. This is agreed – all aspects of an activity will have its own footprint and needs to be considered However, the area of such an indentation would be very small as a proportion of the whole area and mobile sediments would still fill in the holes depending on the sedimentary equilibrium being reached. As there is a Humber vessel anchoring ground south of the area then this is a feature of this part of the North Sea.

2.15.1.3 NE requires that the seabed profile is restored following the excavation of exit pits (particularly given the sensitivities of this area). They indicate that material from elsewhere should not be brought in for reinstatement, therefore steps should be taken to store the excavated sediment in a suitable location (potentially onshore). There should be an element of sorting of sediment to enable the sediment structure to be reinstated. They further consider that the appropriate storage of material should be secured in the DCO/dML as mitigation. However, such a strategy would be unusual given the quantity of material; it is questioned whether NE suggests that vessels with their attendant emissions, anchoring, pumping structures etc. should be used to pump the material onshore from a dredger and then replace it afterwards thereby creating an impact on land. This does not seem an environmentally friendly option and is highly unusual. Seabed storage of material has been used elsewhere but, even then, storing and then re-locating the material will affect the environment, even if it stayed in one place, which is unlikely as there will be some winnowing of material.

2.15.1.4 NE are correct is assuming that the impact of elevated suspended sediment concentrations (SSCs) and associated sediment deposition due to the excavation of HDD exit pits could affect other sensitive features nearby such as the Holderness Inshore MCZ. Furthermore, they indicate that there is no mention of the reinstatement of the seabed profile following backfilling of the exit pits and require an assessment of the potential range of change in intertidal/subtidal elevation and coastal retreat over the lifetime of the project following reinstatement. Natural England, therefore, cannot agree with the assessment of significance of this impact pathway. It is emphasised here that the levels of SSC should be put in context of the prevailing levels especially given the very high levels naturally occurring along the Holderness coast (>g l-1) and the behaviour of the Humber plume (several g l-1). Given the prevailing sediment features and sediment mobility, it is expected that the pits would fill naturally without the need to expend additional energy and CO_2 to fill them. The report (Figure 1.8) indicates SPM to 100 mg.l-1 but this is likely to be much higher in the 1-3km band from the shoreline.

3 General Points

3.1.1.1 This report has attempted to cover all the points raised by the respondents although further effort would be required to tackle every point raised in the initial and subsequent responses. While there are more comments relating to NE needing more engineering explanation, these can be answered by the developer albeit with more information once construction begins.

3.1.1.2 As indicated above, NE consider there to be gaps in the evidence presented in support of this application. These include: Adequate data/evidence on the underlying geology, seabed sediments and dominant morphological features in the vicinity of, and within, the proposed project area, and sufficient baseline characterisation and understanding of the Flamborough Front through and/in the vicinity to the HP4 array, coupled with an adequate assessment of the effects of the array on tidal flows, turbulent wakes, and mixing within the water column. They emphasise the need for a detailed investigation of the geomorphology of Smithic Bank, its evolution, and the impact of the proposed development on its form and function. It would be highly unlikely that this information has been omitted given the intimate relation between the development and the seabed, its structure and functioning. While an analysis of its structure ('form') is straightforward and has been given, an analysis of its function(ing), by definition rate processes, is more complex and would require a detailed time series and analysis under differing environmental conditions, including storms. Even with this information, modelling with the array in place might not be sufficient to predict anything other than extreme changes and hence small-scale field measurements may be required but may be logistically and cost prohibitive.

3.1.1.3 Given many of the points raised by the respondents, the developer should put more emphasis on quantities (of area affected, amounts moved, etc) as a proportion of the whole area to show the activities in context – for example, SSC created in relation to natural SSC in the readily observed coastal plumes. The reviewer gets the impression that many of the questions raised especially by NE have been addressed but the volume of information may be obscuring the discussion. For example, NE are concerned that cable protection should be avoided if the cable passes over Smithic Bank but they should be aware that as a mobile sandbank then there is the potential for the cable to become exposed in the more highly mobile areas. They require the developer to demonstrate any separation distance is sufficient. Cable protection has the potential act as an underwater groyne with sediment build up depending on the current direction and strength and it may stabilise the bank and create elevated sediment surface on one or both sides. The operator is aware of scouring near the cable protection.

