# 5 ASSESSMENT

## 5.1 Assessment approach and methodology

This SEA covers an enormous marine area comprising all UK waters with water depth from the intertidal to more than 2,400m. The draft plan/programme includes for the licensing of offshore oil and gas activities, the storage of gas and $CO_2$, offshore wind farms and marine renewables. The assessment therefore has to address complex issues and multiple interrelationships, where a simplistic score based matrix assessment would be inadequate. Following discussion with the SEA Steering Group an evidence based consideration was agreed. In addition, significant use has been made of Geographical Information System (GIS) tools to collate, process, analyse and present spatial information.

The assessment for this SEA is a staged process (Figure 5.1) incorporating inputs from a variety of sources:

- Baseline understanding of the relevant receptors (including other users) grouped according to the SEA Directive (see Appendix 3 Environmental baseline and Section 4 Environmental information and the range of underpinning technical reports produced for the SEA process) together with existing environmental problems and the likely evolution of the baseline conditions. Given the comprehensive nature of the environmental baseline produced for OESEA, only updates to the baseline section since the publication of OESEA or baseline information relevant to the new aspects of the OESEA2 draft plan/programme are included in this report.

- The likely activities, and potential sources of effect (see Box 5.1) and the existing mitigations, regulatory and other controls (see Appendix 5).

- The evolving regulatory framework.

- The evolution of technology.

- The SEA objectives (see Section 3).

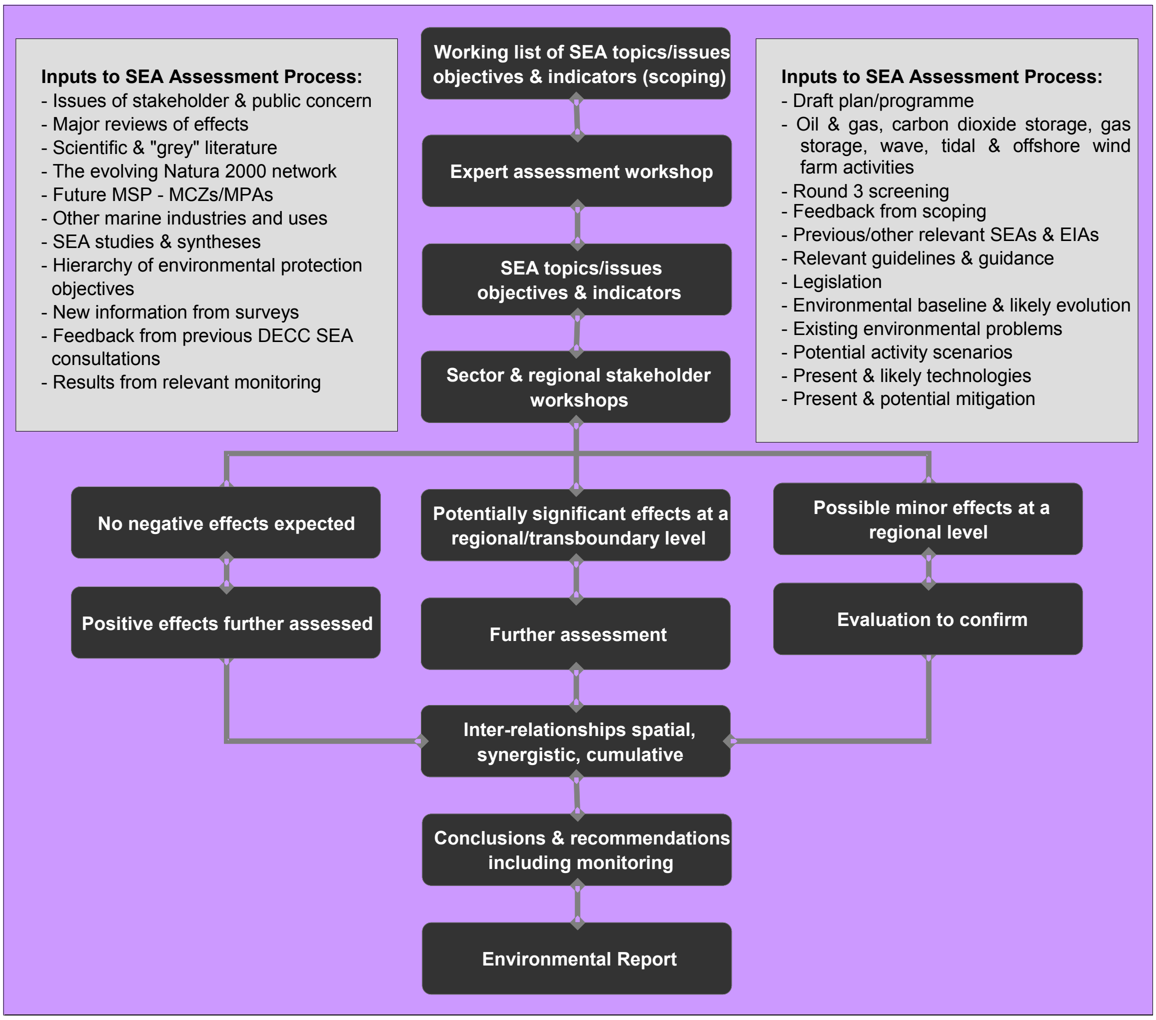
- The evidence base regarding the relative risks and potential for significant effects from offshore wind farm, wave, tidal stream and tidal range developments, offshore oil and gas exploration and production, carbon dioxide storage and gas storage related activities.

- Steering Group, statutory consultee and stakeholder perspectives on important issues, information sources and gaps, and potential areas to exclude from licensing derived from scoping, assessment workshop, regional stakeholder workshops, sector workshops, meetings and other communications – see Appendix 1 and 2.

At a strategic level, a distinction has been drawn for various effect mechanisms between impacts which may be significant in terms of conservation status of a species or population (and hence are significant in strategic terms), and impacts which may be significant to individual animals, but which will not influence sufficient numbers to have a significant effect on population viability or conservation status (and hence strategically significant).

Examples of this approach include the consideration of acoustic effects on marine mammals, collision risk for birds and oil spill effects. This approach does not imply that mortality or sub-lethal effects on individual animals are unimportant (clearly there are welfare considerations, particularly for avian and mammalian species); but it is appropriate that strategic considerations are made at a biogeographic population or species level – as is done for example, in the selection of qualifying features for Natura 2000 sites.

Figure 5.1 – Assessment process




## 5.2 Potential sources of significant effects

Potential sources of effects from the activities which could follow adoption of the draft plan/programme have been variously discussed with the SEA Steering Group and stakeholders (see Appendix 1 & 2) in terms of the likely significant effects on the environment, including on the SEA topics – these are listed in Box 5.1 below. A questionmark indicates uncertainty of potential for effect.

The sources of potentially significant effect identified in Box 5.1 have been categorised by Assessment Topic (left hand column, see key at end of table) which forms the basis of the subsequent assessment sections. The potentially significant effects identified in Box 5.1 represent potential issues which merit further consideration (location of assessment signposted in right hand column, Assessment Section).

| Assessment Topic | Box 5.1<br>Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | **SEA Topic Biodiversity, habitats, flora and fauna** | | | | | | | | |
| | Physical damage to habitats from infrastructure construction, vessel/rig anchoring etc | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish from seismic surveys | X | X | X | | | | | 5.3.2.1<br>5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with piling and construction noise | X | X | X | X | X | X | X | 5.3.2.1<br>5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with operational noise | X | X | X | X | X | X | X | 5.3.2.1<br>5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise | X | X | X | X | X | X | X | 5.3.2.1<br>5.3.2.2 |
| | Potential for non-native species introductions in ballast water discharges or spread through “stepping stone” effect | X | X | X | X | X | X | X | 5.6.2.4<br>5.9.2 |
| | Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities | X | X | X | X | X | X | X | 5.6.2 |
| | Collision risks to birds | | | | X | X | | X | 5.6.2.2<br>5.6.3 |
| | Collision risk to marine mammals, fish and large water column animals | | | | | X | X | X | 5.6.2.2<br>5.6.3 |
| | Barriers to movement of birds (e.g. foraging, migration) | | | | X | | X | | 5.6.2.1 |
| | Barriers to movement of fish and marine mammals | | | | | X | X | X | 5.6.2.1 |
| | Changes/loss of habitats from major alteration of hydrography or sedimentation | | | | | ? | X | ? | 5.4.2.2 |
| | Potential for effects on flora and fauna of produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | X | X | X | X | X | ? | X | 5.9.2 |
| | EMF effects on sensitive species | | | | X | X | X | X | 5.6.2.5 |

| Assessment Topic | Box 5.1<br>Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | The nature and use of antifouling materials | | | | ? | X | ? | X | 5.9.2 |
| | Accidental events - major oil or chemical spill | X | ?[1] | ?[1] | ?[1] | ?[1] | ? | ?[1] | 5.13.2.1 |
| | Accidental events - major release of $CO_2$ | | | X | | | | | 5.13.2.1 |
| | **SEA Topic Geology, substrates and coastal geomorphology** | | | | | | | | |
| | Physical effects of anchoring and infrastructure construction (including pipelines and cables) on seabed sediments and geomorphological features (including scour) | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Sediment modification and contamination by particulate discharges from drilling etc or re-suspension of contaminated sediment | X | X | X | X | X | X | X | 5.9.2 |
| | Effects of reinjection of produced water and/or cuttings and injection of $CO_2$ | X | X | X | | | | | 5.9.2 |
| | Onshore disposal of returned drilling wastes – requirement for landfill | X | X | X | | | | | 5.10.2 |
| | Post-decommissioning (legacy) effects – cuttings piles, footings, foundations etc | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Changes to sedimentation regime and associated physical effects | | | | | X | X | X | 5.4.2.2<br>5.5.2 |
| | Accidental events - risk of sediment contamination from oil or chemical spills | X | ?[1] | ?[1] | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.2<br>5.13.2.3 |
| | Accidental events – blow out impacts on seabed | X | X | X | | | | | 5.13.2.2<br>5.13.2.3 |
| | **SEA Topic Landscape/seascape** | | | | | | | | |
| | Potential visual impacts and seascape effects of development including change to character | X | X | X | X | X | X | X | 5.8.2.4<br>5.8.3 |
| | **SEA Topic Water environment** | | | | | | | | |
| | Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | X | X | X | X | X | ? | X | 5.9.2 |

| Assessment Topic | **Box 5.1**<br>**Sources of potentially significant effect** | **Oil & Gas** | **Gas Storage** | **$CO_2$ Storage** | **Offshore Wind farms** | **Tidal Stream** | **Tidal Range** | **Wave** | **Assessment Section** |
|---|---|---|---|---|---|---|---|---|---|
| | Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment | | X | X | | | X | | 5.5.2<br>5.9.2 |
| | Energy removal downstream of wet renewable devices | | | | | X | X | X | 5.5.2 |
| | Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.2<br>5.13.2.3 |
| | **SEA Topic Air quality** | | | | | | | | |
| | Local air quality effects resulting from exhaust emissions, flaring and venting | X | X | X | X | X | X | X | 5.11.2 |
| | Air quality effects of a major gas release or volatile oil spill | X | X | X | | | | | 5.13.2.3 |
| | **SEA Topic Climatic factors** | | | | | | | | |
| | Contributions to net greenhouse gas emissions | X | X | | | | | | 5.12.2.5 |
| | Reduction in net greenhouse gas emissions | | | X | X | X | X | X | 5.12.2.5 |
| | **SEA Topic Population & Human health** | | | | | | | | |
| | Potential for effects on human health associated with effects on local air quality resulting from atmospheric emissions | X | X | X | | | | | 5.11.2 |
| | Potential for effects on human health associated with effects of discharges of naturally occurring radioactive material in produced water | X | X | ? | | | | | 5.9.1 |
| | Accidental events – potential food chain or other effects of major oil or chemical spills or gas release | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.3 |
| | **SEA Topic Other users and material assets** | | | | | | | | |
| | Positive socio-economic effects of reducing climate change[2] | | | X | X | X | X | X | 5.12.2.2 |
| | Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, “sanctuary effects”) | X | X | X | X | X | X | X | 5.7.2.2 |

| Assessment Topic | Box 5.1<br>Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Other interactions with shipping, military, potential other offshore renewables and other human uses of the coastal and marine environment | X | X | X | X | X | X | X | 5.7.2.1<br>5.7.2.3<br>5.15.1<br>5.15.2 |
| | Accidental events – socio-economic consequences of oil or chemical spills and gas releases | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.3 |
| | **SEA Topic Cultural heritage** | | | | | | | | |
| | Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access. | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |

*[1] Via shipping collision risks*
*[2] Outline assessment only*

**Key to Assessment Topics**

| | | | |
|---|---|---|---|
| | Noise | | Marine discharges |
| | Physical damage to features and habitats | | Air quality |
| | Physical presence | | Climatic factors |
| | Landscape / Seascape | | Accidental events |

## 5.3 Noise

### 5.3.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Potential behavioural and physiological effects on marine mammals, birds and fish from seismic surveys | X | X | X | | | | | 5.3.2.1 5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with piling and construction noise | X | X | X | X | X | X | X | 5.3.2.1 5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with operational noise | X | X | X | X | X | X | X | 5.3.2.1 5.3.2.2 |
| | Potential behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise | X | X | X | X | X | X | X | 5.3.2.1 5.3.2.2 |

Previous SEAs have considered the potential for acoustic disturbance by noise generated by offshore wind farms (OESEA, Round 2 SEA) and by hydrocarbon exploration and production activities (OESEA, SEAs 1-7). This assessment updates the previous work and includes an assessment of potential acoustic disturbance associated with carbon dioxide storage, gas storage and power generation from wave and tidal sources.

In general, marine mammals show the highest sensitivity to acoustic disturbance, and the severity of potential effect has therefore been related principally to marine mammal species composition and abundance in the area under consideration, although effects on fish (including spawning aggregations) have also been considered. For both marine mammals and fish, various effects will generally increase in severity with increasing exposure to noise; a general distinction may be drawn between effects associated with physical injury or physiological effects, and effects associated with behavioural disturbance.

Noise broadly falls into three categories (e.g. Harland & Richards 2006) and its description can be highly technical. Impulsive (pulse) noise is transient in nature and is generally of wide bandwidth and short duration. It is best characterised by quoting the peak amplitude and repetition rate. Continuous broadband noise is normally characterised as a spectrum level, which is the level in a 1Hz bandwidth. This level is usually given as intensity in decibels (dB) relative to a reference level of 1 micro Pascal (µPa). Tonals are very narrowband signals and are usually characterised as amplitude in dB re 1µPa and frequency. Noise levels may also be quoted as zero-peak, peak-peak or root-mean-square (rms) values. A comprehensive introduction to underwater noise measurement in the context of seismic surveys is provided by OGP (2008).

In relation to offshore energy developments, pile-driving of foundations may generate high source levels and has been widely recognised as a potential concern, in particular for large offshore wind developments where many piles may be installed sequentially over long time scales. Pile-driving also occurs in connection with oil and gas facilities, although the pile diameters are smaller than wind turbine monopiles and typically result in lower source levels and durations.

Seismic surveys generate among the highest source levels of any non-military marine activity; the potential for significant effect in relation to oil and gas and carbon dioxide storage activities is therefore largely related to the anticipated type, extent and duration of seismic survey. Although less commonly used in recent years, explosive cutting of wellheads or decommissioned structures may also produce high intensity impulsive noise.

The range over which noise propagates (and effects may result) varies with water depth, density stratification, substrate and other factors; and is therefore area-specific. Finally, the sensitivity of species such as marine mammals may be influenced by previous experience (i.e. sensitisation/habituation) and by the level of background ambient noise in the area.

## Offshore wind farms

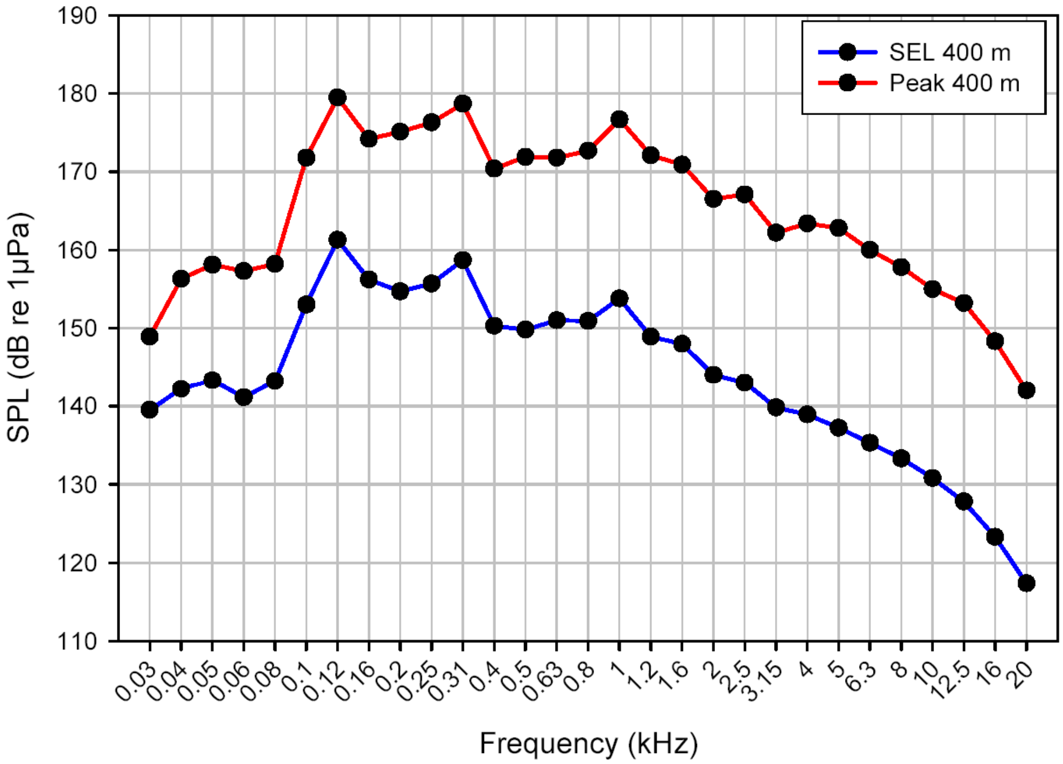
Sources of noise associated with offshore wind farms can be considered to fall into three broad categories: construction, particularly of foundations; operation; and decommissioning. Pile-driving of monopile foundations is the principal source of construction noise, which will be qualitatively similar to pile-driving noise resulting from harbour works, bridge construction and oil and gas platform installation. There is now a reasonable body of evidence for wind farm foundation pile-driving (Nedwell *et al*. 2003, Nedwell & Howell 2004, Madsen *et al*. 2006, Thomsen *et al*. 2006, Nedwell *et al*. 2007), with a conference on assessing and managing the potential impact of marine piling noise within the evolving regulatory framework organised by the Underwater Sound Forum in February 2010. Source levels vary depending on the diameter of the pile and the method of pile-driving (impact or vibropiling). The frequency spectrum ranges from less than 20Hz to more than 20kHz with most energy around 100-200Hz. Sound produced during pile-driving propagates through the air into water, through the water column and, to a lesser degree, through the sediment and from there successively back into the water column. The single pulses are between 50 and 100ms in duration with 30-60 beats per minute. It usually takes between 1–2 hours to drive one pile into the seabed (Thomsen *et al*. 2006).

McKenzie-Maxon (2000) measured a broadband peak sound pressure level of ~205dB re 1µPa at 30m distances from the source during pile-driving at Utgrunden, Sweden; sound exposure levels[21] at 30m varied between 140 and >180dB re 1µPa, with the highest pressure around 250Hz. The foundation type was a monopile with each pile 34m long and 3m in diameter. Sound exposure levels were measured in 1/3 octave bands at different distances from the source (frequency range = 4-16kHz; distances 30, 320, 490 and 750m).

Elmer *et al*. (2006) and Thomsen *et al*. (2006) report measurements of pile-driving noise as peak sound pressure levels and sound exposure levels in 1/3 octave bands from construction of the FINO-1 research platform in the German Bight, North Sea (jacket-pile, diameter 1.5m, sandy bottom, water depth ~30m; 60 beats per minute). The estimated broadband peak source level was $228dB_{0\text{-}p}$ re 1µPa at 1m. Third octave sound levels were recorded as peak sound pressure levels and sound exposure levels at 400m from the source (Figure 5.1). Sound pressure level was highest at the 125Hz centre frequency ($179.5dB_{0\text{-}p}$ re 1µPa at 1m) with additional maxima at 315Hz and 1kHz and considerable pressures above 2kHz. Throughout the frequency spectrum, peak levels were about 20dB higher than the corresponding sound exposure levels.

[21] Sound Exposure Level (SEL) is defined as ten times the logarithm to the base ten of the ratio of a given time integral of squared instantaneous frequency-weighted sound pressure over a stated time interval or event.

Figure 5.1 - Frequency spectrum (third octave band level) of pile-driving pulse noise at FINO 1-platform; red = $dB_{0\text{-}p}$ re 1µPa, blue = $dB_{AE}$ re 1µPa




*Source: Thomsen et al. (2006)*

Nedwell *et al*. (2007) re-analysed pile-driving data from North Hoyle and Scroby Sands, on piles of 4 and 4.2m diameter respectively. The re-analysis includes the effects of sound absorption losses during propagation. Further measurements of pile-driving noise were also reported from Kentish Flats (4.3m diameter piles) and at Burbo Bank and Barrow (4.7m diameter piles). The source levels of these five pile-driving operations varied between 243 and 257dB re 1µPa at 1m, with an average value of 250dB re 1µPa at 1m.

Noise during operation has been measured from single turbines (maximum power 2MW) in Sweden and Denmark and has been found to be of much lower intensity than the noise during construction (reviewed by Madsen *et al*. 2006). The tonal noise from a wind turbine is created by vibrations in the gear-box inside the nacelle, and has both radial and tangential components (see references cited by Madsen *et al*. 2006). The vibrations are coupled to the water column and the seabed through the turbine foundations. Thomsen *et al*. (2006) reported operational noise measured in peak sound pressure levels and equivalent sound pressure levels in third-octave bands at 110m distance from a 1.5MW turbine in Sweden. During operation, the third-octave sound pressure levels ranged between <90 and 142 $dB_{Leq}$ re 1µPa at 1m, with most energy at 50, 160, and 200Hz at wind speeds of 12m/s.

Bailey *et al*. (2010) measured pile-driving noise during the installation of the Beatrice wind farm demonstrator project in the Moray Firth, northeast Scotland, in 2006. Tubular steel piles of 1.8m diameter, were driven into a sandy substrate in a water depth of 45m. Pile-driving noise was measured between distances of 100m (maximum broadband p-p sound level 205dB re 1µPa) and 80km (no longer distinguishable above background noise) from the source. The mean measured sound level at 20km from source was 152dB re 1µPa. Sounds were measured between frequencies of 10Hz-96kHz. Close to source (up to 2km distance), the sound was highly broadband; peak energy occurred at 100Hz-2kHz, but there was substantial energy up to 10kHz. High frequencies were rapidly attenuated with distance from the source, and beyond 4km the majority of the sound consisted of frequencies <5kHz. A sound propagation model was based on the recorded sound measurements, with the best-fit model giving a source level of 250dB re 1µPa at 1m, a spreading loss of 20 and absorption loss coefficient of 0.4dB per km. It was noted that field measurements suggested this model to probably greatly over-estimate the actual source level and sound pressure levels <300m from the source (Bailet *et al*. 2010).

The effective noise propagated from an array of operational turbines is less well characterised, although Ingemansson Technology (2003) reported an increased sound level caused by increases in the number of active wind turbines in a wind farm. Nedwell *et al*. (2007) also reported that the level of noise from operational wind farms was relatively low. The noise could be recognised by the tonal components caused by rotating machinery, and by its decay with distance. Typically, even in the immediate vicinity of the wind turbines, the noise from the wind farm turbines only dominated over the background noise in a few limited bands of frequency. Even within this range, the noise was usually only a few dB above the background noise. In some cases, the tonal noise caused by the wind farms was dominated by the tonal noise from distant shipping. In some cases, such as North Hoyle and Kentish Flats, the level of noise measured within the wind farm was slightly greater, by up to 10dB or more, than that measured outside. However, in other cases, such as Barrow and Scroby Sands, the level of noise measured within the wind farm was actually lower than that measured outside.