3.1.1.4 As indicated above, Natural England does not agree with the assessment of magnitude and sensitivity as they consider that not all sensitive receptors have been interrogated (as discussed above). They advise that further mitigation may be required. This is repeated often but one questions if any further mitigation is possible. Given the limited time available for review, this requires a separate discussion. It is also emphasised that all receptors have been addressed although not necessarily in the same part of the documentation. For example, NE consider that the potential impact of this WCS on sensitive receptors and/or designated sites (e.g. Holderness Offshore MCZ) needs to be considered. A large number of points relate to the remobilisation and transport of sediments whether from drilling or dredging – the effects need to be explained in terms of timing, receiving areas, transport, etc, near and far field effects. The spring tide ellipses (Figure 1.15) indicates the patterns of particles in suspension. Each of these aspects is covered albeit in different places. While the EIS and ES are very thorough and professional, perhaps the volume of information and data are overwhelming and have led to consultation fatique.

3.1.1.5 The comments by the MMO and NE focus on the uncertainty in the predictions, the need for more evidence and the lack of knowledge and data. However, many of their comments are not focussed on the detection of the signal of change against a background of 'environmental noise', the inherent variability in the system. As yet there are few indications of the agreed tolerable limits of change and the level of study and replication required to detect a nominated change is often prohibitively high; for example, assessing EIA for OWF, Franco et al. (2015) showed that an agreed level of change could not be detected in complex, variable areas with a tolerable amount of field and laboratory study.

4 Selected References

Allen, J. H. (2003) The analysis and prediction of the shallow subtidal benthic communities along the east coast of England, Unpubl PhD thesis University of Hull 2003

Berthot, A., Pattiaratchi, C., (2006) Mechanisms for the formation of headland-associated linear sandbanks. Continental Shelf Research 26 (2006) 987–1004.

Blanet, C. (Ed.) 2020. The Law of the Seabed: Access, Uses, and Protection of Seabed Resources. Brill Publ., The Netherlands.

Borja, Á., Dauer, D.M., Elliott, M., & Simenstad, C.A., (2010). Medium- and Long-term Recovery of Estuarine and Coastal Ecosystems: Patterns, Rates and Restoration Effectiveness. Estuaries and Coasts (2010) 33:1249–1260.

Boyes, S.J., Barnard, S. & Elliott, M. 2016. The East Riding Coastline: Past, Present and Future. Prepared for East Riding of Yorkshire Council (ERYC) by the Institute of Estuarine and Coastal Studies (IECS), University of Hull. Funded through the Defra Coastal Change Pathfinder project and the East Riding Coastal Change Pathfinder (ERCCP). Institute of Estuarine and Coastal Studies, University of Hull, Hull, HU6 7RX, UK.

Burdon, D., Barnard, S., Boyes, Elliott, M (2018a). Oil and gas infrastructure decommissioning in marine protected areas: system complexity, analysis and challenges. *Marine Pollution Bulletin*, 135: 739-758.

Burdon, D., Boyes, S.J., Elliott, M., Smyth, K., Atkins, J.P., Barnes, R.A. & Wurzel, R.K., (2018b). Integrating natural and social marine science to sustainably manage vectors of change: Dogger Bank transnational case study. *Estuarine, Coastal and Shelf Science* 201: 234-247, [redacted]

Carpenter et al 2016

Cutts, N., Elliott, M., Lacambra, C Read, S (2000) Hunmanby Gap Cable Landfall: Marine Characterisation. Report S106-F-2000, Institute of Estuarine & Coastal Studies, University of Hull.

Duarte, CM, Borja, A, Carstensen, J, Elliott, M, Krause-Jensen, D, Marbà, N (2015; electronic 2013). Paradigms in the Recovery of Estuarine and Coastal Ecosystems. Estuaries and Coasts, 38(4): 1202-1212. DOI 10.1007/s12237-013-9750-9

Elliott, M. & V Quintino (2007) The Estuarine Quality Paradox, Environmental Homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. *Marine Pollution Bulletin*, 54, 640-645.

Elliott, M., Barnard, S., Boyes, S.J., Burdon, D., Cutts, N.D., Franco, A. & Smyth, K., 2020a. *The framework and options for compensation for Marine Annex 1 habitats for offshore wind farms. Unpublished Report* YBB875-F-2020, Report for Ørsted Wind Power NS, Strategic Environment Team (Contract No. 0456). University of Hull and International Estuarine & Coastal Specialists (IECS) Ltd., pp 1-115.