In general, Madsen *et al*. (2006) note that for additive effects to take place, the sound source levels of the individual sources must be high enough to propagate to ranges at which interference might occur. The interference pattern created by the signals from several wind turbines will create a complex sound field. The received level in some locations may decrease due to negative interference with signals from different wind turbines. Depending on the geometry of the turbines, the received levels within the wind farm and nearby could increase with increasing number of wind turbines at a constant range from the measurement location, depending on the additive nature of the signals.

Noise will be generated during decommissioning works. While practical examples are lacking, decommissioning of both offshore and onshore elements of a development entails a similar set of activities and associated noise emissions to construction and installation, with the notable exception of an absence of extensive pile-driving activities.

Following removal of the upper sections of wind turbines (shaft, nacelle, blades), the foundations would be removed. Depending on the type of support structure adopted and the nature of fixture to the seabed, the structure would either be lifted out of the seabed and installed on a barge for removal or, in the case of piled foundations, cut at a suitable depth below the seabed, leaving buried piles in place. Such operations are common in the offshore industry. It may be necessary to remove cables, or these may be left in-situ if their long-term residual risk is considered acceptable.

The dismantling of wind farm structures will generate noise from the use of cutting machinery; underwater noise emissions from cutting tools, many of which are operated by divers, are unlikely to result in sufficient levels of noise to cause significant disturbance to marine life. The use of explosive cutting methods may produce high intensity impulsive noise, although such activities have been less frequently used in recent years and would be subject to various levels of activity-specific assessment and regulation similar to those for pile-driving and seismic survey, with alternative cutting methods sought where possible.

## Wave and tidal power

Due to the current state of development, there is limited available information on construction and operational noise associated with wave and tidal power generation. Although several wave power units have deployed (e.g. Wavegen Limpet on Islay; Pelamis off Aguçadoura, Portugal), quantitative noise measurements do not appear to have been made.

The SeaGen 1.2MW tidal energy converter was installed in Strangford Lough in April 2008. Noise associated with SeaGen has been reported by Nedwell & Brooker (2007) and summarised in a biological noise assessment by SMRU (2010). SeaGen produces underwater noise during operation that contains both tonal and broadband components which cover a frequency range similar to the most sensitive hearing range of several marine species. The source level of SeaGen was back-calculated using the field measurements and the sound propagation models; source level (rms, root square mean, see below) was estimated to be 174dB re 1µPa. Although this is lower than some anthropogenic noise sources (e.g. seismic airguns), levels are comparable to a large vessel underway and it is important to highlight that SeaGen produces noise more or less continuously requiring longer exposure times to be taken into account when predicting hearing damage.

Noise measurements of SeaGen carried out with high-precision instruments from a drifting boat showed that it produces narrowband, tonal components as well as broadband noise. The main narrowband components are tones at frequencies of 110-120Hz, 750Hz and 1500Hz. The maximum measured power spectral density at 49m distance was 153dB re 1 µPa/Hz$^2$ and originates from the 750Hz tone. At close ranges, the power spectral density of the broadband noise is generally 40dB below that of the tones. Ambient noise level measurements at slack tide and low sea state appear to be less than 80dB re 1 µPa/Hz$^2$ at frequencies higher than 20-30Hz. These conditions are likely to reflect minimum ambient noise levels in Strangford Lough since noise increases dramatically with wind speed and particularly tidal currents. This becomes obvious when comparing the ambient noise levels (1/3 octave bands) at slack tide to those of a previous impact assessment where measurements were made in conditions with strong tidal currents and slightly higher sea state (Nedwell & Brooker 2007), showing that strong tidal flow can increase ambient noise levels by 15-20dB in a frequency range between 0.1kHz and 10kHz. Increased ambient noise levels as a result of strong tidal flow remain high even at frequencies above 10kHz, which is most likely the result of moving shingles on the seafloor (Nedwell & Brooker 2007).

As with offshore wind farms, the noise emissions associated with decommissioning of wave and tidal developments can be said to be of a similar nature to those generated during construction and installation, with the exception of an absence of extensive pile-driving noise.

## Oil & gas

Noise associated with exploration and production is produced by both continuous and impulse sources and has been discussed, in terms of source characteristics, in previous SEAs and supporting studies (e.g. Hammond *et al*. 2003, 2006). Airgun arrays used for seismic surveys are one of the highest energy anthropogenic sound sources in the sea; broadband source levels of 248-259dB re 1µPa are typical of large arrays (Richardson *et al*. 1995). Seismic survey duration may extend from a period of a few hours, to several weeks. Smaller sources may be used for specific purposes, including high resolution site surveys and Vertical Seismic Profiling (VSP) or borehole seismic in connection with well operations.

Airgun noise is impulsive (i.e. non-continuous), with a typical duty cycle of 0.3% and slow rise time (in comparison to explosive noise). Most of the energy produced by airguns is below 200Hz, although some high frequency noise may also be emitted. Peak frequencies of seismic arrays are generally around 100Hz; source levels at higher frequencies are low relative to that at the peak frequency but are still loud in absolute terms and relative to background levels.

Airgun arrays are directional and the design, dimensions and orientation of arrays have a substantial influence on received noise pressure in the farfield (i.e. at distances where individual gun sources are not distinguished). A correction factor of 20dB has been suggested as "conservative", to compensate for horizontal array effects (i.e. reduction of effective source levels in the horizontal plane relative to the vertical plane: MMS 2004). Nedwell *et al*. (2003) reported axial directivity of noise from a 3D seismic survey (14 gun array, 3,335 cubic inch firing flip-flop) in the northern North Sea of around 10dB; extrapolation of measured sound pressures indicated a source level of 262dB re 1µPa at 1m, higher than expected. This apparent discrepancy was attributed to either non-linear range effects, or to sound trapping in a surface channel. Other reviews have suggested directional correction factors of 10 to >30dB; a value of 15dB has been used in the assessment below.

Nedwell *et al*. (2003) noted a significant degree of scattering of measured sound levels, over a range of 10dB, including non-systematic differences between approach and retreat of the array from the measurement location attributed to spatial or temporal heterogeneities of the sea. Measurement during soft-starts, achieved by gradual increase in the number of airguns being discharged, showed a fairly consistent relationship between the total volume discharged by the array and the resulting level of sound. Frequency-weighting of received sound using an audiogram for harbour porpoise (i.e. emphasising high frequencies) increased the observed scatter in weighted levels, due either to variability in propagation or variability in array characteristics. Nedwell *et al*. (2003) conclude that their results indicate that at the measured range, the effectiveness of the soft start procedure (as perceived by marine mammals) is masked by the random variability in received level.

Sound levels for continuous noise sources are generally defined in terms of root-mean-square (rms) values, broadly equivalent to the average sound pressure over a given time. Although rms values are of little relevance to a periodic impulse sound, such as seismic, virtually all observational data for marine mammal sensitivity to noise (and regulatory criteria, where applicable) are related to rms levels, and conversion from peak-to-peak (p-p) values is therefore necessary.

For an ideal sinusoid, the rms level is 9dB lower than the peak-peak value (Richardson *et al*. 1995). However, seismic and other impulse sources are not ideal sinusoids, and the conversion to rms values is highly dependent on the array duty cycle and integration time. As noted below, the signature of an airgun array also varies with range, due to various factors including multiple reflections and differential frequency propagation, usually resulting in an increase in pulse duration and downward sweep in frequency (or "chirp") – the relationship between p-p and rms levels will therefore also vary. A range of p-p to rms conversion factors have been proposed, although there is very little data in the scientific literature; these range from a theoretical –35dB (based on a theoretical airgun signature, duty cycle 10s) to empirical values of –12 to –18dB for short impulsive sounds without regard to duty cycle (Greeneridge Sciences cited by OGP/IAGC 2004). A value of –18dB has been used in the following assessment.

Dragoset (2000) and Caldwell & Dragoset (2000) provide an introduction to the acoustics of airgun arrays, updated by OGP (2008) *Fundamentals of underwater sound*; and an

*Overview of the Impacts of Anthropogenic Underwater Sound in the Marine Environment*, prepared by OSPAR (2009n).

Available measurements indicate that drilling activities produce mainly low-frequency continuous noise from several separate sources on the drilling unit (Richardson *et al*. 1995, Lawson *et al*. 2001). The primary sources of noise are various types of rotating machinery, with noise transmitted from a semi-submersible rig to the water column through submerged parts of the drilling unit hull, risers and mooring cables, and (to a much smaller extent) across the air-water interface. Under some circumstances, cavitation of thruster propellers is a further appreciable noise source, as may be the use of explosive cutting methods (e.g. for conductor removal).

Measured farfield sound pressure of around 170dB re 1µPa, in the frequency range 10-2,000Hz (Davis *et al.* 1991) is probably typical of drilling from a semi-submersible rig and is of the same order and dominant frequency range as that from large merchant vessels (e.g. McCauley 1994). Drilling noise has also been monitored west of Shetland, in the vicinity of the Foinaven and Schiehallion developments (Swift & Thompson 2000). High and variable levels of noise in three noise bands (1-10Hz, 10-30Hz and 30-100Hz) were initially believed to result from drilling related activity on two semi-submersible rigs operating in the area. However, subsequent analysis showed that noise events and drilling activity did not coincide. In contrast, a direct correlation between the use of thrusters and anchor handlers, during rig moves, and high levels of noise in all three bands was found (Swift & Thompson 2000). Drilling duration may range from a few weeks for an exploration well, to years in the case of a large development programme.

Pipelay operations will result mainly in continuous noise (associated with rotating machinery), with relatively little impulse or percussive noise in comparison to many other marine construction activities. The overall source levels resulting from pipelay operations on the UKCS have not been measured; however, near-field cumulative sound levels associated with pipelay for the Clair project were predicted to be a maximum of 177dB (Lawson *et al*. 2001), with a duration of weeks or months.

Although there is little published data, noise emission from production platforms is qualitatively similar to that from ships, and is produced mainly by rotating machinery (turbines, generators, compressors). The compression required for gas export may be a significant source of noise, but propagation into the water column will be limited. Gas storage developments are predicted to be very similar, in terms of noise, to existing gas production.

A further source of noise associated with all stages of the offshore oil industry is helicopter overflights. There is relatively little quantitative information on the transmission of helicopter airborne noise to the marine environment (Richardson *et al*. 1995). Measurements of an air-sea rescue helicopter over the Shannon estuary (Berrow *et al*. 2002) indicated that due to the large impedance mismatch when sound travels from air to water, the penetration of airborne sound energy from the rotor blades was largely reflected from the surface of the water with only a small fraction of the sound energy coupled into the water.

## Carbon dioxide storage

Noise characteristics of potential carbon dioxide storage developments are likely to be very similar to existing oil and gas developments, particularly in the foreseeable future when re-use of existing infrastructure and reservoirs is a likely development scenario. Development and operational noise sources will include drilling and well operations, and compressor noise (as for gas export). There appear to be no quantitative measurements of operational noise in the vicinity of existing gas production facilities to inform the assessment of carbon dioxide storage developments.

Additional geophysical survey, in particular 4D seismic surveys (i.e. repeated, high resolution 3D surveys), may be necessary for monitoring of storage reservoirs during carbon dioxide storage operations to assess migration and leakage concerns. This may involve the deployment of permanent seabed geophone arrays. The frequency and cumulative acoustic disturbance associated with geophysical monitoring of carbon dioxide storage is not clear, although at Sleipner, time-lapse 3D (4D) seismic data were acquired in 1994, prior to injection, and again in 1999, 2001, 2002, 2004, 2006 and 2008 with around 11 million tonnes of $CO_2$ in the reservoir at the time of the last survey. In addition to the 3D seismic, other monitoring surveys have been deployed, including high resolution 2D seismic (in 2006), seabed gravity (in 2002, 2005 and 2009), seabed controlled source electromagnetics (CSEM) (in 2008), and seabed imaging and bathymetry (in 2006). This suggests that the frequency of survey effort associated with demonstration carbon dioxide storage projects is likely to be high, at least in initial years.

### Gas storage

As with carbon dioxide storage, noise associated with gas storage in depleted reservoirs or salt caverns is predicted to be very similar to the survey, drilling and operational phases of conventional gas exploration and production. Environmental assessment for the proposed Gateway Gas Storage Project (a salt cavern development) indicates drilling a total of 20 wells (total 300 days drilling) using a conventional jack-up drilling rig.

## 5.3.2 Consideration of the evidence

### 5.3.2.1 Marine mammals

It is generally considered that the most sensitive receptors of acoustic disturbance in the marine environment are marine mammals, due to their use of echolocation and vocal communication. Richardson *et al.* (1995) defined a series of zones of noise influence on marine mammals, which have been generally adopted by SMRU commissioned reports for SEAs (Hammond *et al*. 2001, 2002, 2003, 2004, 2005, 2006, 2008); and in relation to which data on marine mammal responses have been exhaustively reviewed (e.g. Richardson *et al*. 1995, Gordon *et al*. 1998, Lawson *et al*. 2001, Simmonds *et al*. 2003, Nowacek *et al*. 2007, Weilgart 2007, Southall *et al*. 2007). Four zones are recognised which will generally occur at increasing sound level: (1) the zone of audibility; (2) zone of responsiveness; (3) zone of masking; (4) zone of hearing loss, discomfort or injury. Potential acute effects include physical damage, noise-induced hearing loss (temporary and permanent threshold shifts) and short-term behavioural responses. Postulated chronic effects (for which evidence is almost entirely absent) include long-term behavioural responses, exclusion, and indirect effects. The most likely physical/physiological effects are generally considered to be shifts in hearing thresholds and auditory damage.

Other effects of sound have been postulated, including triggering the onset of Decompression Sickness (DCS) either through behavioural modification or direct physical activation of microbubbles (Fernandez *et al*. 2005, Jepson *et al*. 2005).

The difficult issue of determining when noise causes biologically significant effects in marine mammals has been addressed by NRC (2005). This clarifies the term *biologically significant* in the context of the US Marine Mammal Protection Act (MMPA), which considers two levels of harassment, level A and level B harassment; in turn specified by National Marine Fisheries Service (NMFS) criteria as noise pressure thresholds of 180 and 160dB re 1µPa rms respectively. These values were derived by the high energy seismic survey panel of experts convened in 1999 to assess noise exposure criteria for marine mammals exposed to seismic pulses. The consensus was that, given the best available data at that time, exposure to airgun pulses with received levels above 180dB re 1µPa (averaged over the pulse duration) was "likely to have the potential to cause serious behavioural, physiological, and hearing effects." The panel noted the potential for ±10dB variability around the 180dB re 1µPa level, depending on species, and that more information was needed.

More recent threshold values for marine mammals were provided by NOAA as part of a ruling on a permit application for a military sonar exercise (NOAA 2006). This provides an acoustic energy threshold for temporary hearing loss, referred to as Temporary Threshold Shift (TTS), of 195dB re $1µPa^2s$. Being energy based, this takes account of the cumulative duration of exposure as well as for level. These thresholds were based on measurements made by Schlundt *et al*. (2000) of TTS induced in bottlenose dolphins and beluga after exposure to an intense 1 second narrow band tone. A threshold for Permanent Threshold Shift (PTS) of 215dB re $1µPa^2s$ was also specified by NOAA (2006) based on the typical values for the additional dB above TTS required to induce PTS in experiments with terrestrial mammals. SMRU (2007) noted that the best acoustic sensitivity of harbour porpoise is higher than that of bottlenose dolphins and beluga whales, albeit at high frequencies, and porpoises may be more vulnerable to TTS than the species tested by Schlundt *et al*. (2000).

The NMFS has continued to use a "do not exceed" exposure criterion of 180dB re 1µPa for mysticetes and (recently) all odontocetes exposed to sequences of pulsed sounds, and a 190dB re 1µPa criterion for pinnipeds exposed to such sounds. These criteria were also used in a study of potential mitigation methods carried out by SMRU (2007). Higher thresholds have been used in the U.S. for single pulses such as explosions used in naval vessel-shock trials. Behavioural disturbance criteria for pulsed sounds have typically been set at an SPL value of 160dB re 1µPa, based mainly on the earlier observations of mysticetes reacting to airgun pulses. However, the relevance of the 160dB re 1µPa disturbance criterion for odontocetes and pinnipeds exposed to pulsed sounds is not at all well-established. Although these criteria have been applied in various regulatory actions (principally in the U.S.) for more than a decade, they remain controversial, have not been applied consistently in the U.S., and have not been widely accepted elsewhere (Southall *et al*. 2007). Similarly, although the MMPA is intended to be precautionary in that it is intended that the burden of proof is placed "not on conservationists, but on any activities with the potential to injure or disrupt marine mammals" (McCarthy 2007), the MMPA has been the subject of criticism on various levels (e.g. McCarthy 2007, Horowitz & Jasny 2007).

NRC (2005) describes a conceptual model framework that identifies the different stages required to move from marine mammal behaviour to a determination of population effects of behavioural change. The proposed model first characterises an acoustic signal, the resulting behavioural change, and a determination of the "life function" or activity affected. It then describes the resulting change in vital rate, such as life span, and finally suggests population effects and effects on following generations. A series of recommendations were made to assist in further development and implementation of the model.

A review of marine mammal responses to anthropogenic noise by Nowacek *et al*. (2007), although comprehensive, was limited to studies in which noise exposure levels of the subject animals were quantified. Nowacek *et al*. (2007) are of the view that this information is critical to interpretation of animals' responses (in terms of the dose-response relationship). Weilgart (2007) disagreed, pointing out the range of other factors which may be more important (e.g. auditory perception, masking, cumulative effects and long-term population effects). Weilgart's (2007) review focused, in part, on strandings and mortalities of beaked whales in which received sound levels were typically not high enough to cause hearing damage, implying that the auditory system may not always be the best indicator for noise impacts; in addition, mechanisms of population effect and management implications were reviewed.

Southall *et al*. (2007) have proposed injury criteria composed both of unweighted peak pressures and M-weighted sound exposure levels which are an expression for the total energy of a sound wave. The M-weighted function also takes the known or derived species-specific audiogram into account. For three functional hearing categories of cetaceans, proposed injury criteria are an unweighted 230dB re 1µPa peak-to-peak for all types of sounds and an M-weighted sound exposure level of 198 or 215dB re 1µPa$^2$·s for pulsed and non-pulsed sounds. For pinnipeds, the respective criteria are 218dB 1µPa peak-to-peak and 186 (multiple pulse) or 203 (non-pulse) re 1µPa$^2$·s (M-weighted). These proposals are based on the level at which a single exposure is estimated to cause onset of permanent hearing loss (parameterised as PTS) by extrapolating from available data for TTS.

Southall *et al*. (2007) concluded that developing behavioural criteria was challenging, in part due to the difficulty in distinguishing a significant behavioural response from an insignificant, momentary alteration in behaviour. Consequently, they recommended that onset of significant behavioural disturbance resulting from a single pulse is taken to occur at the lowest level of noise exposure that has a measurable transient effect on hearing (i.e. TTS-onset). For multiple pulse and non-pulse (i.e. continuous) sources, they were unable to derive explicit and broadly applicable numerical threshold values for delineating behavioural disturbance. A scoring paradigm was used to numerically rank, in terms of severity, behavioural responses observed in either field or laboratory conditions. However, due to various statistical and methodological problems, much of this data was not considered to provide sufficient scientific credence for establishment of exposure criteria. Southall *et al*. (2007) noted the importance of contextual variables in determining behavioural response; together with the presence or absence of acoustic similarities between the anthropogenic sound and biologically relevant natural signals (e.g. calls of conspecifics, predators, prey). They suggest that a context-based approach to deriving noise exposure criteria for behavioural responses will be necessary.

SMRU (2007) considered work by Lucke *et al*. (2007), at that time unpublished, to measure TTS in harbour porpoise to be “fundamentally important”. A specific aim of this study was to assess the likely impact of low-frequency impulsive noise from pile-driving on harbour porpoise hearing. The hearing sensitivity of a captive harbour porpoise was measured at three frequencies: 4, 32 and 100kHz, using auditory brainstem response techniques before and after exposure to a single pulse from a 20 cubic inch airgun. The airgun generated a strong impulsive signal with most energy content below 500Hz, acoustically similar to pile-driving noise. TTS was proven to occur at 4kHz after exposure to a single airgun pulse with received pressure levels above 184dB re 1µPa p-p, and a received energy of 165dB re 1µPa$^2$·s. Threshold levels were also elevated at 32kHz but did not exceed the researcher’s conservative TTS criterion. There were no indications of a threshold shift at 100kHz. Recovery of full sensitivity at 4kHz took more than a day to occur. Lucke *et al*. (2007) noted that the study animal had an elevated hearing threshold compared to published audiograms which may have been due to auditory masking in the relatively noisy test environments or electrical “masking” in their equipment. They suggest therefore that the measured effects should be considered masked temporary threshold shifts (MTTS). MTTS is detected at higher exposure levels than TTS, thus SMRU (2007) consider that these results overestimate the exposure required to induce TTS.

## Offshore wind farms – construction and operation

Empirical studies of porpoise behaviour during construction of offshore wind farms at Horns Rev (North Sea) and Nysted (Baltic) were reported by Tougaard *et al*. (2003a, b, 2005, 2009a) and Brandt *et al*. (2009).

At Horns Rev, acoustic activity of porpoises – indicated by the interval between acoustic encounters (minimum separation 10 min) – decreased shortly after each pile-driving event and returned to baseline conditions after 3-4h. This effect was not only observed in the direct vicinity of the construction site but also at monitoring stations approximately 15km away, suggesting that porpoises either decreased their acoustic activity or left the area during construction activity (Tougaard *et al*. 2003a, 2009a). It was also found that densities of porpoises during construction were significantly lower in the entire area. Behavioural observations showed that during pile-driving, porpoises exhibited relatively more directional swimming patterns compared to observations obtained on days without construction where relatively more non-directional swimming patterns were observed. This effect was found at distances of more than 11km, perhaps also 15km from the construction site (Tougaard *et al*. 2003a). Thomsen *et al*. (2006) note that these distances rather represent the radius of observations than the zone of responsiveness, as no observations or acoustic logging happened at greater distances. These reaction distances might therefore be viewed as the minimum zone of responsiveness.

Further monitoring studies using passive acoustic monitoring devices (T-PODs) to record porpoise echolocation clicks during installation of Horns Rev II, involving 92 monopile foundations, were reported by Brandt *et al*. (2009). The percentage of porpoise positive ten minutes per hour (PPM/day) decreased from the baseline period to the piling period at the POD-positions close to the construction site, while no effect or even a small increase was found at further distances. At a finer temporal scale, analysing porpoise positive ten minutes per hour (PPM/H), a negative effect of piling was also observed at close proximity but no effect or a slight increase was found at the furthest distances.

Analysis of the duration of waiting times between porpoise encounters offered the best method to define the duration of an effect and suggested a sudden decrease in the length of effect at POD-positions south of the reef at distances of at least about 10km. This sudden decrease was attributed to differences in sound transmission at different water depths, as sound was probably attenuated to a large degree in the shallow waters of the reef.

The relatively long recovery time observed near the construction site was almost as long as the time between piling events, and consequently porpoise activity and possibly density was reduced near the construction site over the entire five months that pile-driving took place. However, based on the study results, porpoise density was expected to recover in the area within one to two days after construction was finished.

The change in acoustic activity is considered most likely related to changes in porpoise density rather than to changes in acoustic behaviour; the animals had probably left the impact area during and following pile-driving. The temporal scale of the effect was much longer than what was found during studies on pile-driving effects on porpoises at Horn Rev I, while the spatial scale over which it was observed was considerably smaller.

Similar effects on acoustic activity were found during the construction (combination of pile-driving and vibropiling) of the Nysted offshore wind farm. Porpoise abundance also reportedly declined after construction with no return to baseline levels (Tougaard *et al*. 2005). However, since absolute abundance of porpoises was low from the start, these latter results are difficult to interpret (Tougaard *et al*. 2005). In addition, in both areas, pingers and seal-scarers were used before pile-driving as a mitigation measure to deter porpoises and seals from the vicinity of the construction sites, suggesting the possibility that effects were caused by a combination of the mitigation measures, along with the pile-driving (although decrease of acoustic activity was also found during pile-driving in a harbour close to the Nysted site, with no mitigation measures employed).

Thompson *et al*. (2010) used passive acoustic monitoring to assess whether cetaceans responded to pile-driving noise during the installation of two 5MW offshore wind turbines in the Moray Firth off northeast Scotland in 2006. Pile-driving was of approximately 2 hours duration for each of the 8 piles installed over five separate days, with hammer strikes occurring about once every second during active piling. A maximum broadband p-p sound level of 205dB re 1 µPa was recorded at 100m from source. Monitoring was carried out at both the turbine site and a control site in 2005, 2006 and 2007. Harbour porpoises occurred regularly around the turbine site in all years, but there was some evidence that porpoises did respond to disturbance from installation activities. In July and August 2006, the period in which the main installation work was carried out, porpoises were detected for significantly fewer hours per day when compared with a similar period in 2007, whereas similar comparisons for the adjacent months of June, September and October did not show significant differences in porpoise detections. Analysis of a different variable, the waiting time until the next porpoise detection, showed variable results, with waiting times within the typical distribution for the piling of the first sub-structure, and an extreme outlier of zero porpoise detections during piling of the second structure. Despite attempts at complementary visual monitoring, it could not be determined if these differences in acoustic detections were due to different numbers of animals within the sample area, or from changes in the echolocation behaviour of animals within the sample area (Thompson *et al*. 2010).

Using satellite telemetry, Tougaard *et al*. (2003b) also showed that harbour seals transited Horns Rev during pile-driving. However, at Nysted, Edren *et al*. (2004) found a 10–60% decrease in the number of hauled-out harbour seals on a sandbank 10km away from the construction during days of pile-driving activity compared to days with no pile-driving. However, this effect was of short duration, since the overall number of seals remained the same during the whole construction phase.

Madsen *et al*. (2006) used the impact zones of Richardson *et al*. (1995) as defined above (Zones 1 to 4) for assessment of the possible impact of noise generated from constructing and operating offshore wind turbines. Taking into account the problems in comparing effects thresholds (in dB rms) with transient noises, and non-geometric attenuation due to sound-scattering and refraction processes, the calculated ranges clearly indicated that pile-driving sounds are audible to the four species of marine mammals considered (bottlenose dolphin, harbour porpoise, northern right whale and harbour seal) at very long ranges of more than 100km, and possibly up to more than a thousand kilometres. In the light of limited behavioural data (see above), Madsen *et al*. (2006) also concluded that pile-driving operations have the potential to cause disruption of normal behaviour in marine mammals at ranges of many kilometres. However, maximal detection distances by bottlenose dolphin and harbour porpoise of operating turbines were predicted to be somewhere between 200 and 500m; thus, the impact on small toothed whales of known noise levels and spectral properties from operating wind turbines is likely to be minor. The zone of masking for seals in the case of turbine noise was also assumed to be small for all practical purposes.

David (2006) assessed likely sensitivity of bottlenose dolphins to pile-driving noise, concluding that at 9kHz, masking of strong vocalisations could potentially occur within 10–15km and weak vocalisations up to approximately 40km. The potential masking radius was predicted to reduce with increasing frequency to 6km at 50kHz and 1.2km at 115kHz. The impacts of masking are expected to be limited by the intermittent nature of pile driver noise, the dolphin's directional hearing, their ability to adjust vocalisation amplitude and frequency, and the structured content of their signals.

Attenuation of modelled pile-driving noise at different distances from the source have been compared to audiograms of harbour porpoise and harbour seals and to ambient noise levels by Thomsen *et al*. (2006), although with considerable difficulties in consistency of measurement units, time integration and pulse modification during propagation. However, it was concluded that this theoretical assessment indicated that pile-driving noise, under realistic North Sea conditions, would be audible to harbour porpoises and seals over distances of at least 80km. Thomsen *et al*. (2006) also applied the dBht value (ht = hearing threshold) for behavioural reactions postulated by Nedwell *et al*. (2003) (sound pressure levels 75 and 90dB above hearing threshold should lead to mild and strong behavioural reactions in cetaceans); suggesting that mild behavioural reactions (e.g. subtle change in swimming direction) in harbour porpoises might occur between 7 and 20km distance from the pile-driving source. Thomsen *et al*. (2006) noted that this analysis includes considerable speculation and uncertainty, including derivation of dBht values from studies on humans and fish, and problems in calculating the required rms values for transient pulse noises.

Nedwell *et al.* (2007) developed a simplified, two-zone model of effect from pile-driving noise based on measurements from North Hoyle, Scroby Sands, Kentish Flats, Barrow and Burbo Bank. A Noise Injury Zone, bounded by the 130dBht contour, defines the area in which hearing injury can occur, and, in addition, the areas in which lethal and physical injury could occur, since the ranges at which these will occur are much less than those for hearing injury. This area typically extends to a few hundred metres from pile-driving. The Behavioural Effect Zone, bounded by the 90dBht level contour, typically extends from a kilometre up to perhaps 10km or more. Within this area, the modelling suggested that species were likely to display a strong avoidance reaction to the noise.

Koschinski *et al*. (2003) reported behavioural responses in harbour porpoises and harbour seals to playbacks of simulated offshore turbine sounds at ranges of 200-300m, indicated by theodolite tracking and recordings of acoustic activity (porpoises). However, they did not model or measure received sound pressure levels and Madsen *et al*. (2006) discussed other potential pitfalls of the study such as the introduction of playback artefacts. Lucke *et al*. (2007) found that simulated offshore wind turbine noise (1.5MW) was only able to mask the detection of low frequencies up to 2kHz by a harbour porpoise. The received level necessary for masking was 128dB re 1μPa. This would result in a masking zone of 20m around smaller turbines. These conclusions are only valid for relatively small turbines; it is likely that bigger turbines will be noisier with the sound most likely shifted to lower frequencies.

Wind turbine operational noise has two main sources: air flow and turbulence noise from the wings and machinery noise (Tougaard *et al*. 2009b). The machinery noise stems mainly from the gear box and generator located in the nacelle. Machinery noise is the main contributor to underwater noise; vibrations from the machinery are transmitted from the nacelle through the steel tower into the foundation and radiated into the water column and seabed. Airborne noise is produced mainly by the blades and is almost completely reflected from the water surface, therefore does not contribute significantly to the underwater noise level. The noise from gearbox and generator contain strong spectral peaks, which are generated from the repetitive contact between gear teeth. Since the turbines are maintained at a constant rate of revolution independent of wind speed, only the height of the peaks and not their location on the frequency axis is affected by increased wind speed.

Underwater noise was recorded by Tougaard *et al.* (2009b) from three different types of wind turbines in Denmark and Sweden (Middelgrunden, Vindeby, and Bockstigen-Valar) during normal operation. Wind turbine noise was only measurable above ambient noise at frequencies below 500 Hz. Total sound pressure level was in the range 109–127 dB re 1 µPa rms, measured at distances between 14 and 20m from the foundations. The 1/3-octave noise levels were compared with audiograms of harbour seals and harbour porpoises. Maximum 1/3-octave levels were in the range 106–126 dB re 1 µPa rms. Maximum range of audibility was estimated under two extreme assumptions on transmission loss (3 and 9 dB per doubling of distance, respectively). Audibility was low for harbour porpoises extending 20–70m from the foundation, whereas audibility for harbour seals ranged from less than 100m to several kilometres. Behavioural reactions of porpoises to the noise appear unlikely except if they were very close to the foundations. However, behavioural reactions from seals cannot be excluded up to distances of a few hundred meters. It was unlikely that the noise reached dangerous levels at any distance from the turbines and the noise was considered incapable of masking acoustic communication by seals and porpoises.

Another factor that has to be considered is the tonal content of the noise emitted by turbines in operation (Dewi 2004, Wahlberg & Westerberg 2005, Madsen *et al*. 2006). In larger turbines, narrow tones with clearly defined peaks might considerably exceed background noise levels, and the zone of audibility of these rather discrete frequencies might be much larger than for relatively broadband noise (Dewi 2004). For example, Dewi (2004) simulated sound emissions of a 2.5MW turbine based on their measurements of a 1.5MW offshore turbine in operation. They estimated that the sound pressure levels of the simulated 2.5MW turbine would be between <10 to 30dB higher compared to the 1.5MW turbine, depending on frequency. Nedwell *et al*'s (2007) recent results on comparably low operational noise levels from wind turbines up to 3MW do not necessarily contradict these simulations as their ambient noise levels were relatively high.

## Seismic noise

Until recently, research effort in the effects of anthropogenic noise on marine mammals has concentrated on seismic exploration, with a particular focus on baleen whales. However, airgun arrays also produce significant energy over the frequency range in which behavioural audiograms suggest that odontocetes are most sensitive. Behavioural responses to anthropogenic noise have generally been studied by visual or acoustic monitoring of abundance. Visual monitoring of cetaceans during seismic surveys has been carried out for several years throughout the UKCS. Statistical analysis of 1,652 sightings during 201 seismic surveys, representing 44,451 hours of observational effort, was reported by Stone (2003) and Stone & Tasker (2006). Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., all small odontocetes combined and all cetaceans combined were found to be significantly lower during periods of shooting on surveys with large airgun arrays. In general, small odontocetes showed the strongest avoidance response to seismic activity, with baleen whales and killer whales showing some localised avoidance, pilot whales showing few effects and sperm whales showing no observed effects. A recent programme of marine mammal observation off Angola concluded that the encounter rate (sightings/h) of humpback and sperm whales did not differ significantly according to airgun operational status (Weir 2008). The mean distance to humpback and sperm whale sightings was greater during full-array operations than during guns off, but this difference was not significant. Atlantic spotted dolphin encounters occurred at a significantly greater distance from the airgun array during full-array operations than during guns off. Positive-approach behaviour by Atlantic spotted dolphins (n = 9) occurred only during guns off periods. There was no evidence for prolonged or large-scale displacement of each species from the region during the 10 month survey duration. Sperm whale sightings showed a significant increase during the survey, while Atlantic spotted dolphin encounters occurred at similar rates. A decreased occurrence of humpback whale sightings corresponded with established seasonal migration out of the survey area. Contrary to expectation based on perceived sensitivity, Atlantic spotted dolphins exhibited the most marked overt response to airgun sound of the three cetacean species examined.

Miller *et al*. (2009) used at-sea experiments to study the effects of airguns on the foraging behaviour of sperm whales in the Gulf of Mexico. Acoustic exposure and behaviour of eight sperm whales were recorded with acoustic and movement-recording tags before, during and after five separate 1-2h controlled sound exposures of industry-provided airgun arrays. None of the whales changed behavioural state following the start of ramp-up at distances of 7-13km, or full array exposures at 1-13km. Direction of movement was random with respect to the airguns, but correlated with direction of movement just prior to the start of exposure, indicating that the tested whales did not show horizontal avoidance of the airguns. Oscillations in pitch generated by swimming movements during foraging dives (providing an index of relative locomotion effort) were on average 6% lower during exposure than during the immediately following post-exposure period, with all foraging whales exhibiting less pitching ($p=0.014$). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure but given natural variation in buzz rates and the small numbers of whales, this effect was not statistically significant ($p=0.141$). Though additional studies are strongly recommended, these initial results indicate that sperm whales in the highly exposed Gulf of Mexico habitat do not exhibit avoidance reactions to airguns, but suggest they are affected at ranges well beyond those currently regulated due to more subtle effects on their foraging behaviour.

## Oil and gas drilling and production, carbon dioxide storage, gas storage

There have been far fewer studies of marine mammal responses to continuous drilling noise (Richardson *et al*. 1995), with most available data relating to baleen whales. Sorensen *et al*. (1984) observed distributions of a similar range of small cetacean species to that found around the UK (including common, Risso's, bottlenose and *Stenella* dolphins), in the vicinity of drilling activities off New Jersey, and reported no difference in sightings per unit effort with and without the presence of rigs.

As noted above, the acoustic sources and characteristics of carbon dioxide and gas storage are comparable to those of conventional hydrocarbon exploration and production, and effects on marine mammals are likely to be similar in nature and incremental in terms of net overall effect (i.e. it is likely that carbon dioxide and gas storage activities will partially offset reduction in conventional E&P).

## Wave and tidal power

Potential biological effects of noise produced by the SeaGen 1.2MW tidal energy converter in Strangford Lough were assessed by SMRU (2010). It was predicted that under low ambient noise conditions, noise from SeaGen would be audible to marine mammals over relatively large areas; predictions suggest that seals and porpoise would detect SeaGen at ranges of 63km and 13km respectively. However, these low ambient noise conditions are likely to only be encountered during slack tide when the turbine is not producing noise. In conditions with high tidal flow Seagen would only be audible up to about 1.4km. Throughout normal SeaGen operation, the actual range is likely to be closer to the lower estimate. However, without detailed data describing how both ambient noise levels and SeaGen noise vary over the tidal cycle it is difficult to say this with absolute certainty.

Two models were developed to evaluate the potential behavioural effects of the different components of the noise (tonal peaks and broadband) on marine mammals. It was predicted that noise from SeaGen has the potential to elicit behavioural avoidance responses in porpoise and both seal species. The initial model suggested that behavioural responses could be predicted from the frequency band containing the tonal peaks up to 77m from SeaGen for porpoise and up to 150m for seals. The second model based on broadband noise levels predicted much larger behavioural response zones; porpoises and seals were predicted to show behavioural responses up to 1-6.5km (depending on the same ambient noise considerations as for prediction of zones of audibility, above) and 610m from SeaGen respectively. These predictions must be viewed in the context of the observed behaviour of marine mammals around the turbine. Land-based observations, telemetry derived data on seal movements and TPOD detections of harbour porpoise echolocation all indicate that seals and porpoises are regularly occurring within the distances within which they were predicted to display behavioural avoidance responses.

The evaluation of hearing damage in marine mammals showed that short-term exposure to SeaGen noise is very unlikely to cause non-auditory tissue damage. It was predicted that temporary damage to the auditory system of seals could occur if animals remain within 85, 372 or 720m of SeaGen for periods of 1, 8, or 24 hours respectively. For porpoises, temporary damage was predicted at ranges of 4, 14 or 27m for the same periods. This is only likely to be a concern if there is an important foraging location close to SeaGen or breeding male harbour seals set up breeding territories close to SeaGen resulting in them maintaining a location for periods of several days.

#### 5.3.2.2 Other receptors

In addition to marine mammals, effects of noise are possible in other species. Many species of fish are highly sensitive to sound and vibration (reviewed by MMS 2004), although the mechanisms of hearing and detection of vibration vary widely. Wahlberg & Westerberg (2005) reviewed and assessed the impact of underwater noise from wind turbines on fish. They concluded that operational turbine noise could potentially affect fish behaviour at ranges of several kilometres, but they also pointed out that available data on sound production and fish behaviour is too rudimentary to clarify if noise from wind farms is actually causing any effects on fish. The wind turbine noise is of too low intensity to cause permanent or transient hearing impairment in fishes, even at ranges of a few metres from the wind turbines (Wahlberg & Westerberg 2005).

Hastings & Popper (2005) provide an overview of results from five experimental studies of pile-driving on fish; four in the US and one in the UK. Species investigated included the shiner surfperch (*Cymatogaster aggregata*), Sacramento blackfish (*Orthodon microlepidotus*), brown trout (*Salmo trutta*), steelhead (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*) and northern anchovy (*Engraulis mordax*). Behavioural observations were undertaken on caged fish held at different distances from piling. However, experimental conditions were in most cases difficult to control and the conclusions drawn were viewed by Hastings & Popper (2005) as being rather limited. For example, Nedwell *et al*. (2003) filmed brown trout in cages positioned at different distances from vibro and impact pile-driving operations in Southampton harbour. ‘Startle-reactions’ and ‘Fish activity level’ observations revealed no evidence that trout reacted to impact piling at 400m, nor to vibropiling at close ranges (<50m; source level of impact pile-driving, 194dB p-p re 1µPa). However, Hastings & Popper (2005) critically review some aspects of this study (e.g. control observations were performed on the same animals as tested; not all of the cage could be observed).

Hastings & Popper (2005) also review reports in the grey literature that pile-driving kills fishes of several different species if they are sufficiently close to the source; for example, mortalities observed after pile-driving in the course of the San Francisco-Oakland Bay Bridge Demonstration Project. Sound levels at a distance of 100-200m from the pile were between

160 and 196dB rms re 1µPa (Caltrans 2001). The zone of direct mortality was about 10-12m from piling, the zone of delayed mortality was assumed to extend out at least to 150m to *ca*. 1,000m from piling. Tests on caged fish revealed greater effects when using a larger hammer (1,700kJ, as compared with 500kJ). The greatest effects were observed in a range of 30m from piling. Preliminary results indicated increasing damage rates to the fish together with extended exposure times (Caltrans 2001). However, reviewing these and other studies, Hastings & Popper (2005) consider that the results provided are highly equivocal, noting that no clear correlation between the level of sound exposure and the degree of damage could be determined and criticising aspects of the pathological and histological analysis.

Thomsen *et al*. (2006) also considered wind farm (construction and operation) noise effects on fish, reviewing the general aspects of fish hearing and carrying out species-specific assessments for dab, Atlantic salmon, cod and herring. Dab and salmon are considered relatively insensitive and detect particle motion rather than sound pressure. Cod have a gas-filled swim bladder and are able to detect both particle motion and sound pressure; while clupeids including herring have structural specialisations to the swim bladder and inner ear resulting in high sensitivity, particularly at higher frequencies (>1kHz). Most of the energy of pile-driving noise falling in the hearing range of the assessed species exceeds background noise over a range of at least 80km. For dab and salmon sound pressure levels to 80km distance are above the hearing threshold and/or ambient noise at certain frequencies, although the more appropriate parameter would be particle motion and not sound pressure. It has to be also noted that for demersal fishes such as dab, the characteristics of the received sounds will be much different from those swimming in the water column as bottom-scattering and other effects will alter the pulse-sound significantly. Another important aspect is the sound propagation through the sediment and its probable detection by demersal species such as dab (for a description of pathways of pile-driving noise see Nedwell *et al*. 2003).

A recent COWRIE study performed experimental research on effects of pile-driving noise on cod and sole, with the intention of improving the understanding of behavioural responses of commercially important fish to pile-driving operations in the marine environment (Mueller-Blenkle *et al*. 2010). Pile-driving noise was played back to cod and sole held in two large pens located in a quiet bay on the west coast of Scotland, with received SPL and particle motion measurements taken and the movements of fish analysed using a novel acoustic tracking system. There was a significant movement response to the pile-driving stimulus in both cod and sole at relatively low received SPLs (sole: 144-156dB re 1µPa peak; cod: 140-161dB re 1 µPa peak, particle motion between $6.51 \times 10^{-3}$ and $8.62 \times 10^{-4} m/s^2$ peak). Sole showed a significant increase in swimming speed during the playback period compared to before and after playback. Cod exhibited a similar reaction, yet results were not significant, although cod did show a significant freezing response at onset and cessation of playback. There were indications of directional movements away from the sound source in both species. Some observations suggested a level of habituation to the noise source. As seen in previous studies, a high variability in behavioural reactions across individuals was observed, along with a decrease of response with multiple exposures.

Mueller-Blenkle *et al*. (2010) describe that their results further imply a relatively large zone of behavioural response to pile-driving sounds in marine fish, although note that it is difficult to explain the nature and biological significance of these responses. Many responses observed suggest avoidance reactions, although it was noted that in a wild marine environment a wider demographic of animals will be present, and there will be other ecological drivers (e.g. food, reproduction) at play, both of which will influence the nature of reactions.

With regard to operational noise, nearfield acoustic effects need to be taken into consideration, since in close proximity to the turbine, the particle motion component will be much higher for the respective sound pressure values. This is especially important for fish species that are primarily sensitive to particle motion, e.g. dab and salmon. Thomsen *et al*. (2006) estimate that the nearfield at 16Hz will extend to about 47m, and to about 14m at 50Hz; suggesting that in a range of probably <100m around the turbines, hearing generalists that are primarily sensitive to particle motion will perceive much higher relevant impulses. Thomsen *et al*. (2006) conclude that dab and salmon might detect operational noise of a wind turbine at relatively short distances of no more than 1km. The zone of audibility for cod and herring will be larger, perhaps up to 4-5km from the source. However, these values have to be viewed as preliminary.

Behavioural responses (Wardle *et al*. 2001) and effects on fishing success ("catchability") have been demonstrated following seismic survey (Pearson *et al*. 1992, Skalski *et al*. 1992, Engås *et al*. 1993). MMS (2004) consider that the "consensus is that seismic airgun shooting can result in reduced trawl and longline catch of several species when the animals receive levels as low as 160dB". However, no associations of lower-intensity, continuous drilling noise and fishing success have been demonstrated, and large numbers of fish are typically observed around North Sea and other production platforms.

Spawning and nursery grounds for most species are dynamic features and are rarely fixed in one location from year to year. Therefore, while some species have similar patterns of distribution from one season to the next, others show greater variability (Coull *et al*. 1998). Discrete banks of clean gravel found in the southern North Sea, Moray Firth and other UK coastal waters are used by spawning herring. The sub-populations of North Sea (and west coast) herring spawn at different times and localised groups of herring can be found spawning in almost every month (Rogers & Stocks 2001). The potential for seismic survey and piling activities to disturb or disrupt spawning shoals of herring (and other species) is recognised and mitigated through the activity consenting processes (PON14 or FEPA licence). Guidance on sensitive periods for fish spawning (based on advice from FRS and CEFAS) is available to developers, and may be incorporated into licence conditions, including prohibitions of some activities in certain months.

Direct effects on seabirds because of seismic exploration noise could occur through physical damage, or through disturbance of normal behaviour. Diving seabirds (e.g. auks) may be most at risk of physical damage. The physical vulnerability of seabirds to sound pressure is unknown, although McCauley (1994) inferred from vocalisation ranges that the threshold of perception for low frequency seismic in little penguins would be high, hence only at short ranges would penguins be adversely affected. Mortality of seabirds has not been observed during extensive seismic operations in the North Sea and elsewhere. A study has investigated seabird abundance in Hudson Strait (Atlantic seaboard of Canada) during seismic surveys over three years (Stemp 1985). Comparing periods of shooting and non-shooting, no significant difference was observed in abundance of fulmar, kittiwake and thick-billed murre (Brünnich's guillemot). It is therefore considered unlikely that offshore seismic noise will result in significant injury or behavioural disturbance to seabirds.

The effects of pile-driving noise from offshore wind farm construction, which is more likely to expose inshore bird populations, including wintering seaduck and divers, have not been characterised although behavioural disturbance effects are more likely than physical injury. Baerwald *et al*. (2008) attributed high mortality in bats at onshore wind energy facilities to pulmonary barotrauma (caused by decompression near moving turbine blades) and suggested that the respiratory anatomy of birds is less susceptible to barotrauma than that of mammals; it is uncertain whether similar considerations would apply to exposure to high levels of impulse sound in water. Consideration of disturbance effects in birds such as common scoter (e.g. Kaiser *et al*. 2006) have identified sensitivity to moving vessels (i.e. visual disturbance) rather than acoustic effects, and it seems likely that displacement due to visual cues will be the dominant process in birds. In the case of piscivorous species such as divers and auks, indirect effects through acoustic disturbance of prey species could be postulated, although such effects are likely to be local and not significant at a population scale.