Elliott, M., Birchenough, S.N.R. (2022) Man-made marine structures – Agents of marine environmental change or just other bits of the hard stuff? Marine Pollution Bulletin, 176, March 2022, 113468; https://doi.org/10.1016/j.marpolbul.2022.113468

Elliott, M., Borja, A., Cormier, R. (2020b). Activity-footprints, pressures-footprints and effects-footprints – walking the pathway to determining and managing human impacts in the sea. Marine Pollution Bulletin, 155: 111201; [redacted]

Elliott, M., Quintino, V.M. (2019). The Estuarine Quality Paradox Concept. *Encyclopaedia of Ecology*, 2nd Edition, (Editor-in-Chief B Fath), Elsevier, Amsterdam, Volume 1, p78-85; ISBN: 978-0-444-63768-0. [redacted]

ERM (1997). Environmental Assessment for a Natural Gas Storage Facility at Aldbrough: Volume 1 Environmental Statement. Environmental Resources Management, Oxford.

Foote, Y.L.M. (1994). Waves, currents and sand transport predictors on a macro-tidal beach. Unpubl. PhD Thesis University of Plymouth.

Franco, A, Quintino V, Elliott M (2015). Benthic monitoring and sampling design and effort to detect spatial changes: a case study using data from offshore wind farm sites. Ecological Indicators, 57: 298-304.

Gluyas, J.G. Bagudu, U. (2020). The Endurance CO2 Storage Site, Blocks 42/25 and 43/21, UK North Sea. Geological Society Memoirs 52: 163-171. https://doi.org/10.1144/M52-2019-47 c Geological Society of London 2020.

Gray, JS & M Elliott (2009). Ecology of Marine Sediments: science to management. OUP, Oxford, 260pp.

Hill et al. (1993) Dynamics of tidal mixing fronts in the North Sea. Phil. Trans. – Physical Sciences & Engineering. 343(1669) 431-446.

Houthuys, R., Trentesaux, A., De Wolf, P. (1994) Storm influences on a tidal sandbank's surface (Middelkerke Bank, southern North Sea) Marine Geology 121(1-2):1994, Pages 23-41

[redacted]

Lonsdale, J., Weston, K., Elliott, M., Blake, S., Edwards, R. (2017). The Amended European Environmental Impact Assessment Directive: UK Marine Experience and Recommendations. *Ocean and Coastal Management,* 148: 131-142.

Lonsdale, J-A, Nicholson, R, Judd, A, Elliott, M, Clarke, C (2020). A novel approach for cumulative impacts assessment for marine spatial planning. Environmental Science & Policy, 106: 125-135.

McLean, D.L., L.C. Ferreira, J.A. Benthuysen, K.J. Miller, M-L. Schläppy, M.J. Ajemian, O. Berry, S.N. R. Birchenough, T. Bond, F. Boschetti, A.S. Bull, J.T. Claisse, S.A. Condie, P. Consoli, J.W.P. Coolen, M. Elliott, I.S. Fortune, A.M. Fowler, B.M. Gillanders, H.B. Harrison, K.M. Hart, L-A. Henry, C.L. Hewitt, N. Hicks, K. Hock, K. Hyder, M. Love, P.I. Macreadie, R.J. Miller, W.A. Montevecchi, M.M. Nishimoto, H.M. Page, D.M. Paterson, C.B. Pattiaratchi, G.T. Pecl, J.S. Porter, D.B. Reeves, C. Riginos, S. Rouse, D.J.F. Russell, C.D.H. Sherman, J. Teilmann, V.L.G. Todd, E.A. Treml, D.H. Williamson, M. Thums (2022). Influence of offshore oil and gas structures on seascape ecological connectivity. *Global Change Biology*, 2022;00:1–22, DOI: [redacted]

McTiernan, K.L., Sharman, K.T., (2020) Review of Hybrid Offshore Wind and Wave Energy Systems *J. Phys.: Conf. Ser.* **1452** 012016

Nihoul, J.C.J. (1980). Residual circulation, long waves and mesoscale eddies in the North Sea Oceanol. Acta, 1980, 3, 3, 309-316.

Thrush, S.F., Hewitt, J.E., Pilditch, C.A., Norkko, A (2021). Ecology of Coastal Marine Sediments: form, function and change in the Anthropocene. OUP, Oxford, pp200.

Timko, P.G., Arbic, B.K., Hyder, P., Richman, J.G., Zamudio, L., O'Dea, E., Wallcraft, A.J. Shriver, J.F. (2019) Assessment of shelf sea tides and tidal mixing fronts in a global ocean model. Ocean Modelling 136: 66-84. [redacted]

5 Professor Mike Elliott

Prof. Mike Elliott, *Chair in Estuarine & Coastal Sciences, Research Professor, Department of Biological and Marine Sciences*, The University of Hull, UK; and Director, International Estuarine & Coastal Specialists Ltd
[redacted]