Sharks and turtles are not thought to be sensitive to acoustic disturbance (in comparison to marine mammals and teleost fish, e.g. McCauley 1994) and occur at very low densities in the UKCS. Although the biology of basking sharks is not well understood, including the location of breeding areas, the known distribution in UK waters is concentrated in "hotspots" in western coastal waters (satellite tracking studies are ongoing); turtles are essentially vagrants in UK waters. The risk of significant disturbance to these species is therefore considered to be negligible.

Planktonic and benthic invertebrates generally do not have gas-filled body cavities and are considered less susceptible to acute trauma and behavioural disturbance resulting from noise and vibration. Cephalopods, with a well-developed nervous system and complex behavioural responses, are a possible exception. Hearing abilities at >400Hz, through the use of auditory brainstem responses (ABR), have been demonstrated in two species of cephalopod, *Octopus vulgaris* and *Sepia lessoniana*, at frequencies between 400-1000Hz and 400-1500Hz respectively (Hu *et al*. 2009). For both species, maximum sensitivity (in terms of a minimum threshold SPL of 120-130dB re 1µPa) was at 600Hz. Also using an ABR method, Lovell *et al*. (2005) demonstrated that the crustacean *Palaemon serratus* is responsive to sounds ranging in frequency from 100 to 3000Hz with maximum sensitivity (in terms of a minimum threshold SPL of 100-110dB re 1µPa) observed at 100Hz, suggesting peak sensitivity to potentially be at frequencies <100Hz.

In both studies, hearing abilities were attributed to the statocysts (balance organs) (Hu *et al*. 2009, Lovell *et al*. 2005). However, both crustaceans and the vast majority of cephalopods lack the gas-filled chambers to act as resonating structures which are present in fish and mammals. Their hearing ability has been described as comparable to those of fish without a mechanically coupled gas bladder to the inner ear (Hu *et al*. 2009, Lovell *et al*. 2005).

## Operational airborne noise

Airborne operational noise from wind energy developments in the terrestrial environment has received considerable attention in relation to issues of disturbance to nearby residents, particularly where turbines are located in rural areas with low ambient noise levels. Noise assessment criteria (*ETSU-R-1997*[22]) provide guidance on the assessment and mitigation of such effects from wind farm developments. Noise emissions from turbines are dominated by aerodynamic noise caused by the interaction of the turbine blade with the turbulence produced both adjacent to it and in its near wake. This is of low frequency in nature and, when weighted in accordance with the sensitivity of human hearing, peak sound pressure levels are between approximately 500-1000Hz at 30-35dB(A) at 305m, based on a single 2.5MW turbine (Kamperman & James 2008). The majority of this aerodynamic noise is below the region of best sensitivity of hearing in birds which is 2-4kHz (Dooling 2002).

Mostly, the character of aerodynamic noise is broad band, i.e. it does not contain a distinguishable note or tone. The dominant character of aerodynamic noise is perceived as

[22] ETSU-R-97: The Assessment and Rating of Noise from Wind Farms.
http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file20433.pdf

a ‘swish’. Blade swish is not completely steady, but fluctuates at the rate at which the blades pass a fixed point. These fluctuations are known as aerodynamic modulation (AM), and are characterised by a cycle of increased and then reduced level of sound which is typically at the blade passing frequency of around once per second. At a small number of sites, disturbance complaints from residents neighbouring wind turbines have arisen in relation to AM noise.

Reports of AM were investigated by Moorhouse *et al*. (2007) in a UK-government commissioned report. They described that in the majority of wind energy installations AM is a few dB which is subjectively acceptable. It is not clear why in some situations the modulation depth increases to the point where it becomes subjectively unacceptable, and potentially annoying. Through surveys of the 133 operational wind farm sites at the time, AM was considered to be a factor in four of the sites, where analysis of meteorological data suggests that the conditions for AM would prevail between about 7% and 15% of the time.

Airborne operational noise from offshore wind farms is not widely documented, and is currently not considered to be a major source for concern. This is primarily due to the large distances between turbines and coastal settlements, which allows for sound attenuation between source and receptor.

### 5.3.3 Spatial consideration

General aspects of noise propagation are discussed in Box 5.2. Most environmental assessments of noise disturbance use simple spherical propagation models of the form **SPL = SL – 20log(R)**, where SL = source level, R = source-receiver range, to predict sound pressure levels (SPL) at varying distances from source (Figure 5.2). Cylindrical spreading, **SPL = SL – 10log(R)**, is usually assumed in shallow water, where depth < **R**. However, several workers have measured or modelled additional signal modification and attenuation due to a combination of reflection from sub-surface geological boundaries, sub-surface transmission loss due to frictional dissipation and heat; and scattering within the water column and sub-surface due to reflection, refraction and diffraction in the propagating medium (see SEA 4). In shallow water, reflection of high frequency signals from the seabed results in approximately cylindrical propagation and therefore higher received spectrum levels than for spherically propagated low frequency signals (which penetrate the seabed). Attenuation of signal with distance is frequency dependent, with stronger attenuation of higher frequencies with increasing distance from the source. Frequency dependence due to destructive interference also forms an important part of the weakening of a noise signal. Simple models of geometric transmission loss may therefore be unreliable in relatively shallow water; in areas of complex seabed topography and acoustic reflectivity; where vertical density stratification is present in deep water; and where the noise does not originate from a point source.

**Box 5.2 - Acoustic propagation**

Sound produced by various ambient noise sources propagates to a receiver through the very complex underwater environment. Because of variation in temperature, salinity and pressure the path followed by the sound waves can deviate markedly from a straight line. The structuring is most marked in the vertical plane, causing sound to be refracted upwards or downwards, depending on the temperature gradient, but horizontal structuring can also be encountered. As sound is refracted up or down it may interact with the surface and the seabed by reflection and scattering. The level of signal arriving at a distant point is a complex sum of many paths that may or may not interact with the seabed and sea surface. Variations of salinity are generally very small, except perhaps at the mouth of major rivers, and pressure variations are due entirely to depth so temperature variations have the major effect on sound propagation in shallow water.

Under some conditions, a mixed isothermal layer forms close to the sea surface that traps the acoustic signals and a source and receiver located within this surface duct experience significantly less propagation loss than when there is no surface duct. During the day the sea surface can heat up and introduce a temperature gradient close to the sea surface that causes downwards refraction and hence increased propagation loss.

Because the sound can interact strongly with the seabed, the sediment types and seabed roughness can affect propagation loss. Similarly, waves on the surface can also affect propagation loss by scattering the sound interacting with the surface rather than just reflecting it.

Suspended sediments or bubbles can also cause additional propagation loss.

Propagation loss varies on a diurnal basis, particularly during the early summer, and on an annual cycle, as the air temperature variations through the year warm and cool the water. A period of sustained strong wind can also disrupt the temperature structuring.

**Multi-path effects**

Because of the surface and seabed reflections sound can travel between a source and receiver by a multitude of paths. This has the effect of dispersing the arrived signal in time. This effect is particularly important for wideband impulsive sounds such as explosions, pile-driving or seismic exploration air-guns. If any of the propagation effects are frequency sensitive then frequency dispersion will also occur. A common example of this is the sound of air guns operating at distances of 20-30 miles in which the low frequencies travel more slowly than the high frequencies so the single impulse at the source turns into a pronounced frequency sweep at the receiver. The effect of time dispersion is to reduce the peak energy in the received signal. The integrated level is unchanged by time dispersion, but the peak levels can be significantly reduced. When considering the contribution to ambient noise levels this can be an important factor.

Source and receiver depth

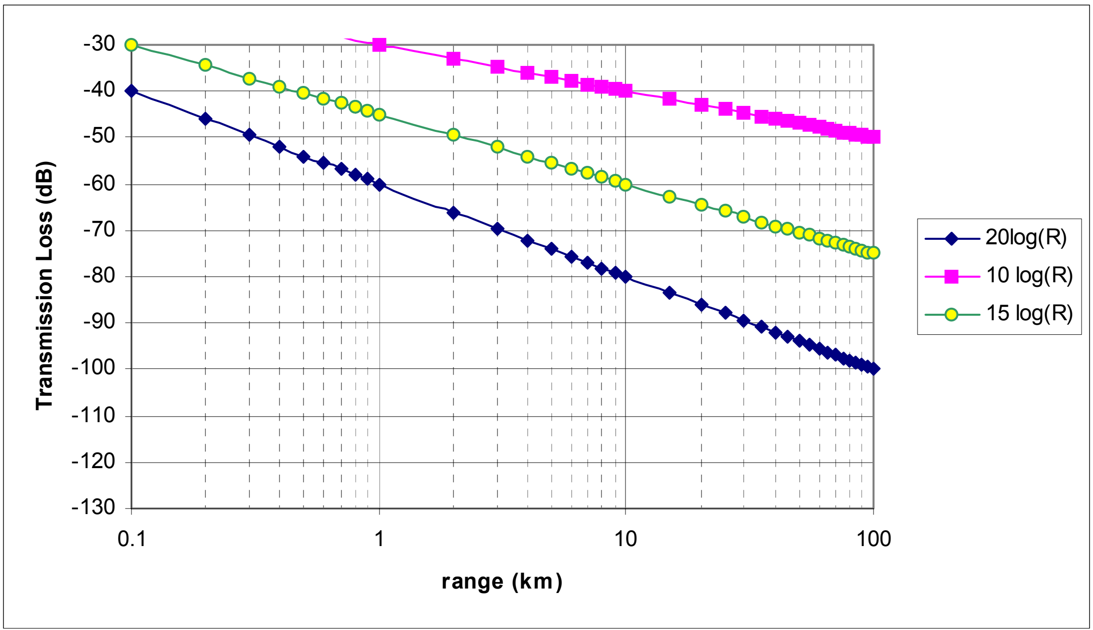
The vertical temperature and pressure structure described above can lead to significant variations in the propagation loss between a sound source and the receiver as the depth of the source and/or the receiver is varied. The most extreme example is the surface duct where a shadow zone may form under the duct. Within the shadow zone levels from a distant sound source in the duct are much reduced compared with the level from the same source within the duct.

Tides

In the relatively deep waters of much of the continental shelf, slope and troughs, variations in depth due to tides are insignificant. However, in inshore waters the effect is much more pronounced and can significantly alter ambient noise fields through the tidal cycle.

*Source: Harland & Richards (2006)*

Figure 5.2 – Theoretical Transmission Losses (TL) calculated for spherical spreading 20log(R), cylindrical spreading 10log(R) and intermediate spreading 15log(R).



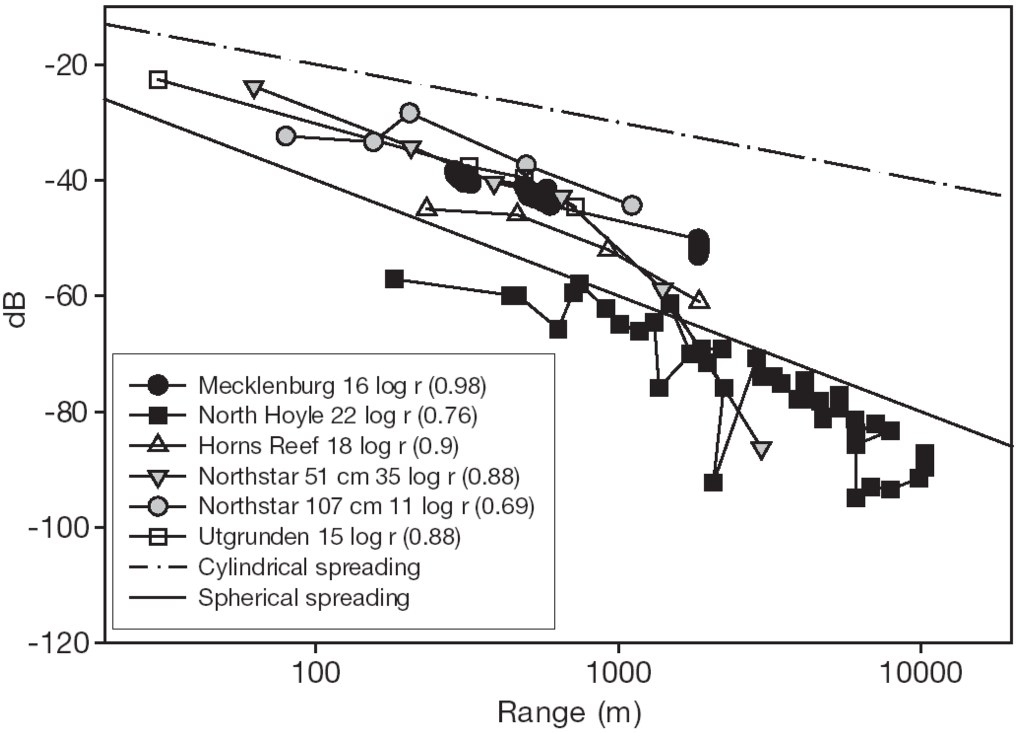

*Source: SEA 4 (DTI 2003)*

Transmission loss has been measured for sounds from pile-driving as well as sounds from operating wind turbines (Madsen *et al*. 2006; Figure 5.3). For the transient impact sounds from pile-driving, the available data suggest that transmission losses are close to spherical spreading up to ranges of more than 1km. At longer ranges the transmission loss may deviate considerably from what can be predicted by a simple spreading model, e.g. data for Horns Rev reflect a range-dependent attenuation much steeper than the 20dB slope at longer ranges.

Recent quantitative modelling of seismic noise propagation has been carried out in Queen Charlotte Basin, Canada (MacGillivray & Chapman 2005) and in the Rockall Basin (IOSEA3 2008). The Queen Charlotte Basin is characterised by shallow water, complex bathymetry, and a highly variable sound speed profile. In this situation, key findings of the modelling study included:

- Received noise levels in the water are influenced by the source location, array orientation and the shape of the sound speed profile with respect to water depth.
- Received noise levels are lowest in those areas of the basin with shallow bathymetry due to scattering and absorption of sound at the seabed.
- In contrast, surface-duct propagation conditions in deeper water result in the highest received levels at long ranges.
- The effect of the sound speed profile on received levels increases significantly with range from the source, with differences greater than 20dB observed beyond 100km, between down-refracting and surface-duct propagation conditions.
- Mean ranges to the 170dB sound level contour (approximately equivalent to NMFS 180dB 90% rms threshold level) vary from 0.54km to 1.15km. The range to the 170dB contour is greater in shallower water than in deeper water.
- The highest horizontal levels from the airgun array are in the broadside direction, which is the direction of maximum energy transmission from the array.

Figure 5.3 – Transmission loss during pile-driving of wind turbine foundations at 5 locations: linear regression of transmission loss model TL = x log (range) is given (regression coefficient in parentheses). Peak sound levels are in decibels relative to back-calculated level at 1m distance.




*Source: Madsen et al. (2006)*

In the deep water Rockall Basin, a generic 5,000 cubic inch airgun array towed at a depth of 10m was modelled in eight directions radiating outwards to a distance of 100km (IOSEA 2008). In addition to array directionality in the horizontal plane, propagation modelling showed a large asymmetry between upslope and downslope propagation. Sound propagating in the downslope direction couples into the deep sound channel, allowing it to propagate to long range with little attenuation. In contrast, sound propagating upslope suffered rapid attenuation due to frequent interactions with the seabed. Cumulative sound exposures were calculated for a notional 3D seismic survey in a 20 by 30km rectangle (i.e. 600km$^2$) with a total of about 49,200 shots fired over some 150 hours: the highest downslope exposure levels are found in the 1,000 to 1,750m depth range which includes the deep sound channel axis. The maximum distance from the survey boundary at which any shots exceeded 140dB re 1μPa$^2$·s was 80km in the downslope direction and 32km upslope. In the downslope, array broadside direction, all shots exceeded 130dB re 1μPa$^2$·s at the maximum modelled range of 100km, and it was predicted that some shots would still exceed this threshold out to a range of at least 600km (it was also noted that this propagation path intersects the shallow water of the Rockall Bank at a range of around 300km, which would result in upslope propagation conditions and a consequent rapid reduction in SEL). Upslope, the maximum distance from the survey boundary at which any shot exceeded 130dB re 1μPa$^2$·s was 82km.

Typical spatial extents of 3D seismic surveys are of the order of 25km in any direction (625km$^2$ area). Assuming propagation distances of audible sound to around 100km in all directions (see above), the theoretical instantaneous area of audibility is a circular area of 31,400km$^2$, and the total area of audibility during a survey is a rectangular area of 50,625km$^2$.

### 5.3.4 Controls and mitigation

Both planning and operational controls cover acoustic disturbance resulting from activities on the UKCS, specifically including geophysical surveying and pile-driving. The *Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001* - (the Habitats Regulations), now amended by the *Offshore Petroleum Activities (Conservation of Habitats) (Amendment) Regulations 2007*, to include all areas within territorial waters; and the *Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007* (amended in 2009 and 2010, the Offshore Marine Regulations, OMR) outside territorial waters – all state that it is an offence to deliberately injure or disturb wild animals of any species listed on Annex IVa of the Habitats Directive (which includes all cetaceans), particularly where disturbance is likely to impair breeding, rearing, hibernation and migration or to affect significantly the local distribution or abundance of the species to which they belong.

Any proposed activity with a potentially significant acoustic impact within a designated SAC or SPA would also be subject to the requirement for Habitats Regulation Assessment (HRA) under the above Regulations.

Application for consent to conduct seismic and other geophysical surveys is made using *Petroleum Operations Notice No 14* (PON14) supported by an Environmental Narrative to enable an accurate assessment of the environmental effects of the survey. Consultations with Government Departments and other interested parties are conducted prior to issuing consent, and JNCC may request additional risk assessment, specify timing or other constraints, or advise against consent.

The major operational control and mitigation over seismic and other geophysical surveys in the UK are through JNCC's *Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys (*latest version October 2009). The JNCC guidelines were originally introduced UK-wide on a voluntary basis as part of the UK's commitment under ASCOBANS, but have subsequently been required by oil and gas licence conditions and through the PON14 approval process. The guidelines have subsequently been reviewed several times by the JNCC following consultation with interested parties and in the light of experience after their use since 1995.

The guidelines require visual monitoring of the area by a dedicated Marine Mammal Observer (MMO) prior to seismic testing to determine if cetaceans are in the vicinity, and a slow and progressive build-up of sound to enable animals to move away from the source. A variety of planning and best practice measures are recommended to minimise risk and maximise the effectiveness of mitigation; Passive Acoustic Monitoring (PAM) may also be required to supplement visual observations, or as the main mitigation tool if the seismic survey activity commences during periods of darkness or poor visibility, or during periods when the sea state is not conducive to visual mitigation.

JNCC have also produced a statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise; and guidelines for minimising the risk of injury to marine mammals whilst using explosives; both of which contain broadly similar MMO observation and progressive introduction of the activity.

Under current arrangements the mitigation package relating to wind farm developments is likely to be secured under FEPA conditions, rather than under the *Electricity Act* s.36 consent. Conditions drafting is likely to vary according to project specific issues. In relation to offshore pile-driving, the Marine Management Organisation (formerly the Marine and

Fisheries Agency (MFA)) has adopted a standard FEPA licence condition for the use of soft start (where the hammer energy is gradually increased), MMOs and PAM, in consents associated with the installation of Round 2 offshore wind farms. In such cases, MMOs and PAM would be used for the detection of marine mammals, basking sharks and turtles within a monitoring zone and appropriate protocols would specify how construction activities should take place. For example, a licence condition might stipulate that piling activities should not commence until half an hour has elapsed during which marine mammals have not been detected in or around the monitoring zone. It should be noted that additional measures would probably be required in areas where environmental impact assessment suggests that high cetacean densities or site fidelity may occur.

In 2008, JNCC consulted on guidance on the new disturbance offence under the Habitats Regulations 2007 for England and Wales and the Offshore Marine Regulations 2007. The consultation ended in June 2008 and feedback was considered in the following months much improving the document. In January 2009 there were amendments made to the regulations, which meant that the guidance also had to be slightly amended to reflect those changes and this has meant a delay in its publication. Currently the guidance is in draft and a final version was expected in 2010.

The JNCC, Natural England and Countryside Council for Wales draft guidance is intended to provide a resource for marine users, regulators, advisors and the enforcement authorities when considering whether an offence of deliberately disturbing or injuring/killing a marine EPS is likely to occur or to have occurred as a result of an activity. The guidance is based on a risk assessment approach, assessing the likelihood of a statutory offence, and then whether a licence to undertake the proposed activity should be sought. The likelihood of an activity resulting in injury or disturbance to a marine EPS will very much depend on the characteristics of the activity, of the environment and the species concerned, hence the need for a case-by-case approach when assessing the risk of it occurring. However, there is scope for broader collaborative impact assessments to be carried out and its conclusions to feed back to individual operations.

The guidelines suggest that activities with the potential to deliberately injure or kill a marine EPS in areas can be long or short-lived, and include explosive use, seismic surveys, navigation by high speed vessels, and pile-driving. However, if mitigation measures are appropriate and effectively implemented, the risk could be reduced to negligible levels. The JNCC guidelines for minimising the risk of injury to marine mammals from seismic surveys, pile-driving and use of explosives (see above) consider that compliance with the guideline recommendations will reduce the risk of injury to EPS to negligible levels.

The draft EPS guidelines also suggest that for most cetacean populations in UK waters, disturbance, in terms of the HR or OMR, is unlikely to result from single, short-term operations, e.g. a seismic vessel operating in an area for 4-6 weeks, or the driving of a dozen small diameter piles. Such activities would most likely result in temporary disturbance, which on its own would not be likely to impair the ability of an individual to survive, reproduce, etc, nor result in significant effects on the local abundance or distribution. Non-trivial disturbance, which would constitute an offence under the Regulations, would most likely result from more prevalent activities in an area, chronically exposing the same animals to disturbance or displacing animals from large areas for long periods of time. These considerations are assessed in the context of this SEA in Section 5.3.5 below.

JNCC and the Statutory Nature Conservation Advisors (SNCAs) are currently considering advice to the relevant regulators (MMO, Marine Scotland, WAG & DECC) in relation to consenting risks associated with European protected species (EPS) and offshore wind farm proposals, particularly regarding the use of pile-driving as a construction method. A range of issues are under consideration, including the scale of proposed construction and the need to actively manage the timing and location of some activities in order to meet the good environmental status objective of the MSFD (see below).

SMRU (2007) investigated the potential for using acoustic mitigation devices (AMDs) for mitigation during wind farm construction, drawing some general and fairly qualitative conclusions from the exercise:

- Propagation conditions have a very substantial effect. For example, mitigation ranges are low when 20log(R) propagation loss is assumed but can be very high when 15log(R) propagation applies. Both values are likely in some shallow water locations. Propagation can however be modelled and also measured in the field once operations begin
- According to this model, PTS could occur in some circumstances, for example, where there is no soft start and animals show little avoidance. However, this is an unlikely set of circumstances. Observations of avoidance reactions can be made to provide real data on responsive movements
- Thresholds for risk of hearing damage based on single pulses and cumulative exposure may be exceeded at substantial ranges, especially when transmission loss is low
- This exercise certainly does not support any suggestion that the risk of auditory damage to marine mammals from pile-driving can be discounted

SMRU (2007) also conclude that the risk of damage can be substantially reduced if animals can be reliably removed from within hundreds to low thousands of metres before piling is initiated. "*Acoustic mitigation devices will thus need to be able to move animals over these types of ranges to be effective…. using the NOAA (2006) criteria…. if 15log(R) propagation loss is assumed then animals could experience TTS at range of over 6km. To reduce this, animals would need to be moved to that range before piling began which would require an effective AMD to be used for 120 minutes before the initiation of piling*" [in view of estimated swimming speeds]. Soft starts are of some help (provided animals respond to them appropriately) but will not, on their own, reduce risk sufficiently.

In a COWRIE-sponsored study, technical options and costs of potential engineering solutions for the mitigation of the impacts of underwater noise arising from the construction of offshore wind farms were reviewed by Nehls *et al*. (2007). In addition to soft starts, technical mitigation measures have so far mainly focussed on bubble curtains (air bubbles released at the seafloor around a source of noise). Bubble curtains can efficiently reduce underwater noise but because of the slow ascent rate of the bubbles, it is considered to be impossible to install bubble curtains in the offshore environment at great water depths and tidal currents.

Attempts to mitigate noise from pile-driving by prolonging the duration of the blows of the piling procedure through modification of the pile driver were rejected at this stage. As a prolongation of the blows may result in a loss of piling energy this may impair the success of the piling. However, further research on this method is recommended.

Nehls *et al*. (2007) described two methods considered to be effective and practicable to construct a permanent noise barrier around the piles, using foam or air. For the air method, an inflatable piling sleeve which can be permanently mounted below the piling gate at the construction platform. The sleeve is meant to be released after insertion of the pile into the piling gate and inflated to a 50mm layer of air during the piling operation. The sleeve is expected to reach an attenuation of 20dB broadband. For the foam method, a telescopic double-wall steel tube with an interspace filled with foam is constructed in several segments to reduce the height when released on the seafloor underneath the piling gate. The pile is inserted into the tube which is lifted to full length during the piling operation. A 100mm foam layer is calculated to reach an attenuation of 15dB broadband. Both methods are considered to be compatible to the piling process and per pile costs are roughly estimated at €20,000 for the inflatable sleeve and about €25,000 for the telescopic tube. The inflatable sleeve appears to have the advantage of resulting in very little interference in the piling process. The noise attenuation from these methods is considered to be high enough to achieve a substantial reduction of the impacts on marine wildlife. Calculated radii of physical damage may be reduced by more than 90% and radii of disturbance by two-thirds.

COWRIE subsequently commissioned studies (Kastelein *et al.* 2010) on the audibility of sounds produced by three selected AMDs and their effect on the behaviour of harbour porpoises and harbour seals (playback experiments). In addition, the study estimated the distances at which sounds from AMDs are audible to, and elicit behavioural responses in, harbour porpoises and harbour seals. The distances at which harbour porpoises can hear the three AMDs were estimated for two extreme situations, by submitting information from the present study, the source levels of the AMDs, and two background noise levels to two generic propagation models. Under optimal conditions (quiet and with good propagation), the audible distance was up to 91km; under poor conditions (noisy and with poor propagation), up to 18km. Hearing thresholds of two young adult female harbour seals were obtained by the same method as used for the porpoise, with very similar results. Behaviour of a young adult harbour porpoise and two young adult female harbour seals in response to each AMD sound was tested at three source levels which were determined during pre-tests. For the porpoise, responses were characterised at a level which just did not cause a behavioural change, a level which caused a small change in the surfacing rate and swimming pattern, and a level which caused the porpoise to swim away from the transducers (i.e., exhibit displacement). For the harbour seals, the corresponding levels (1) just did not cause a behavioural change, (2) caused a seal to haul out very occasionally, and (3) caused a seal to haul out approximately 10% of the time. Two of the selected AMDs were concluded to have the potential to deter harbour porpoises and harbour seals at useful distances (between 0.2 and 1.2km for porpoise; between 0.2 and 4.1km for seals) provided that there is no attraction (such as a food source) in the immediate area of the AMD. Because of high levels of variability in response distances due to variation in environmental variables, distance ranges, rather than exact distances, at which each AMD elicits a response, should be considered when planning mitigation measures.

In the context of monitoring marine mammal responses, Diederichs *et al*. (2008) reported on methodologies for measuring and assessing potential changes in marine mammal behaviour, abundance or distribution arising from the construction, operation and decommissioning of offshore wind farms. The report reviewed impacts from offshore wind farms on marine mammals and defines the spatial and temporal scope of investigations in order to detect impacts on marine mammals, and assessed the standard methods used in studies on marine mammals. The statistical power of line transect surveys using aircraft and ships and Static Acoustic Monitoring (SAM) using T-PODs was analysed from datasets obtained in German studies.

Diederichs *et al*. (2008) recommend a combination of line transect surveys using aircraft or ships with SAM, with the following specific recommendations:

- an impact study on offshore wind farms should ideally cover two years before construction, the construction period and at least two years of operation
- if longer lasting effects are detected, the study during the operational phase should be extended

- it is recommended to conduct line transect surveys in monthly intervals
- in areas with a marked seasonal occurrence, surveys may be restricted to periods with high abundance, when sufficient data are more likely to be obtained
- continuous recordings of harbour porpoises with SAM are recommended for all areas, where these animals occur in relevant numbers.

SAM will provide data which are needed to detect short-term changes in behaviour and abundance as expected in response to pile-driving, but also to detect changes on a much smaller spatial scale as can be detected by other methods as well as long-term changes in response to construction of operation. For seals and dolphins severe problems in assessing the impacts remain, as their behaviour or low densities make it very difficult to obtain enough data for statistical analysis.

Specific to decommissioning, the EIA process for offshore wind farms requires consideration of effects, including noise, throughout the life cycle of the wind farm from construction through to decommissioning, while the *Energy Act 2004* introduced a statutory decommissioning scheme for offshore wind and marine energy installations (see guidance in DTI 2006). Strengthened provisions for the consenting and decommissioning of offshore renewable installations are provided by the *Energy Act 2008*, the *Planning Act 2008* and is proposed in the *Marine and Coastal Access Act*, together with the various Marine Bills proposed by the devolved administrations.

### 5.3.5 Cumulative impact considerations

The *Marine Strategy Framework Directive (2008/56/EC)* (MSFD) requires that the European Commission (by 15 July 2010) should lay down criteria and methodological standards to allow consistency in approach in evaluating the extent to which Good Environmental Status (GES) is being achieved. ICES and JRC were contracted to provide scientific support for the Commission in meeting this obligation. A total of 10 reports have been prepared relating to the descriptors of GES listed in Annex I of the Directive. Eight reports have been prepared by groups of independent experts coordinated by JRC and ICES in response to this contract.

Task Group 11 reported on underwater noise and other forms of energy (Tasker *et al*. 2010). The Task Group developed three possible indicators of underwater sound. In no case was the Task Group able to define precisely (or even loosely) when Good Environmental Status occurs on the axes of these indicators. This inability is partly to do with insufficient evidence, but also to no fully accepted definition of when, for example, a behavioural change in an organism is not good.

Indicator 1 relates to high amplitude, low and mid-frequency impulsive anthropogenic sounds including those from pile-driving, seismic surveys and some sonar systems. The following initial indicator is proposed as a way of geographically quantifying the occurrence of loud impulsive anthropogenic noise: ***the proportion of days within a calendar year, over areas of 15'N x 15'E/W in which anthropogenic sound sources exceed either of two levels, 183 dB re 1μPa$^2$.s (i.e. measured as Sound Exposure Level, SEL) or 224 dB re 1μPa$_{peak}$ (i.e. measured as peak sound pressure level) when extrapolated to one metre, measured over the frequency band 10 Hz to 10 kHz.*** This indicator would be based on reports of occurrence by those undertaking activities likely to generate these sounds, rather than on direct independent measurement. Recording would be on the basis of Regional Seas (or national parts of Regional Seas). The Task Group expected that sounds made by most commercial seismic surveys, by pile-driving, by low and mid-frequency sonar and by explosions would be included and that most sources to be included therefore be quantifiable from either relevant impact assessments or reports from activities required under national licensing regimes. The proportion of days would be set by Member States and could be based on a review of relevant activities in the immediate past and on their view on sustainable impact.

The size of grid rectangle was chosen as a compromise. An index sensitive to small changes in activity would have small rectangles, while large rectangles are likely to be administratively easier to use. The Task Group recommends the choice of 15'N x 15'E/W rectangles, but other choices would be possible at approximately this scale.

The choice of frequency bandwidth (10Hz to 10kHz) is based on the observation that sounds at higher frequencies do not travel as far as sounds within this frequency band. Although higher frequency sounds may affect the marine environment, they do so over shorter distances than low frequency sounds. This choice of bandwidth also excludes most depthfinding and fishery sonars.

Indicator 1 is focussed on those impulsive noise sources that are most likely to have adverse effects. The source levels will include all classes of high intensity sounds that are known to affect the marine environment adversely for which the activities that generate such sounds are routinely licensed or are assessed, but not to include some lower intensity sounds that are rarely subject to licence. The Task Group recommended that these levels be reviewed in the future in the light of any new scientific publications.

A further two indicators were recommended by the Task Group, relating to high frequency impulsive sounds (typically depth sounding sonar systems on small vessels); and low frequency, continuous sound, comprising ambient noise defined as background noise without distinguishable sound sources (including natural biological and physical processes and anthropogenic sounds.

In their consideration of advice to regulators in relation to consenting risks associated with European protected species (EPS) and offshore wind farm proposals, JNCC and the SNCAs note the need to reach judgements about the cumulative effect of several developments on the Favourable Conservation Status of populations of species. In addition to UK regulators, other member states will need to also consider cumulative impacts on the same population of species. Work being developed through the MSFD noise indicator will help clarify the need for trans-boundary collaboration on the issue of sound in the marine environment with the development of the noise register.

## Seismic survey

Seismic survey coverage of the UKCS is extensive (Figure 5.4), reflecting more than 40 years of activity, and covering virtually all areas of the shelf.

Historic seismic survey effort on the UKCS between 1997 and 2003 was reviewed for a DTI submission to the Advisory Committee to ASCOBANS (DTI 2005a), and subsequently updated for 2007-2008 (Genesis 2009). These reports calculated shot point density information per 1º by 1º rectangle, by dividing the number of seismic shot points per quadrant by the offshore sea area within each quadrant up to the median line. The PON14 database was also analysed to identify both the number of surveys being carried out concurrently and the combined size of airguns in use concurrently for different regions of the UKCS.

A summary of 2D and 3D seismic survey activity is shown in Figure 5.5. The great majority of survey activity (measured by shot points) is 3D, with an overall total over the ten year period of approximately 63 million shot points. Following a decrease over most of the period, survey activity increased in 2005 and 2006.

Figure 5.4 – Seismic survey coverage of the UKCS over the last 40 years

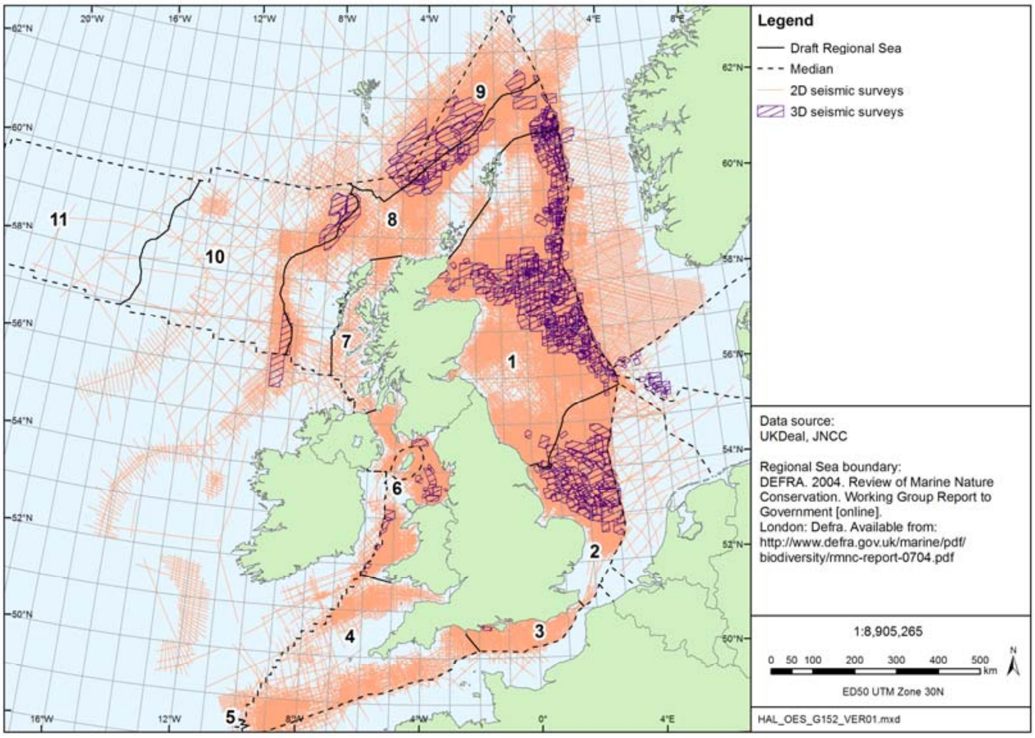
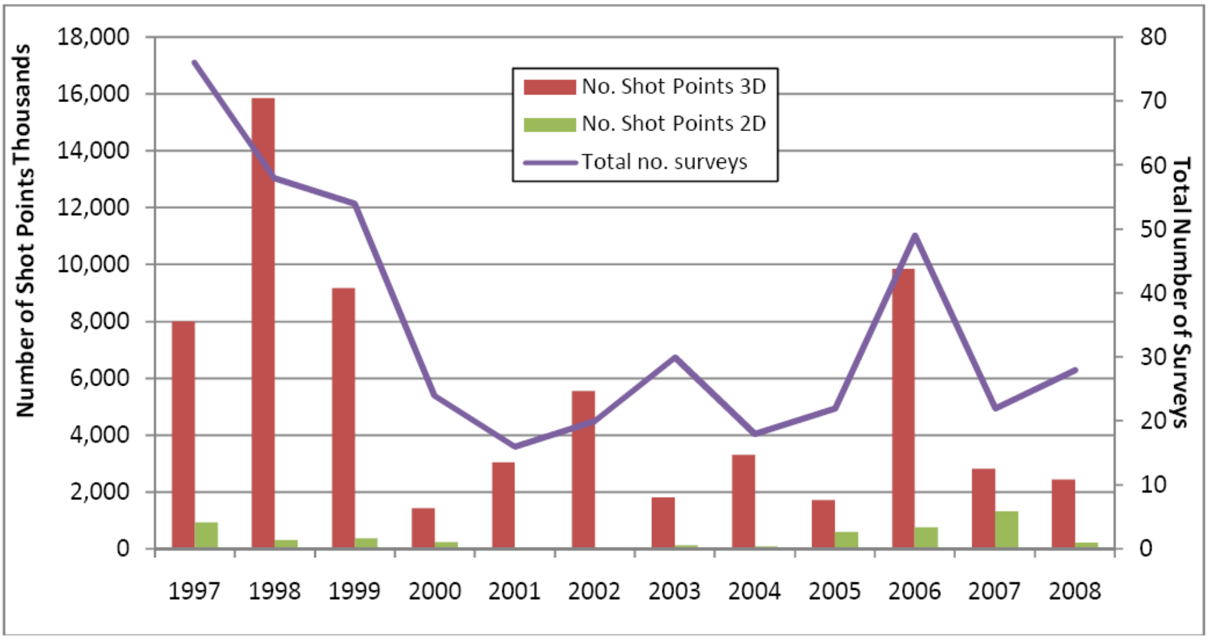



Figure 5.5 – Overview of survey activity 1997-2008




*Source: Genesis 2009*

As considered in the previous OESEA, the vast majority of historic seismic survey effort on the UKCS has been undertaken in the developed (in terms of oil and gas) areas of Regional Seas 1 and 9, with a small amount in Regional Seas 2, 4, 6 and 10. The total survey period (2D + 3D, assuming a 10s shot interval) was equivalent to between 188 days/year (2000) to 1195 days/year (2006) – i.e. on average during 2006, more than three surveys were carried out concurrently in the whole of the UK waters. In addition to this UK seismic noise budget, noise propagating from surveys in contiguous national waters (particularly Irish, Faroese and Norwegian deep waters) will be present.

In 2008, the 25th Round of licensing involved the offer of 2,300 blocks covering all prospective areas of the UKCS, and resulted in the offer of 303 blocks through 192 Seaward Production Licences ('Traditional', 'Promote' and 'Frontier'). Applications for these included firm commitments for seven 2D and nine 3D seismic surveys in Regional Seas 1, 2 (North Sea), 8 and 9 (west of Shetland) – around 30% of total seismic survey activity in 2006. The recent (October 2010) 26th Round awarded 268 blocks through 144 Licences and applications for these included firm commitments for seven 2D and thirteen 3D seismic surveys in Regional Seas 1, 2 (North Sea) and 9 (west of Shetland).

As noted above, both carbon dioxide and gas storage developments are likely to require geophysical survey effort, which (as in the case of Sleipner CCS) may involve 4D seismic and therefore result in locally intense cumulative acoustic effects repeated at intervals of one to a few years. The geographical location of possible carbon dioxide and gas storage developments is not known, although it is likely that developments would be located in the existing developed gas fields of the central and southern North Sea.

## Offshore wind farm pile-driving

At the date of the previous OESEA (September 2008), a total of about 260 turbines had been constructed in Round 1 and Round 2 leased areas; with a further 1,120 consented for construction. In November 2010, the RenewableUK website[23] reported 436 offshore turbines constructed, 309 under construction, 814 approved for construction and 519 submitted for approval (total 2,078).

Virtually all of these had foundations of steel monopile construction. Assuming a hammer rate of 45/minute (range 30-60/minute; Thomsen *et al*. 2006) and duration of 90 minutes/pile (range 1-2h; Thomsen *et al*. 2006), this equates to approximately 1.7M hammer strikes to date, with a further 4.5M consented. These values could be halved or doubled, within the range of operational experience described by Thomsen *et al*. (2006). Making further broad assumptions about the construction rate of consented projects, the previous OESEA compared an approximate strike rate of 0.5-1.5M/year, to historic seismic shot activity on the UKCS of around 1.7M/year (2000) to 10.6M/year (2006, see above), and predicted shot activity of approximately 3.8M/year (derived by comparison with firm commitments resulting from the 25th Round, and DECC expectations for effort in previously unlicensed areas of Regional Seas 3 and 4).

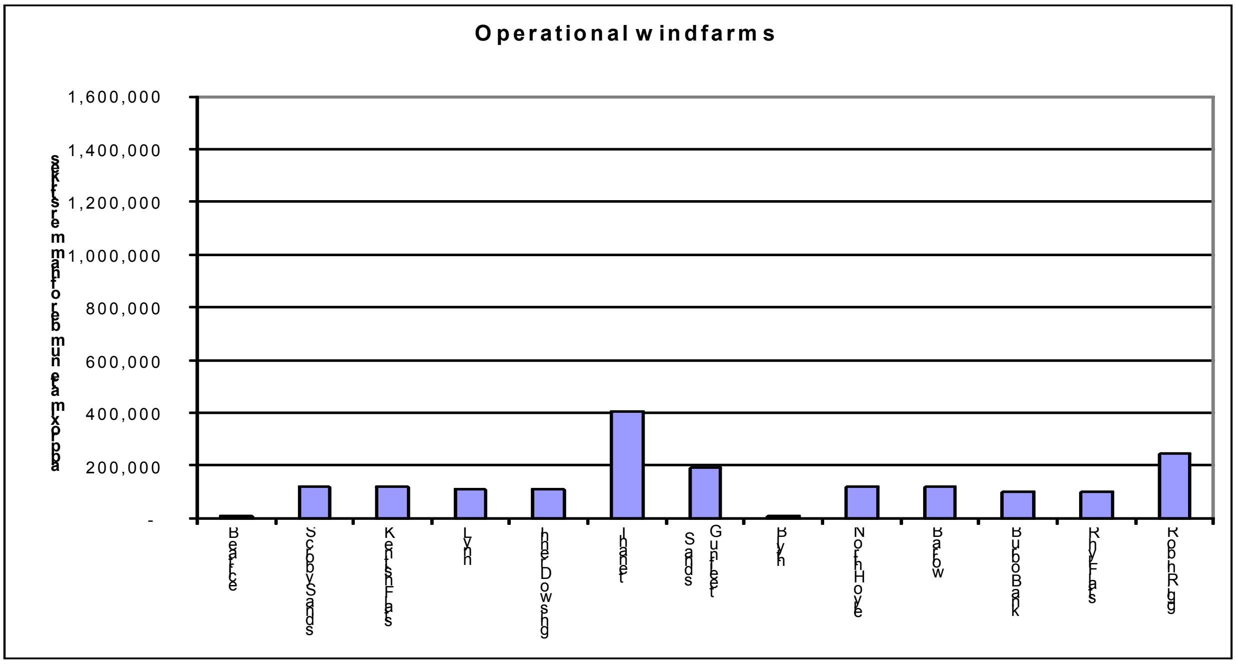
Of the ~1.7M pile-driver strikes carried out to date (Figure 5.6 overleaf), approximately 1,000,000 have been in Regional Sea 2 (Scroby Sands, Kentish Flats, Lynn, Inner Dowsing) and 680,000 in Regional Sea 6 (North Hoyle, Barrow, Burbo Bank, Robin Rigg, Rhyl Flats). Consented projects expected to be constructed over the next few years are also predominantly in Regional Sea 2 (~3M strikes) and Regional Sea 6 (~1.4M strikes).

[23] http://www.bwea.com/ukwed/offshore.asp

A nominal scenario of the potential quantity of pile-driving resulting from the proposed offshore wind leasing, as a function of the target of 25GW by 2020 together with likely developments in turbine size, is shown in Figure 5.7 overleaf (note that this assumes that all developments use monopile foundations).

With regard to decommissioning, it is possible that the future decommissioning of wind farms may occur when new wind farms are being constructed. However, there is a regulatory framework in place to ensure that significant individual and in-combination effects of these activities do not occur. The EIA process for offshore wind farms requires consideration of effects throughout the life cycle of the wind farm from construction through to decommissioning.