Mike is the Director of International Estuarine & Coastal Specialists (IECS) Ltd and also the Professor of Estuarine and Coastal Sciences at the University of Hull, UK. He was Director of the former Institute of Estuarine & Coastal Studies (IECS) at the university from 1996-2017. He is a marine biologist with a wide experience and interests and his teaching, research, advisory and consultancy includes estuarine and marine ecology, policy, governance and management. Mike has published widely, co-authoring/co-editing 20 books/proceedings and >300 scientific publications. This includes co-authoring *'The Estuarine Ecosystem: ecology, threats and management'* (with DS McLusky, OUP, 2004), *'Ecology of Marine Sediments: science to management'* (with JS Gray, OUP, 2009), and '*Estuarine Ecohydrology: an introduction*' (with E Wolanski, Elsevier, 2015). He was an editor and contributor to the '*Coasts and Estuaries: the Future*' (Wolanski, Day, Elliott and Ramachandran; Elsevier, 2019) and the *Treatise on Estuarine & Coastal Science* (Eds.-In-Chief - E Wolanski & DS McLusky, Elsevier). He has advised on many environmental matters for academia, industry, government and statutory bodies worldwide. Mike is a past-President of the international Estuarine & Coastal Sciences Association (ECSA) and is a Co-Editor-in-Chief of the international journal *Estuarine, Coastal & Shelf Science*; he currently is or has had Adjunct Professor and Research positions at Murdoch University (Perth), Klaipeda University (Lithuania), the University of Palermo (Italy), Xiamen University (China) and the South African Institute for Aquatic Biodiversity. He was awarded Laureate of the Honorary Winberg Medal 2014 of the Russian Hydrobiological Academic Society. He is also a member of many national and international committees linking marine science to policy.

Research Metrics:

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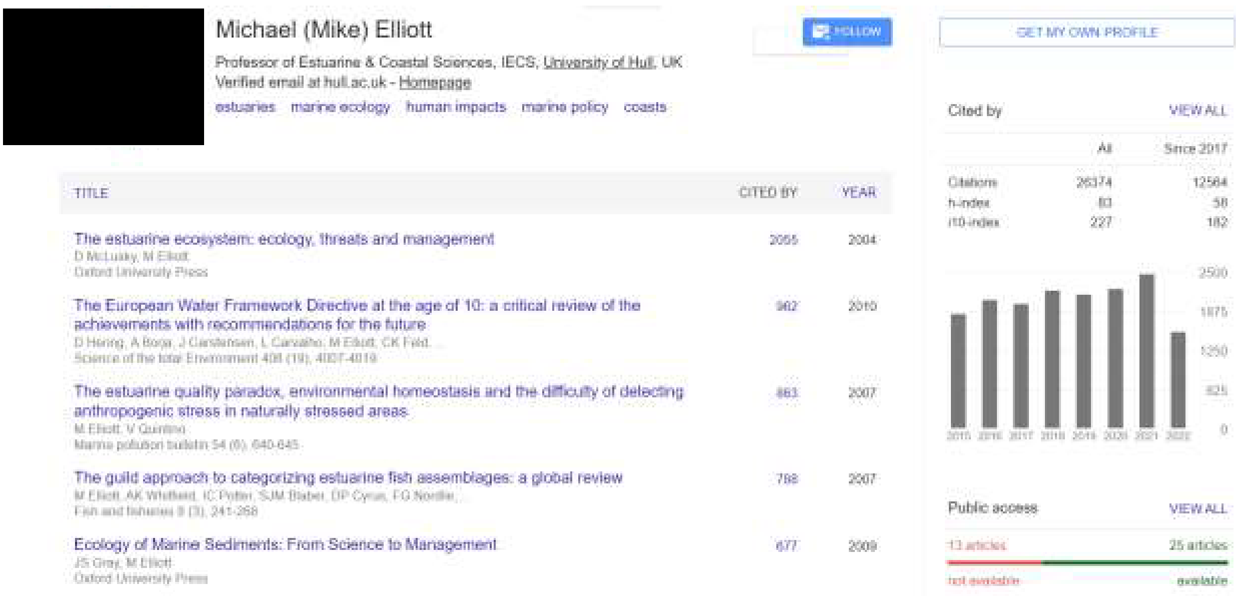
Scopus: [redacted] H index: 62;

Google Scholar: [redacted] H index 81, i10 index 226; citations >26,000.



Web of Science H index 58; ORCID ID 0000-0002-2519-4871; ResearcherID: B-4312-2013.

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(top 0.6%) 190 extended papers	(top 0.4%, rank 13.4K) 12,129 extended citations	(top 0.3%, rank 7.7K) 60 extended h-Index	4.7 avg. Impact Factor

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4th **most cited paper** in *Hydrobiologia the International Journal on Limnology and Marine Sciences* (2002)

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