Figure 5.6 – Estimated number of pile-driving hammer strikes, Rounds 1 & 2 sites



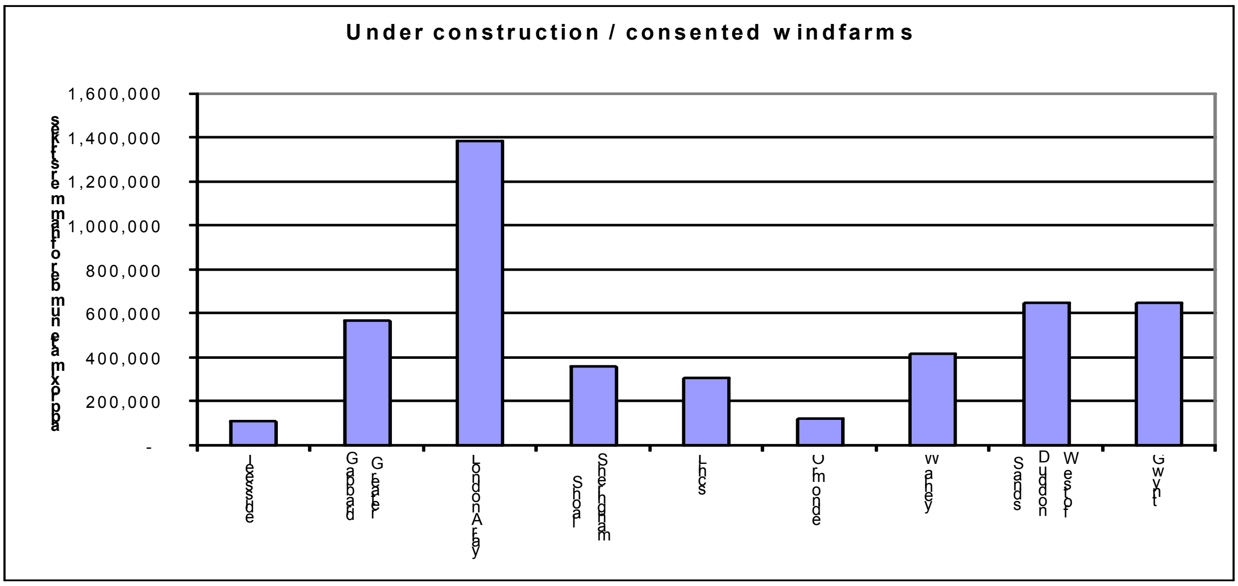
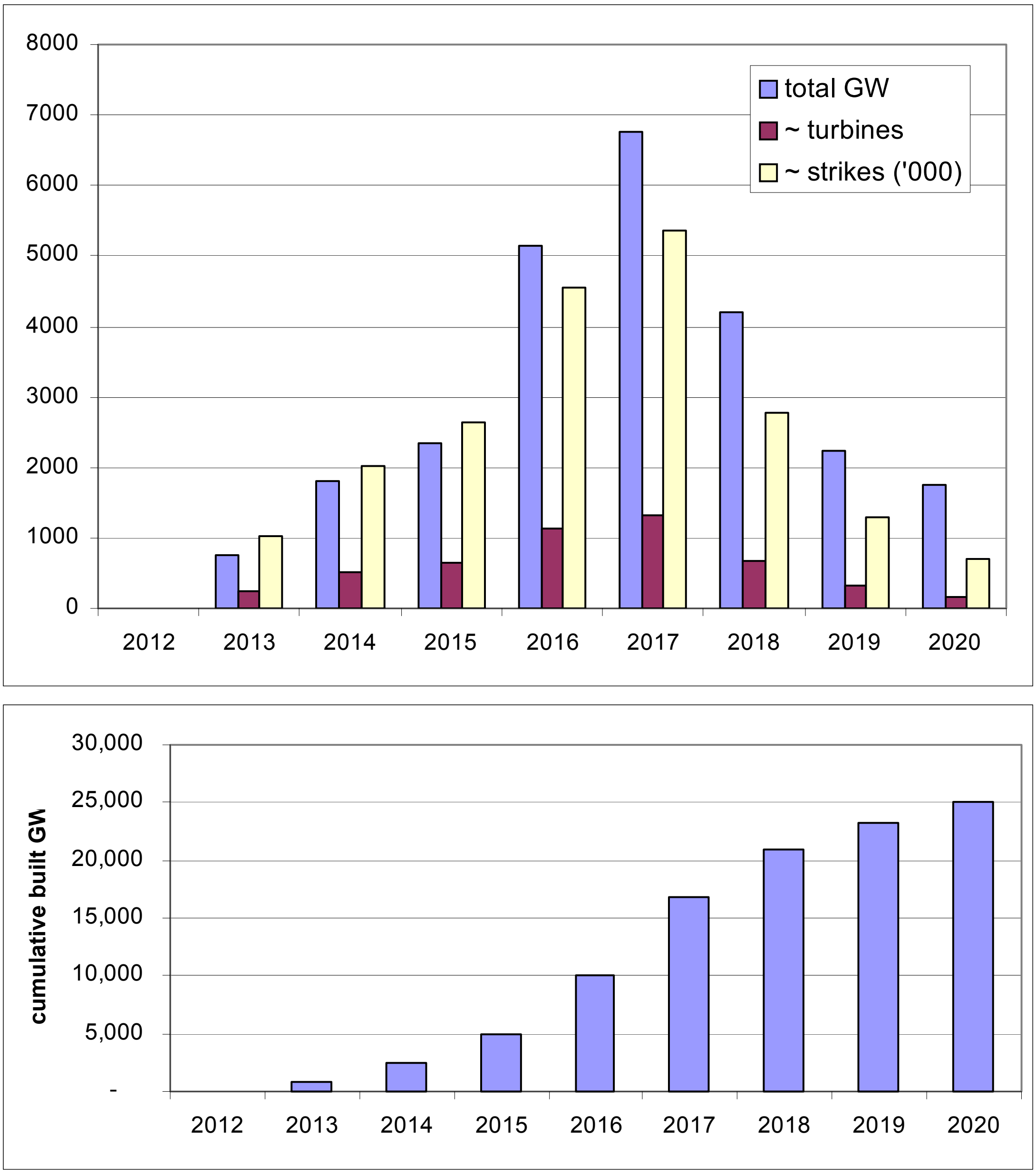



Figure 5.7 – Predicted annual rate of turbine installation and pile-driving. Cumulative total of installed generating capacity also shown.




## 5.3.6 Likelihood of significant effects

As noted above, of the potential acoustic effects under consideration in this SEA, the most likely to be significant are considered to be the effects of pulse sources (associated with seismic survey and pile-driving) on marine mammals and possibly spawning fish. Longer-term, continuous acoustic disturbance effects associated with operational phases of development – both hydrocarbon production and wind turbine generation – were considered less probable in view of the source levels measured from these activities.

The following section considers the potential for significant effect, and potential for mitigation, under the following rationale:

- Definition of possible spatial effects ranges; based on synthesis of source level characterisation, propagation characteristics and effects criteria discussed above
- Consideration of the potential for significant effects, using criteria recommended by JNCC guidelines to the OMR, and noise levels in relation to biologically meaningful disturbance effects
- Consideration of potential activity levels, and specific sensitivities of individual Regional Seas
- Identification of specific geographical areas of concern
- Consideration of requirements for seasonal avoidance (temporal mitigation)
- Consideration of operational mitigation
- Consideration of potential cumulative effects.

As noted above, establishing meaningful received sound levels for more subtle behavioural or ecological disturbance has proved difficult, as have efforts to make statistically powerful observations of such disturbance in wild marine mammals. Given a typical visual observational limit of 500m (under favourable conditions), the low number of individuals which comprise the available dataset, and the inherent variability (and complexity) of the behavioural context, this is not surprising. Although Southall *et al*. (2007) were unable to derive explicit and broadly applicable numerical threshold values for delineating behavioural disturbance resulting from multiple pulse and non-pulse (i.e. continuous) sources, they did note that:

"*For all other low-frequency cetaceans* ([i.e. baleen whales excluding migrating bowhead whales, but] *including bowhead whales not engaged in migration), this onset was at RLs around 140 to 160 dB re 1µPa*".

"*The combined data for mid-frequency cetaceans* [most odontocetes] *exposed to multiple pulses do not indicate a clear tendency for increasing probability and severity of response with increasing RL*".

"*Due to….. the overarching paucity of data, it is not possible to present any data on behavioural responses of high-frequency cetaceans* [i.e. porpoises] *as a function of received levels of multiple pulses…. We note the need for empirical behavioural research in these animals using sound sources (such as airgun or pile-driving stimuli) unequivocally classified as multiple pulses*"

Figure 5.8, a reproduction from Southall *et al.* (2007), summarises observed behavioural responses of mid-frequency cetaceans to multiple pulse noise categorised into 10dB bins, but was based on only four quantitative studies, noting but excluding the seismic survey monitoring reported by Stone (2003). These were categorised into a behavioural response severity scale (Figure 5.9, a reproduction of Table 4 from Southall *et al.* 2007) ranging from 0 (no observable response) to 9 (outright panic….avoidance behaviour related to predator detection).

The JNCC EPS guidelines recommend that disturbance as described in Regulations 39(1)(b) and 39(1A)(a) of the HR and OMR is interpreted as sustained or chronic disruption of behaviour scoring 5 or more in the Southall *et al*. (2007) behavioural response severity scale. The risk assessment should therefore consider the likelihood of the activity resulting in responses lasting more than 24h or recurring on subsequent days for long periods of time. Disruption of behaviour scoring 5 or more in the Southall et al. (2007) behavioural response severity scale are predicted to occur at received RMS sound pressure level in the range 120-150 dB re 1μPa (mid-range value 135dB re 1μPa; this prediction is considered to be conservative, and is based on a single study of beluga by Miller *et al.* 2005).

Figure 5.8 – Observed behavioural responses of mid-frequency cetaceans to multiple pulse noise categorised into 10dB bins

| | Received RMS sound pressure level (dB re: 1μPa) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Response score | 80 to <90 | 90 to <100 | 100 to <110 | 110 to <120 | 120 to <130 | 130 to <140 | 140 to <150 | 150 to <160 | 160 to <170 | 170 to <180 | 180 to <190 | 190 to <200+ |
| 9 | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | |
| 6 | | | | | **0.17** (3) | **0.17** (3) | **0.17** (3) | | | **1.3** (4) | | |
| 5 | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |
| 1 | | | | | | | | | | | | |
| 0 | | | **0.25** (3) | **0.25** (3) | **3.0** (2) | **4.0** (2) | | | | **6.7** (1, 4) | | |

*Notes: Number (in bold) of mid-frequency cetaceans (individuals and/or groups) reported as having behavioural responses to multiple pulse noise; responses were categorised into 10-dB RL bins, ranked by severity of the behavioural response (see Table 4 of Southall et al. 2007 for severity scaling), and combined with other observations having the same RL/severity score. A summary of the individual studies included in this table is given in the "Mid-Frequency Cetaceans/Multiple Pulses (Cell 5)" section of Southall et al. 2007. Parenthetical subscripts indicate the reference reporting the observations as listed in Table 8 of Southall et al. 2007.*
*Source: Southall et al. (2007)*

Based on the criteria developed by Southall *et al*. (2007), indicative spatial ranges of injury and disturbance for cetaceans and pinnipeds may be calculated as indicated in Table 5.1.

These calculated ranges are broadly consistent with a wide range of environmental assessments for seismic surveys, and suggest that there is negligible risk of auditory damage to cetaceans, and a low to moderate risk of seals being within the required range (136m assuming modified cylindrical spreading) of pile-driving operations. Modified cylindrical spreading is usually considered to occur in water depths <1.5x range, i.e. spherical spreading (20logR) will occur to a range of 60m in a water depth of 40m (indicative of the maximum practicable water depth for monopile construction).

Figure 5.9 – Severity scale for ranking observed behavioural responses of free-ranging marine mammals and laboratory subjects to various types of anthropogenic sound

450 *Southall et al.*

**Table 4.** Severity scale for ranking observed behavioral responses of free-ranging marine mammals and laboratory subjects to various types of anthropogenic sound

| Response score[1] | Corresponding behaviors (Free-ranging subjects)[2] | Corresponding behaviors (Laboratory subjects)[2] |
|---|---|---|
| 0 | - No observable response | - No observable response |
| 1 | - Brief orientation response (investigation/visual orientation) | - No observable response |
| 2 | - Moderate or multiple orientation behaviors<br>- Brief or minor cessation/modification of vocal behavior<br>- Brief or minor change in respiration rates | - No observable negative response; may approach sounds as a novel object |
| 3 | - Prolonged orientation behavior<br>- Individual alert behavior<br>- Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source<br>- Moderate change in respiration rate<br>- Minor cessation or modification of vocal behavior (duration < duration of source operation), including the Lombard Effect | - Minor changes in response to trained behaviors (e.g., delay in stationing, extended inter-trial intervals) |
| 4 | - Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source<br>- Brief, minor shift in group distribution<br>- Moderate cessation or modification of vocal behavior (duration ≈ duration of source operation) | - Moderate changes in response to trained behaviors (e.g., reluctance to return to station, long inter-trial intervals) |
| 5 | - Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source<br>- Moderate shift in group distribution<br>- Change in inter-animal distance and/or group size (aggregation or separation)<br>- Prolonged cessation or modification of vocal behavior (duration > duration of source operation) | - Severe and sustained changes in trained behaviors (e.g., breaking away from station during experimental sessions) |
| 6 | - Minor or moderate individual and/or group avoidance of sound source<br>- Brief or minor separation of females and dependent offspring<br>- Aggressive behavior related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds)<br>- Extended cessation or modification of vocal behavior<br>- Visible startle response<br>- Brief cessation of reproductive behavior | - Refusal to initiate trained tasks |
| 7 | - Extensive or prolonged aggressive behavior<br>- Moderate separation of females and dependent offspring<br>- Clear anti-predator response<br>- Severe and/or sustained avoidance of sound source<br>- Moderate cessation of reproductive behavior | - Avoidance of experimental situation or retreat to refuge area (≤ duration of experiment)<br>- Threatening or attacking the sound source |
| 8 | - Obvious aversion and/or progressive sensitization<br>- Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms<br>- Long-term avoidance of area (> source operation)<br>- Prolonged cessation of reproductive behavior | - Avoidance of or sensitization to experimental situation or retreat to refuge area (> duration of experiment) |
| 9 | - Outright panic, flight, stampede, attack of conspecifics, or stranding events<br>- Avoidance behavior related to predator detection | - Total avoidance of sound exposure area and refusal to perform trained behaviors for greater than a day |

[1]Ordinal scores of behavioral response severity are not necessarily equivalent for free-ranging vs laboratory conditions.
[2]Any single response results in the corresponding score (i.e., all group members and behavioral responses need not be observed). If multiple responses are observed, the one with the highest score is used for analysis.

*Source: Southall et al. (2007)*

Table 5.1 - Indicative spatial ranges of various injury and disturbance indicators for cetaceans and pinnipeds, based on injury and disturbance criteria from Southall *et al.* (2007)

| | cetaceans | | pinnipeds | |
|---|---|---|---|---|
| | seismic | pile-driving | seismic | pile-driving |
| nominal vertical source level (dB p-p) | 260 | 250 | 260 | 250 |
| horizontal array correction | -15 | 0 | -15 | 0 |
| effective horizontal source level | 245 | 250 | 245 | 250 |
| **injury sound pressure level (multiple pulses; dB p-p)** | 230 | 230 | 218 | 218 |
| required propagation loss | 15 | 20 | 27 | 32 |
| deep water (20logR) distance (m) | 5.6 | 10.0 | 22.4 | 39.8 |
| shallow water (15logR) distance (m) | 10.0 | 21.5 | 63.1 | 135.9 |
| | | | | |
| **behavioural response sound pressure level (single pulse; dB p-p)** | 224 | 224 | 212 | 212 |
| required propagation loss | 21 | 26 | 33 | 38 |
| deep water (20logR) distance (m) | 11.2 | 20.0 | 44.7 | 79.4 |
| shallow water (15logR) distance (m) | 25.1 | 54.1 | 158.5 | 341.5 |
| | | | | |
| **severity 5 behavioural response (mid-range, dB re 1μPa)** | 135 | 135 | | |
| required propagation loss | 110 | 115 | | |
| deep water (20logR) distance (km) | 316 | 562 | | |
| shallow water (15 logR) distance (km) | 21544 | 46416 | | |

*Source: Southall et al. (2007)*

Overall, and at a strategic level, the available evidence and approaches to assessment of significant effect suggest the following conclusions, in relation to individual seismic and pile-driving sources:

- Although quantitative observational data on injury and severe behavioural responses resulting from seismic and pile-driving sources are very sparse, such data as do exist indicate that responses are not predicted except in the immediate vicinity (<50m) of the source.
- Using precautionary assumptions and interpretation of very limited available data, propagation distances associated with disruption of behaviour scoring 5 or more in the Southall *et al.* (2007) behavioural response severity scale are predicted to occur, to the order of several hundred km. Sustained or chronic disturbance at this level is therefore possible as a result of large-scale seismic survey or pile-driving operations. In addition, given the population densities of marine mammal populations, effects at this level could potentially affect a large number of individuals.
- These precautionary considerations, although necessary and justified for regulatory purposes, should be viewed in the context of a lack of observed effect of seismic surveys and offshore construction activity worldwide over the last fifty years, during which there has been no conclusive evidence of significant effect on marine mammal populations. Recent studies using acoustic monitoring, tagging and telemetry are consistent with visual survey conclusions that injurious or severe behavioural effects are unlikely. This contrasts with the situation for effects of military sonars, which suggests that a significant and consistent effect would be detectable.

- The spatial scales over which effects on local distribution or abundance might be postulated are at least an order of magnitude greater than those which can be monitored by either visual or passive acoustic methods. Conversely, the spatial scales over which injury and severe behavioural effects are likely to result do not support significant groups of animals.

Qualitatively, these conclusions are consistent with those reached by previous SEAs, e.g. that:

"*The balance of evidence suggests that effects of seismic activities are limited, in species present in significant numbers…. to behavioural disturbance which is likely to be of short duration, limited spatial extent and of minor ecological significance. The numbers of individuals likely to be influenced represent a small to moderate proportion of biogeographic populations*." (SEA 7).

Predicted activity levels resulting from both future oil & gas licensing rounds, and further rounds of offshore wind leasing, are concentrated in Regional Seas 1, 2 and 6; with some additional oil and gas activity likely in Regional Seas 8/9 and OWF activity in Regional Seas 3 and 4. As noted above, it is likely that multiple sources (including simultaneous surveys and pile-driving) will occur at the same time, and that both activities may extend throughout much of the year, and be audible to marine mammals over much of the coastal Regional Seas. However, it seems improbable (given the spatial ranges discussed above) that injurious or severe behavioural levels of effect will coincide.

On the basis of the available data, it is therefore not considered that either regional or local prohibitions on the activities under consideration by this SEA are justified by acoustic disturbance considerations. Given the lack of definition of the actual survey and development programmes which may follow adoption of the draft plan/programme (in terms of duration and extent of acoustic sources, and the potential for temporal or spatial mitigation), it is also not possible to make specific recommendations concerning mitigation. However, it is noted that environmental assessments will be required on a project-specific basis for all areas under the existing regulatory regime, including requirements for consideration of deliberate disturbance of cetaceans (resulting in adverse effects on survival or breeding, or significant effects on local distribution or abundance) under the *Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007*. In addition, Habitats Regulations Assessments will be required for activities which may affect marine mammal populations within designated SACs (see Appendix 5).

Marine mammal sensitivities of individual Regional Seas – based on Appendix 3a.8 – are summarised below:

- **Regional Sea 1** is considered to have a moderate to high diversity and density of cetaceans, with a general trend of increasing diversity and abundance of cetaceans with increasing latitude. Harbour porpoise and white-beaked dolphin are the most widespread and abundant species, occurring regularly throughout most of the year. Minke whales are regularly recorded as a frequent seasonal visitor. Coastal waters of the Moray Firth and east coast of Scotland support an important population of bottlenose dolphins, while coastal to offshore waters off northeast Scotland appear to be important for white-beaked dolphin. Killer whales are sighted with increasing frequency towards the north of the area. Harbour porpoise are widespread and common throughout the Moray Firth, with Minke whale also commonly observed throughout this area, and particularly towards the south coast during summer months. Atlantic white-sided dolphin, Risso's dolphin and long-finned pilot whale can be considered occasional visitors, particularly in the north of the area. Large numbers of grey and harbour seals breed in the area, with high densities observed in many coastal waters and some areas further offshore.

A small, largely resident population of bottlenose dolphins exists off the east coast of Scotland. They typically range from coastal waters of the Moray Firth to the Firth of Forth, with occasional observations from further offshore in the North Sea; the dolphins are most frequently sighted within the inner Moray Firth and close to the southern coast of the Firth. The importance of this population, and the Moray Firth itself, is reflected in the designation of part of this area as a Special Area of Conservation (SAC). Recent studies funded by DECC in support of the SEA and Habitats Regulation Assessment have provided further detail on local distribution within the area, and are planned to provide further monitoring of the effects of anthropogenic noise (Thompson *et al*. 2010, Kongsberg 2010).

- **Regional Sea 2** – compared to the central and northern North Sea, the southern North Sea generally has a relatively low density of marine mammals, with the likely exception of harbour porpoise. While over ten species of cetacean have been recorded in the southern North Sea, only harbour porpoise and white-beaked dolphin can be considered as regularly occurring throughout most of the year, and minke whale as a frequent seasonal visitor. Bottlenose dolphin, Atlantic white-sided dolphin and long-finned pilot whale can be considered uncommon visitors. Important numbers of grey and harbour seals are present off the east coast of England, particularly around The Wash where harbour seals forage over a wide area.

- **Regional Sea 3** – the eastern English Channel generally has a relatively low density and diversity of marine mammals; it is a transition zone between the communities of the southern North Sea and the western Channel/Celtic Sea. Bottlenose dolphins are the most frequently sighted species in coastal waters, followed by harbour porpoise - although these are considered quite rare. Further offshore, sightings are generally of long-finned pilot whales or common dolphin. The area is not particularly important for seals, with no major colonies present and very little activity recorded.

- **Regional Seas 4/5** experience a relatively high density and moderate diversity of marine mammals. Four cetacean species occur frequently in the Regional Sea 4 area: minke whale, bottlenose dolphin, short-beaked common dolphin, and harbour porpoise. Long-finned pilot whale and Risso's dolphin are also regularly encountered. Grey seals are present in the area, but in low densities relative to the rest of UK shelf waters. Harbour seals are rarely encountered.

- **Regional Sea 6** – five species of cetacean are known to occur regularly in this area: harbour porpoise, short-beaked common dolphin, bottlenose dolphin, Risso's dolphin and minke whale. Grey and harbour seals are also regularly present in certain areas. In the Irish Sea, there are concentrations of bottlenose dolphins off west Wales (particularly Cardigan Bay) and off the coast of Co. Wexford in southeast Ireland. Two areas within Cardigan Bay are designated Special Areas of Conservation (SACs) with this species as an interest feature: bottlenose dolphin is a primary feature of the Cardigan Bay SAC located in the south of the bay off the coast of Cardigan, New Quay and Aberaeron; and a qualifying feature of the Lleyn Peninsula and the Sarnau SAC in the northern end of the bay and around the Lleyn Peninsula.

- **Regional Sea 7** – the Minches and western Scotland support a rich diversity and high density of marine mammals. Harbour porpoise and white-beaked dolphins are widespread and numerous. They are encountered throughout the year, although most frequently during summer months, when Risso's dolphins, common dolphins and minke whales are also sighted fairly frequently. Small numbers of bottlenose dolphins also occur around coastal waters of the Hebrides. Killer whales are occasionally observed throughout the area, most notably around seal haul-out sites during summer. Both grey and harbour seals are abundant throughout the area.

- **Regional Sea 8** north and west of Scotland supports a rich diversity and density of marine mammals, and is considered one of the most important areas for these animals in northwest European waters. Containing a variety of habitats, the region supports species commonly associated with shallower coastal areas, offshore shelf waters, and those occupying the deeper waters of the shelf edge and slope. Ten cetacean species are known to occur regularly in this area: harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, bottlenose dolphin, short-beaked common dolphin, killer whale, long-finned pilot whale, sperm whale and minke whale. Large numbers of grey and harbour seals breed in the area, with high densities observed in many coastal waters and some shelf areas further offshore.

- **Regional Sea 9** – the Faroe-Shetland Channel supports a rich diversity and high density of marine mammals. Cetaceans known to regularly occur include: Atlantic white-sided dolphin, bottlenose dolphin, killer whale, long-finned pilot whale, and sperm whale. Beaked whales, common dolphins, Risso's dolphins, and fin, sei and minke whales are also recorded to a lesser extent, while other species of baleen whale such as blue and humpback are occasionally observed. Hooded seals occur to a limited extent, particularly in the north; grey and harbour seals are very uncommon.

- **Regional Seas 10/11** – knowledge of marine mammal occurrence in the deep waters beyond the shelf slope to the west of Scotland is poor relative to other areas in UK waters. However, available information suggests that this is an important area for cetaceans, with a variety of species and high densities recorded, both as residents and large whales on migration.

Key areas of marine mammal sensitivity[24] therefore include:

- Fair Isle – Sumburgh Head (harbour porpoise, white-beaked dolphin, grey seal, harbour seal)
- North and east of Orkney (grey and harbour seals)
- The Moray Firth (bottlenose dolphin, harbour porpoise, minke whale) and coastal waters south to the North of England (bottlenose dolphin, white-beaked dolphin (further from shore)); including Smith Bank (grey and harbour seals), inner Firths (harbour seal), St Andrews Bay and outer Forth (grey seals)
- Areas adjacent to the Farne Islands and Donna Nook (grey seal)
- The Wash, outer Wash and off the Humber (harbour seal)
- Offshore areas of the southern North Sea (harbour porpoise)
- Western English Channel (common dolphin, minke whale)
- Coastal areas around Cornwall (bottlenose dolphin)
- Celtic Sea (common dolphin, minke whale)
- Coastal areas from Cardigan Bay to Liverpool Bay, including the Lleyn Peninsula (bottlenose dolphin, harbour porpoise, Risso's dolphin, grey seal)

[24] Areas suggested to be critical habitat for certain cetacean species in UK waters by the WDCS (reported in Clark *et al*. 2010) fall within the key areas described here.

- Coastal areas around Pembrokeshire (harbour porpoise, Risso's dolphin, common dolphin, minke whale, grey seal)
- Carmarthen Bay (harbour porpoise, grey seal)
- Hebridean Sea – Kintyre to Skye (harbour porpoise, bottlenose dolphin, grey seal, harbour seal)
- Continental shelf edge – Barra Fan to Miller Slide (various cetaceans, hooded seal)
- Stanton Banks (grey seal)
- North Minch and Cape Wrath to North Rona (harbour porpoise, white-beaked dolphin, Risso's dolphin, minke whale, grey seal)
- Hebridean shelf – notably around Monarchs and Flannans (grey seal)
- Deep waters to the west of the UK (various cetaceans including migrating humpback and blue whales)

### 5.3.7 Summary of findings and recommendations

As noted at various points throughout this section, considerable uncertainty surrounds many elements of our understanding of the effects of anthropogenic noise on the marine environment. Efforts to identify and address these gaps in understanding are ongoing through a variety of initiatives, including academic, government and industry projects.

Many identified data gaps relate to the characterisation of noise in the marine environment, such as a lack of understanding of ambient noise conditions, a need for more extensive measurement of noise from anthropogenic activities and its propagation, and clearer agreement on data collection & analysis methods. These underpin the need for greater ecological understanding, particularly with regard to progressing from the identification of individuals' behavioural responses to noise to understanding the ecological consequences of these responses in terms of population-level management objectives.

Despite considerable effort in recent years, notably in relation to wind farm development, the fundamental uncertainty relating to assessment of acoustic effect remains the establishment of meaningful thresholds of significant effect resulting from cumulative exposure. This is due to a combination of the complexity of influential factors, population characteristics of the target species, and conservation and ethical issues associated with direct experimentation; and it is unlikely that substantive progress will be made over the life of this SEA and the potential activities under consideration.

Previous SEAs have recommended that consideration should be given to establishment of criteria for determining limits of acceptable cumulative impact; and for subsequent regulation of cumulative impact (for example, in terms of total "exposure days" of individual blocks to received levels in excess of 120dB). In view of the probable increase in pulse noise generation associated with the combination of oil and gas licensing and offshore wind leasing, and concerns over cumulative effects (as yet not clearly understood), the previous OESEA recommended that within the key areas of marine mammal sensitivity identified above, operational criteria are established to limit the cumulative pulse noise "dose" (resulting from seismic survey and offshore pile-driving) to which these areas are subjected.

This recommendation is consistent with the proposed MSFD noise Task Group Indicator 1, which as noted above relates to high amplitude, low and mid-frequency impulsive anthropogenic sounds including those from pile driving, seismic surveys and some sonar systems, quantified as: **the proportion of days within a calendar year, over areas of 15'N x 15'E/W in which anthropogenic sound sources exceed either of two levels, 183dB re 1µPa$^2$.s (i.e. measured as Sound Exposure Level, SEL) or 224dB re 1µPa peak (i.e. measured as peak sound pressure level) when extrapolated to one metre, measured**

**over the frequency band 10Hz to 10kHz.** Although this metric is proposed as a monitoring indicator, rather than a threshold of acceptable level of effect on marine mammals, it is recommended that this cumulative dose is limited by the relevant regulatory controls, within the key areas of marine mammal sensitivity identified above, to historic dose levels (e.g. 2006) which are considered on the basis of available evidence not to have resulted in significant ecological effects or impact on Favourable Conservation Status. Clearly, this will require retrospective analysis of cumulative dose, which should be feasible based on reporting under existing systems.

In relation to the wind, wave and tidal elements of the draft plan, the recent MASTS[25] Marine Predator JRT workshop in March 2010 listed a series of monitoring issues, research priorities and knowledge transfer issues; several of these relate to the understanding of noise effects on marine mammals and their prey (MASTS 2010). These echo those identified previously by other fora and initiatives, including the previous DECC Research Advisory Group on marine renewable energy and the environment, and Scottish and Northern Irish marine renewables SEAs. Key research requirements in relation to the impact of offshore renewable operational and constructional noise listed by MASTS (2010) included:

- Accurate measurements of operational noise from different designs of wind turbines, wave and tidal devices are required to characterise their acoustic footprint.
- Understanding of variations in ambient noise, and other anthropogenic noise sources, must be improved to assess likely effects of additional noise from construction or operation of marine renewable devices.
- Data are required on the spatial scale at which marine predators and their prey respond to well characterised noise sources, and whether this varies according to individual characteristics, behavioural state or other environmental variables.
- Engineering solutions are required either to develop alternatives to piling (e.g. through Carbon Trust technology accelerator foundation/structures) or to decrease propagation of noise through water and/or sediments.
- Spatial modelling frameworks should be developed to mitigate cumulative effects when planning activity offshore and at ports/harbours. Incorporation of information on the patterns of occurrence of marine mammals in construction areas could also help plan construction activities to minimise costly downtime that might result from compliance with disturbance regulations.

[25] The Marine Alliance for Science & Technology for Scotland

# 5.4 Physical damage/change to features and habitats

## 5.4.1 Introduction

| Assessment Heading | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Physical damage to habitats from infrastructure construction, vessel/rig anchoring etc | X | X | X | X | X | X | X | 5.4.2.1 5.4.2.2 |
| | Changes/loss of habitats from major alteration of hydrography or sedimentation | | | | | ? | X | ? | 5.4.2.2 |
| | Physical effects of anchoring and infrastructure construction (including pipelines and cables) on seabed sediments and geomorphological features (including scour) | X | X | X | X | X | X | X | 5.4.2.1 5.4.2.2 |
| | Changes to sedimentation regime and associated physical effects | | | | | X | X | X | 5.4.2.2 |
| | Post-decommissioning (legacy) effects – cuttings piles, footings, foundations etc | X | X | X | X | X | X | X | 5.4.2.1 5.4.2.2 |
| | Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access. | X | X | X | X | X | X | X | 5.4.2.1 5.4.2.2 |

Several activities associated with the implementation of the draft plan/programme and associated technologies can lead to physical disturbance of the seabed, with consequential effects on seabed features, habitats and biotopes and potentially archaeological artefacts. The main activities which may result in disturbance are:

- Piling of monopile or jacket foundations
- Placement of gravity base and suction caisson foundations (including works to level the seabed)
- Laying and trenching of cables
- Anchoring of semi-submersible rigs
- Placement of jack-up rigs (seabed disturbance by spud cans)
- Wellhead placement and recovery
- Production platform jacket installation and piling
- Anchoring of floating production, wave, tidal and offshore wind installations
- Subsea template and manifold installation and piling
- Pipeline, flowline and umbilical installation and trenching
- Decommissioning of infrastructure

- Physical presence of structures in the water column

## 5.4.2 Consideration of the evidence

### 5.4.2.1 Offshore wind farms

#### Physical effects of anchoring and infrastructure construction on seabed sediments and geomorphological features (including scour)

Previous SEAs have compared the disturbance effects of oilfield activities and OWFs to those of fishing and natural events (e.g. storm wave action), concluding generally that OWF effects are minor on a regional scale (reflected in Round 2 SEA), although the Round 3 SEA does suggest that the risk of effect is highly variable across the nine Round 3 zones. The most important human pressure in terms of its spatial extent and level of impact on the UK marine environment results from fishing (e.g. Dinmore *et al.* 2003, Gage *et al.* 2005, Eastwood *et al.* 2007, Stelzenmüller *et al.* 2008). With the exception of relatively few designated conservation sites and temporarily or periodically closed areas (for fishery stock management purposes), trawl scarring is effectively unregulated in the UK and can be a major cause of concern with regard to conservation of seabed habitats and species (e.g. Witbaard & Klein 1993, de Groot & Lindeboom 1994, Jennings & Kaiser 1998, Kaiser *et al.* 2002a, Kaiser *et al.* 2002b). On the UKCS, concern has focussed on the continental shelf, but with increasing concern in relation to deep water areas (Bett 2000b, Roberts *et al.* 2000, Gage *et al.* 2005). The environmental impacts of trawling continue to be catalogued from a range of seabed habitats around the world (e.g. Mediterranean – Smith *et al.* 2000; Clyde Sea area – Hauton *et al.* 2003; Australian seamounts – Koslow *et al.* 2001; New Zealand seamounts – Clark & O'Driscoll 2003, Campbell & Gallagher 2007). However, implementation of effective mitigation measures is difficult at either a national or international scale (Gianni 2004, UNEP 2006).

To date, OWF developments on the UKCS have taken place in areas dominated by faunal communities rather than those of seagrass or macroalgae, due to either conditions that were too deep, too turbid or of unsuitable substrate. In general, physical damage on seabed properties, benthic populations and communities may result from smothering which can be direct (from physical disturbance or discharges of particulate material) or indirect (scour, or winnowing of disturbed material). The scale of direct damage to features and habitat loss associated with long-term placement of structures on the seabed is generally in proportion to the size of the object, and the duration of effect is equal to the operational lifespan of the structure – or may be indefinite if complete removal is not feasible or cost-effective. In the case of scour-related effects, the scale may be significantly greater than that of the fixed structure (see below).

Round 1 and 2 OWF turbines exclusively used monopole-type foundations. However, as part of Round 3 developments, alternative foundation types for OWFs are being considered (especially gravity base foundations and potentially floating structures for deeper waters), which have varying impacts on the physical environment (Table 5.2).

Table 5.2 – Physical impacts of different offshore wind farm foundation types

| Structure Type | Seabed Preparation Required | Seabed Footprint[1] ($m^2$) | Area of habitat affected ($m^2$) | Effect on hydrodynamic processes | Decommissioning |
|---|---|---|---|---|---|
| Monopile | Generally none | 12 - 300 | 12 – 40 | Minor changes to local sediment transport | May include jet and explosive cutting below the seabed |
| Gravity base | Levelling of seabed and/or removal of soft material and/or placing of stone layer | 300 - 3,500 | 300 - 2,000 | Scour around the base and minor changes to local sediment transport | Reversal of installation, potential for reuse |
| Jacket | Generally none | 6 - 500 | 6 – 25 | Minor changes to local sediment transport | May include jet and explosive cutting below the seabed |
| Suction caisson | Levelling of seabed and/or removal of obstructions | 175 - 2,000 | 175 - 700 | Minor changes to local sediment transport | Completely removed leaving nothing behind. |
| Floating – catenary & tension leg | Unlikely to be required | 5 - 1,200 | 3 - 300 Depending on mooring type | Minimal effects on hydrodynamics or sediment transport | Entire structure removed. Removal of anchors may be required |
| Artificial island | Generally none | 2,000 - 50,000 | 2,000 – 5,000 | Will significantly alter hydrodynamics and sediment transport depending on design and location | Unlikely to be removed |

*Note: [1] calculation of footprint includes allowance for possible scour (detailed below)*
*Source: DECC (2010q)*

## Construction activities

In terms of seabed preparation, monopile and jacket structures used in Rounds 1 & 2 OWF developments, have minimal impact on the seabed with a hole drilled into bedrock into which the monopile is placed and secured using cement. Similarly, floating structures, such as Statoil's Hywind demonstrator turbine and those proposed for deeper UK waters (e.g. by an Energy Technologies Institute study (ETI 2010)), require minimal seabed preparation. Gravity bases and suction caisson designs however require preparation of the seabed through levelling usually done by dredging and the removal of boulders and other obstructions. They also potentially require a thin stone bed or further dredging to create an even horizontal surface. This can affect habitats and biotopes through the direct removal of material from the seafloor, decreased water quality (Hiscock *et al.* 2002) and the mobilisation of sediments into the water column which may temporarily or permanently affect predominantly filter feeding communities through increased turbidity and sediment smothering and associated impacts on fish larvae and eggs (Teske 2000). Studies have however shown that disturbance from dredging is generally temporary with the recovery rate determined by the rate of reproduction, growth and dispersal of communities inhabiting the surrounding area.

The physical placing of a structure on the seabed, the installation of scour protection (see below), cabling and anchor structures all result in direct loss of habitat and sedentary species within the footprint (and any working area) of the structure. Table 5.2 shows broad calculations of the likely size of footprint (including allowance for possible scour) of different foundation types for OWF developments, although this is dependent on strength of the tidal currents in the region and the settling characteristics of sediment suspended during installation activities. Any associated habitat loss is likely to be permanent for all foundation types apart from potentially suction caisson (DECC 2010q) whereby the removal of the structure will allow the restoration of habitats within the footprint, although direct loss of organisms during installation will still occur. As with potential dredging effects, the recolonisation of the working area around the foundations after installation is likely to occur, again with the timescale dependant on dispersal of individuals and seabed preparation method. In terms of floating structures the physical footprint of the anchors on the seabed and therefore direct disturbance is likely to be small, depending on whether embedded anchors, piles, or gravity bases are used, but spread out over a potentially large area (in the case of catenary structures), with large areas included in the overall device footprint that are essentially undisturbed. The calculation of the exact area of habitat affected by each individual structure reflects how much direct disturbance would potentially occur from each foundation type depending on the physical and biological characteristic of the site. The overall physical areas affected by OWF developments are large e.g. 35km$^2$ for the Thanet Wind Farm in the southern North Sea, which began operation in September 2010 (Vattenfall website 2010). However, the spacing between turbines (500m along rows and 800m between rows for Thanet) means that there are large areas of undisturbed seabed within this wider footprint, further quantified in the spatial considerations section (Section 5.4.3).

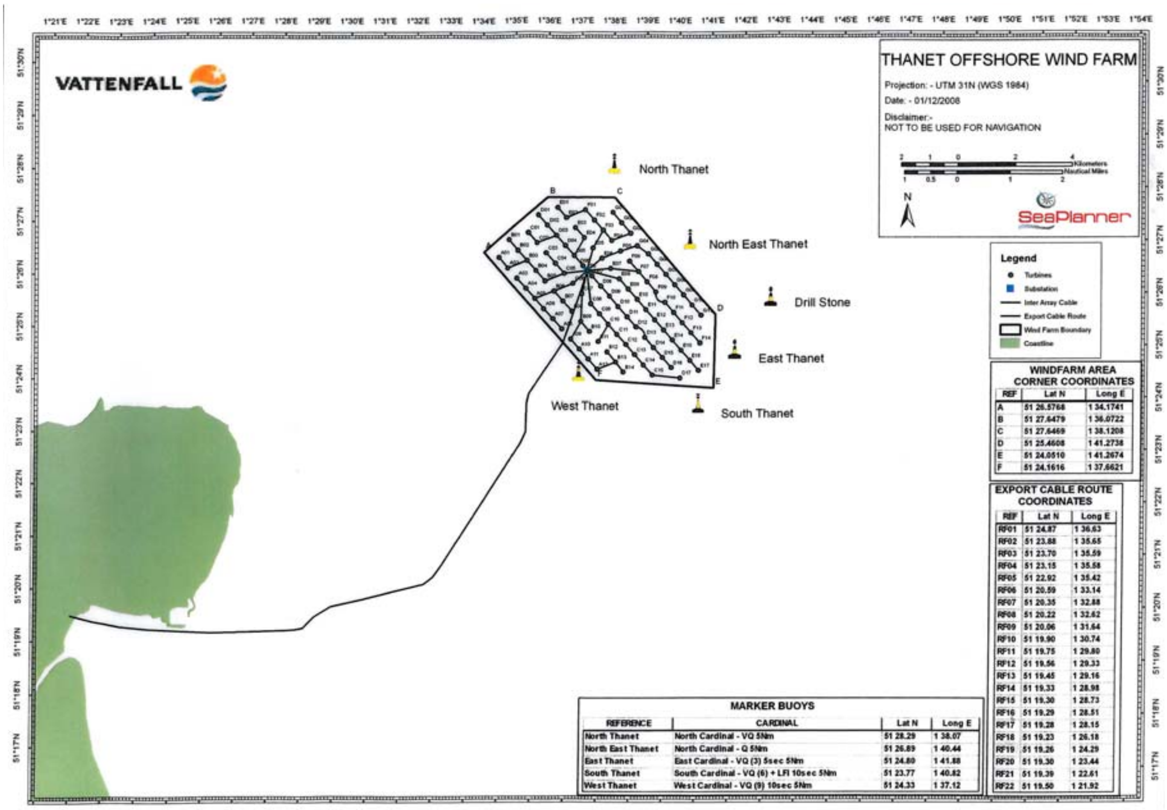
The ongoing construction of Round 1 and 2 sites, the development of Round 3 zones, Round 1 & 2 extensions and Scottish wind farm exclusivity zones means that further extensive cable laying operations are required to transfer the generated power from the OWF to the mainland. A Crown Estate report suggests that up to 8,000km of cabling could potentially be required for Round 3 sites alone (The Crown Estate 2010), with typically 1km long array cables for each turbine connecting 6 to 8 turbines in rows or strings to an offshore substation (RenewableUK 2010) which has a single export cable for close to shore developments (see Figure 5.10). A study by The Crown Estate (2007) demonstrated the feasibility of a trunk cable serving multiple wind farms and other offshore installations along the east coast of the UK from Orkney to the Greater Wash area. If implemented this would serve to reduce the number of export cables from installations and the number of onshore grid connection points, although additional housing, rock armouring or protective mattresses would be likely to be applied at any connection sites between export and trunk cables and at areas of cable cross-over (Lambkin *et al.* 2009). The annual National Grid offshore development information statement provides information relating to the possible development of both offshore and onshore electricity transmission systems, the interconnection of offshore generation with the onshore transmission network and reinforcement of the onshore network to provide the necessary connection and transfer capability. The 2010 statement (National Grid 2010) outlines different design strategies for offshore and associated onshore connection works required to provide licence compliant connection to the main interconnected transmission system (MITS). The three strategies are:

- Radial - Point-to-point connections from the offshore generation to suitable onshore MITS collector substations using current transmission technology.

- Radial Plus – Similar to radial in the use of point to point connections although groups of offshore generators are connected to the radial point-to-point connectors as opposed to a single group being connected radially.
- Integrated – An interconnected offshore design with multiple offshore platforms being interconnected, therefore providing fewer cables and reduced asset volumes.

The report is currently under consultation and will evolve as advised by feedback from the industry with a final report expected in June 2011 and the publication of the 2011 information statement in September 2011.

Figure 5.10 – Layout and cabling of the Thanet Offshore Wind Farm




*Source: Vattenfall (2010)*

Cables are buried by either ploughing, jetting, trenching, rock wheel cutting or mechanical chain excavation or in difficult areas are laid straight onto the seabed and covered with protective mattresses (BERR 2008b) in order to reduce scour effects. Typically the corridor area affected by burial is 4-6m wide (Lambkin *et al.* 2009), with depth of burial dependant on seabed conditions and potential threats to the cables (Table 5.3). During cable burial sediments are placed into suspension and consequentially produce similar environmental effects as dredging activities, discussed above. Although suspended sediment plumes can cause increased turbidity and oxygen demand in the water column, in many cases cabling is likely to take place in regions with already elevated suspended sediment concentrations due to ambient current regimes, occasional storm activity and fishing activities along the cable route (Lambkin *et al.* 2009). A recent study by BERR (2008b) concluded that the effects of sediment suspension are highly localised and temporary despite potentially covering large areas and "for the majority of cabling projects, the seabed and associated fauna and flora would be expected to return to a state similar to the pre-disturbance conditions. Exceptions could occur in hard clays and rock seabed types, where the cable trench would not naturally backfill, requiring intervention to backfill as part of construction works or else leaving permanent scarring of the seabed." A study, based on seabed samples and local hydrological conditions of the Norfolk (Cromer) offshore wind farm (Norfolk Offshore Wind 2002) appears to corroborate this statement. Re-deposition of 90% of the sediment suspended during the cabling process occurs in the near-field region within 200m of the source (Figure 5.11), with coarser sediments settling rapidly within a few metres of the cable route and finer sediments, representing only a small deposition depth, settling and remobilising with each tide. Disturbed areas are likely to be re-colonised by the same organisms, assuming that the substrate and habitats are restored to a similar state (e.g. Lewis *et al.* 2003). Within the FEPA licensing conditions there is a basic requirement for all developers to monitor suspended sediment concentrations and water quality in relation to pile installation (and other foundation types) and cable laying, as well as seabed morphology and scour from both pre and post construction bathymetry and from a subset of adjacent foundations (CEFAS 2009a). This requirement will provide additional information on the variability of these effects with different site sediment types and hydrography.

It is therefore suggested that although the amount of cabling required to support the expanding development of OWF sites will increase significantly, the potential effects are temporary and localised, although the impact of the landfall part of the cabling route is potentially substantial. A report into the grid connections required for Round 3 projects identified four new onshore substations requiring construction and reinforcement of several existing substations (including extensions and increased power lines) to ensure full transmission capacity for the additional power generation (The Crown Estate 2008b).

Table 5.3 – Recommended target cable burial depths for subsea ploughs for varying seabed conditions and threats

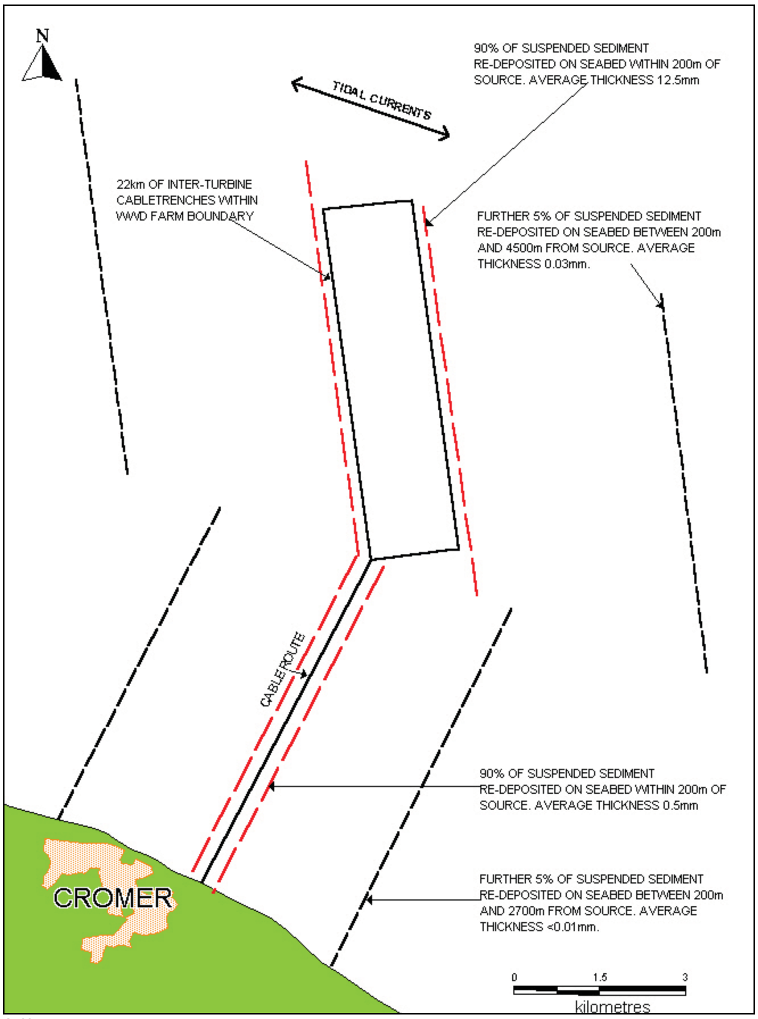
| Threat | Hard Ground (clay > 72kPa, rock) | Soft – Firm Soils (sand, gravel, clay 18-72kPa) | Very Soft – Soft Soils (mud, silt, clay 2-18kPa) |
|---|---|---|---|
| Trawl boards, beam trawls, scallop dredges | <0.4m | 0.5m | >0.5m |
| Hydraulic dredges | <0.4m | 0.6m | N/A |
| Slow net fishing anchors | N/A | 2.0m | >2.0m |
| Ship's anchors up to 10,000t DWT (50% world fleet) | <1.5m | 2.1m | 7.3m |
| Ship's anchors up to 100,000t DWT (95% world fleet) | <2.2m | 2.9m | 9.2m |

*Source: BERR (2008b)*

## Operational activities

Foundations and structures within the water column produce resistance and therefore reduce the water transport capacity of material and subsequent sediment properties, erosion and deposition, in the area. There is also a potential for coastal morphology to be affected by OWF developments through changes in current conditions, sediment erosion and deposition although initial investigations suggest that effects are generally localised to the OWF area (RPS 2005a, Morecambe Wind 2006). As there is a shift towards OWF development in deeper waters with greater wave exposure, different foundation types will be used. Ongoing monitoring of physical effects of monopole and jacket structures (detailed below) on sediments and geomorphological features has provided a base understanding of especially scour and wake patterns associated with these structures and related scour protection measures. However little is known about the effects of other foundation types, especially large (gravity bases) and complex (multi-legged) structures and further research needs to be conducted into the effects of these structures on both the tidal, wave and sediment regimes.

## Figure 5.11 – Maximum extent of sediment re-deposition at the Norfolk (Cromer) offshore wind farm




*Source: Norfolk Offshore Wind (2002)*

Table 5.2 outlines some of the general hydrodynamic effects that different foundation types are likely to have, with lower current speeds in the wake of the installation and slightly higher velocities around the parts of the structure facing the flow, especially for the larger gravity bases. Subsequent effects on sediment entrainment, turbidity, stratification and water quality are however very site-specific. Studies have suggested that for slender structures (e.g. monopiles) and typical wave conditions (those occurring many times each year) the effect of OWF foundations on wave and tidal regimes is minimal (ETSU 2002, ABPmer 2005), although empirical observations of gravity base structures suggest they have the potential to cause significant wave refraction (Lambkin *et al.* 2009).

At the Horns Rev Wind Farm, in 6-10m water depth, modelling work (The Environment Group 2005) suggested that the total current velocity would only be reduced by a maximum of 2% after the construction of the OWF, with little impact of the foundations on water exchange. Monitoring of sandeels, which are sensitive to changes in sediment sizes, completely abandoning sites if the silt/clay content rises above 6%, showed a 300% increase in numbers over a 2 year monitoring period suggesting no increase in the content of silt/clay and very fine sand in the site. A similar modelling study done for the Anholt Wind Farm (Energinet.dk 2009) in 15-20m water depth, investigated the impact of both monopole and gravity base foundation types. The study concluded that only minor hydrographic modifications were to be expected, with a potential reduction in current speeds of less than 2% in the wind farm area and a small increase around the wind farm due to flow diversion. A reduction of wave height of 3% within the wind farm area is not expected to significantly impact the coastlines 20 and 15km away although a small increase in turbulence near the foundations is likely to slightly weaken downstream local stratification of the water column.

In terms of the effects of OWF on large geomophological features, an analysis of the Nysted wind farm (The Environment Group 2005), which has gravity base foundations 15.5m in diameter, suggested a reduction to the wave height on the nearby Rødsand barrier islands of 10% and flow rates by 5-10% with correspondingly reduced sediment transport. The monitoring study used satellite imagery to show that the barrier reefs moved 15m eastwards per year before OWF construction, with the wind farm delaying the natural morphological progression by approximately 3m a year. There is the potential that any changes in sediment distribution and therefore bathymetry may affect the height of shallow sandbanks and therefore the breaking point of waves. Modelling work for the London Array OWF (RPS 2005a) has shown that different foundation types have different magnitudes of wave absorption and transmission effects. Monopile and tripod foundations were shown to have a low obstruction effect and low capacity to absorb energy from passing waves (with minimal far field effects), whereas gravity base foundations have the greatest capacity to absorb energy from passing waves, with increasing effects with decreasing depth of water as relatively more of the water column is occupied by the foundation. Prediction for effects of gravity base structures for the London Array OWF suggest values of 10cm wave height reductions just beyond the development site in north-easterly winds with effects at the Kent coast either negligible for low water and peak tides and up to 5cm at times of high water and peak ebb tides (RPS 2005a). If there was an increase in waves breaking within an OWF then there would be potential for increased turbulence, sediment suspension and scour around the foundations (discussed below), although as yet no monitoring data has provided evidence to support this.

Scour – a localised erosion and lowering of the seabed around a fixed structure – was recognised as an issue in relation to wind farm foundations at an early stage in the development of offshore locations, and has been subject to considerable research and monitoring. A two-stage project to identify, collate and review available field evidence for scour and scour protection from built Round 1 and other European sites was carried out for the UK Government RAG programme (ABPmer 2008, HR Wallingford 2008); these reports also provide a comprehensive bibliography of relevant literature. Five sites formed the principal datasets used in the study (Barrow, Kentish Flats, Scroby Sands, North Hoyle and Arklow Bank); all using monopile structures but representing a range of hydrodynamic conditions. Scour is a complex process, involving various interactions between the structure and water flow patterns and with implications for stability of the structure and sediment transport in the vicinity. Scour depth around piles is often quantified in relation to the pile diameter (S/D): HR Wallingford (2008) reported significant scour at Barrow (up to 0.44D), Kentish Flats (up to 0.46D), Scroby Sands (prior to rock dump scour protection, up to 1.38D), and Arklow Bank (prior to rock dump scour protection, up to 0.8D). These values equate to a maximum scour depth of around 6m (at Barrow and Scroby Sands). At Scroby Sands and Arklow Bank secondary scour i.e. not adjacent to the foundation itself, followed the installation of scour protection. Little or no scour (<0.125D) was observed at North Hoyle – it is not clear whether this was due to the presence of scour protection, the redistribution of drill cuttings (resulting from pilot hole drilling for the piles) which arose during the installation process or natural infill (HR Wallingford 2008). Data for Robin Rigg (Carroll *et al.* 2010) indicated values from 1.3D up to 1.77D, the upper end of data results seen to date. The extensive data set for this site (at 1-10m water depth) and those at Princess Amalia wind farm (at 19-24m water depth) and the range of scour values described by the COWRIE report for the sites, highlights the need for scour calculations to include geotechnical conditions and how the seabed soil structure varies spatially and with depth. In the context of physical damage to features and habitats, the key aspects are the spatial extent, severity and variability of scour, and of increased sediment deposition outside the scour footprint; together with whether the scour exposes seabed habitat which is significantly different from the original surficial sediment.

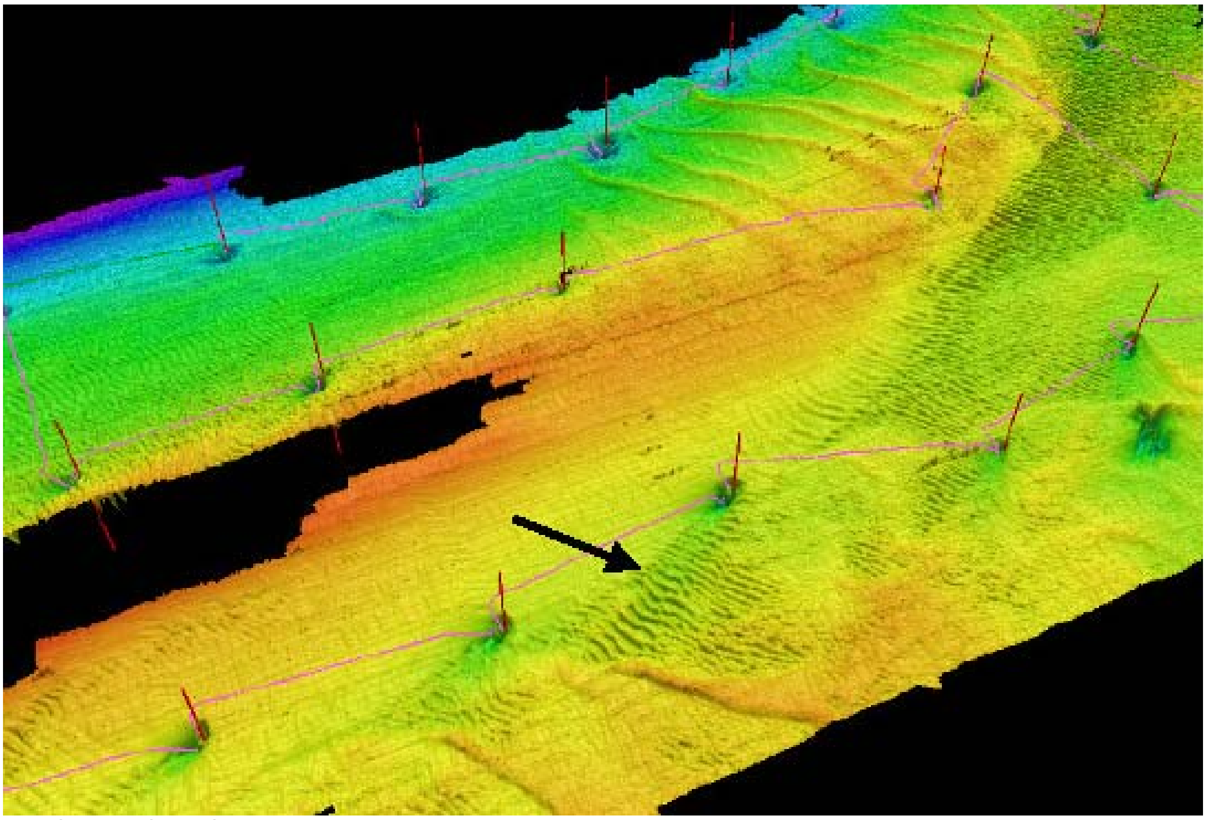
At Barrow, where the seabed consists mainly of sand overlying tillite and clays to a depth reaching 10m but including bedded muddy sands in this surface layer, the scour hole radius of individual piles varied from 0 to 15.7m at up to 62 days following pile installation. The typical total scoured area at this location was of the order of 50-100m$^2$, and exposed sediments differed to the pre-installation substrate (but typical of till exposures in the area). One year later, scour radii were much lower, with areas typically in the range 3-12m$^2$ (excluding the pile itself) and two years later scour depths for most piles were reduced to 0-4m in depth, with a trend for most scour holes to be backfilled to some extent (Carroll *et al.* 2010). The turbines which experienced greatest scour were located to the west of the wind farm area, where the bed consists of fine to medium sand and the thickness of the surficial layer is greatest.

At Scroby Sands, 30 monopiles of 4.2m diameter were installed between November 2003 and February 2004 with a minimum distance between monopiles of 320m. In addition to baseline and construction surveys, swathe bathymetric surveys have been carried out under FEPA licence monitoring conditions, providing a 4 year time series. Analysis by CEFAS (2006) indicates the development of scour pits associated with the monopiles (typical depths up to 5m and horizontal diameter 60m); and scour tails (trains of bedforms) extending from one monopile to the nearest downstream neighbour (see Figure 5.12). Seabed biotope within the scour pits is likely to be significantly altered, whereas it is probable that the depositional and more extensive scour tails do not result in significant habitat alteration (note the whole area is characterised by active sandwaves, which do not appear to be influenced by the construction (CEFAS 2006)).

The seven wind turbine monopiles at Arklow Bank (eastern coast of Ireland) are influenced by strong currents (>2m/s) and design wave heights approaching 6m, with a water depth of 5m over the crest of the bank (i.e. depth-limited wave-breaking occurs during storms). In the short delay between monopile installation and scour protection, scour holes (4m depth, 25m diameter; Figure 5.13) developed due to tidal current alone. Scour protection appears to have stabilised the bathymetry, with raised areas around some piles probably representing rock armour. The spatial extent of habitat modification is therefore around 450m$^2$ per pile (ABPmer 2008).

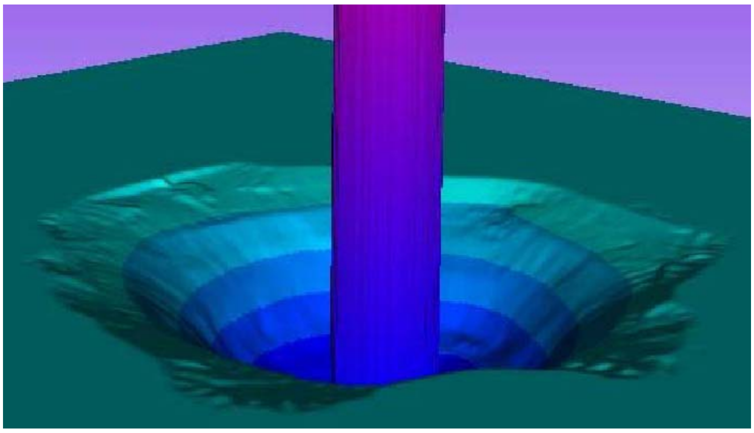
Although jacket structures piled to the seabed have been extensively used throughout the UKCS for oil and gas production, and have experienced substantial scour (and employed scour protection measures) in the southern North Sea (van Dijk 1980), this appears to have been regarded as much less of an environmental concern than for OWF developments. For example, Watson (1973) reported rapid scour around gas platform jacket legs in the southern North Sea to a depth of 1.5-3.5m, with (in some cases) individual scour pits coalescing to form a depression ("dishpan" or "global scour") over a much bigger area, of the same order as the area of the structure supported by the piles (Figure 5.14). Scour protection in the form of gravel, rocks, sandbags, gabions, pre-formed concrete blocks and frond mats is routinely used for subsea structures and for pipelines to prevent free-spanning (with resulting structural and snagging risks), although not always successfully.

Figure 5.12 – Fledermaus image looking northwest showing swathe bathymetry of February 2005 from the Scroby Sands OWF. Arrow shows bedform "tail" downstream from monopile



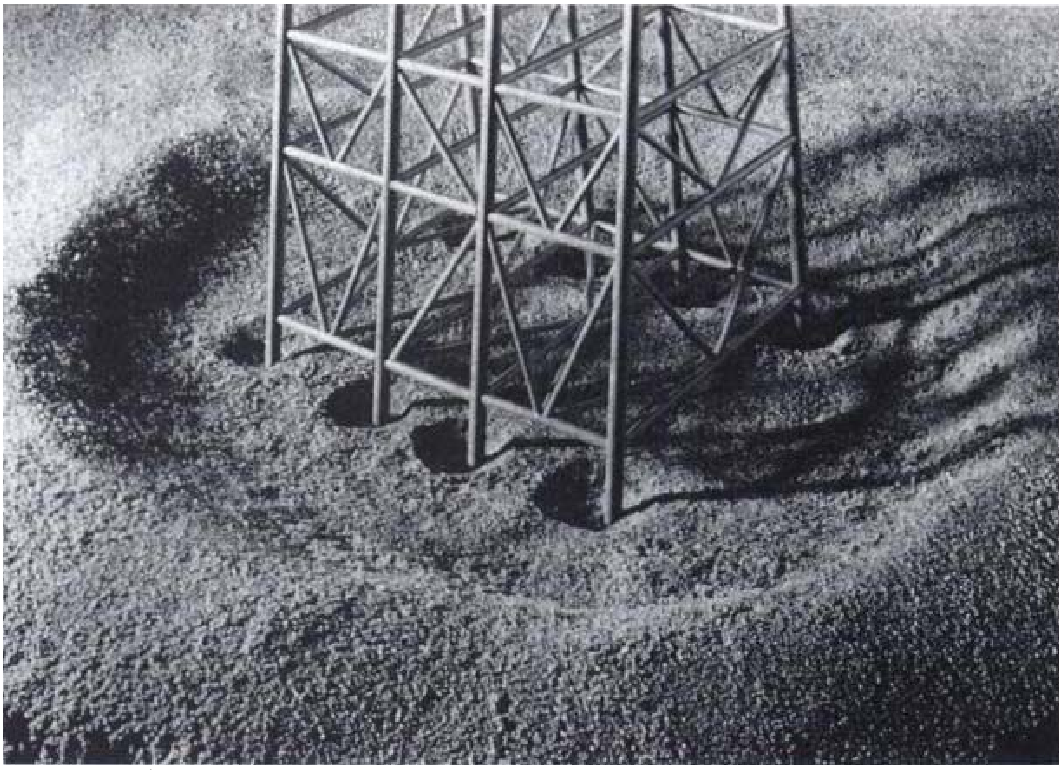
*Source: CEFAS (2006)*

Figure 5.13 – Scour hole observed after monopile installation, Arklow Bank



*Source: HR Wallingford (2008)*

Figure 5.14 – Representation of global and local scour development around a jacket structure



*Source: Angus & Moore (1982)*

Sediment monitoring at the Burbo Bank wind farm site (Carroll *et al.* 2010) suggested that an absence of any significant scour patterns may be attributed to the preparation of the bed before piling, with the type and size of armouring used appearing to be appropriate for the hydrodynamic conditions. This suggests that pre-piling armouring and insertion of filter layers (cobble-sized layer of slate 25-30cm in diameter designed to stabilise bed sediments and reduce scour) could be a useful technique at other sites to reduce the impact of turbines on bed levels.

Caution should however be applied to scour monitoring studies as Harris *et al.* (2010) suggests that scour depth can vary significantly under different current and wave regimes over time and therefore the timing of the survey is critical to comparisons with previous data for individual sites.

## Physical damage to habitats from infrastructure construction, vessel/rig anchoring and major alterations of hydrography or sedimention

Benthic habitats and communities are primarily determined by location, grain size, sediment dynamics and bedforms which are in turn dependent on hydrographical conditions, sediment erosion and deposition and seasonal changes in these parameters. Therefore any changes in local hydrography associated with OWF structures (discussed above) are likely to have an effect on benthic communities (Hiscock *et al.* 2002).

Changes in the benthic communities in the vicinity of the FINO I research platform (German Bight; 28m water depth) were described by Schröder *et al.* (2006). In addition to colonisation of hard surfaces by epifaunal species, changes in sediment composition in the surrounding area due to hydrodynamic effects and the exclusion of trawling were noted. Within scour pits (1-1.5m deep; up to 5m radius), sediment was much more heterogeneous following construction, and consisted of a layer of shell hash (sometimes more than 30cm thickness) in contrast to the fine sand baseline substrate. Changes in faunal communities were consistent with this (i.e. loss of typical sand infauna including *Tellina (Fabulina) fabula*, *Echinocardium cordatum*, *Poecilochaetus serpens*, *Chaetozone setosa, Spiophanes bombyx*) and increase in mobile predators (*Pagurus bernhardus, Liocarcinus holsatus*). The polychaete *Eunereis longissima* also appeared in large numbers within the scour pit (<5m from the pile). Over a wider scale, observed changes over a one-year timescale were related to the absence of fishing in a 500m exclusion zone – increased densities of sedentary filter and deposit feeders; reduced abundance of mobile predators and scavengers compared to fished areas. These effects are probably widespread in relation to exclusion zones around oil and gas infrastructure in the North Sea, but have not been well characterised in monitoring studies (which are focussed on the detection of point source disturbance and contamination effects from the installation). However, Bergman *et al.* (2005) documented a distinct difference between the fishery-closed area around gas production platform L07A in the southern North Sea (Frisian Front) and those from the regularly trawled reference areas. Conspicuous differences included higher species richness and evenness in dredge samples and higher abundances of mud shrimps (*Callianassa subterranea, Upogebia deltaura*) and sensitive bivalves (*Arctica islandica, Thracia convexa, Dosinia lupinus, Abra nitida, Cultellus pellucidus*) in the non-fished area near the platform. Boxcore samples confirmed the higher abundance of mud shrimps in the non-fished platform subarea and also demonstrated higher densities of the brittlestar *Amphiura filiformis*.

There has been considerable monitoring at two Danish OWF sites, Horns Rev and Nysted since their construction in 2002-2003 (DONG Energy *et al.* 2006). Overall, the main effect from establishing the wind farms was the introduction of hard bottom structures (turbine foundations and scour protection) onto seabeds that almost exclusively consisted of sandy sediments. This has increased habitat heterogeneity and changed the benthic communities at the turbine sites from typical infauna communities to hard bottom communities. There were however no-negligible impacts detected from the changes in the hydrodynamic regimes on the native benthic communities, seabed sediment structure or established epifouling communities. At Horns Rev, a general increase in sediment coarseness and changes in infaunal community structure was found from the pre-construction to the post-construction situation. The changes were not attributable to the presence of the wind farm because parallel changes were found at the reference sites. Similarities in the establishment, succession and distribution of epifouling communities on structures and scour protection were found between the Horns Rev and Nysted OWF sites. The differences in species composition were mainly attributable to differences in salinity between the two sites.

Benthic monitoring has been carried out under FEPA licence conditions at constructed Round 1 & 2 OWF sites in the UK with guidelines outlined as part of Round 3 licensing agreements (CEFAS 2010); resulting in a monitoring timescale of several years at some sites. In general, community disturbance outside the immediate area around piles has been minimal, and difficult to distinguish from natural variability. As noted above, exclusion of fishing activity is likely to be a significant factor at most locations, and is difficult to control for in experimental design. For example, at North Hoyle a combination of grab survey and beam trawls were used to assess effects on infauna and epifauna: changes were observed in numbers of species and individuals, but with no uniform pattern, similar changes at control stations and no substantial evidence for changes to habitats from baseline conditions (Npower 2007). At Barrow, an epifaunal survey carried out eight months after installation of the piles (RSK ENSR 2006) reported a typical fouling community dominated by barnacles, mussels, anemones (*Metridium senile*), and hydroids; shrimp (*Crangon*) and whiting were observed in large numbers, particularly where mussel populations were well developed. Despite the scour previously observed at this development (see above), the epifaunal survey noted no effects on seabed habitats, which were variable and ranged from fine sand to cobbles (consistent with a patchy sand veneer over glacial till).

Habitat recovery from temporary disturbance caused by, for example, anchor scarring, anchor mounds, cable scrape and trenching will depend primarily on re-mobilisation of sediments by current shear. Benthic population recovery takes place through a combination of migration, re-distribution (particularly of microfaunal and meiofaunal size classes) and larval settlement. On the basis that seabed disturbance is qualitatively similar to the effects of wave action from severe storms; it is likely that sand and gravel habitat recovery from the processes of anchor scarring, anchor mounds and cable scrape is likely to be relatively rapid (1-5 years) in most of the shallower parts of the UKCS. Muddier sediments support benthic communities characterised by the presence of large burrowing crustaceans and pennatulid sea-pens (*Virgularia mirabilis* and *Pennatula phosphorea*). Pennatulid mortality is probably high following physical disturbance, although crustacea are probably able to restore burrow entrances following limited physical disturbance of the sediment surface (a few cm). However, mud habitats are probably more sensitive to physical disturbance than the coarser sediments typical of high wave- and current-energy areas.

Herring are demersal spawners and dependant on localised areas of suitable substrate (in relatively shallow water); herring eggs are believed to be particularly susceptible to smothering, and there has therefore been a requirement for many years that potential herring spawning areas are identified by sidescan sonar and seabed sampling in advance of oil and gas drilling and development; and that appropriate mitigation such as timing and/or avoidance of specific areas is undertaken with the prior approval of regulatory agencies. Similar controls are applied through the EIA and FEPA licensing processes to OWF developments (CEFAS 2009b).

In addition to the potential effects of smothering, sediment plumes in the water column and settling to the seabed from construction activities and cable or pipeline trenching activities can potentially result in effects on pelagic and benthic biota through clogging of feeding mechanisms, temporarily altering the nature of the seabed sediments or in near surface waters, reduction of light for photosynthesis (Newell *et al.* 1998). The extent of effects will vary according to the frequency of occurrence and the tolerance of the species involved, itself a function of the average and extreme natural levels of sediment transportation/deposition experienced in an area (see also studies of thin-layer (<15cm) disposal of dredged material, Wilber *et al.* 2007). Near-bed concentrations of suspended particulate material (SPM) in coastal and southern North Sea areas and in the Irish Sea are high, and the effects of anthropogenic sediment plumes are unlikely to be significant or long-term.

On the UKCS, habitats which potentially qualify as biogenic reefs under the Habitats and Species Directive Annex I are associated with several species: blue mussels *Mytilus edulis*, horse mussels *Modiolus modiolus*, ross worms *Sabellaria* spp., the serpulid worm *Serpula vermicularis*, the bivalve *Limaria hians* and cold-water corals such as *Lophelia pertusa*. These habitats may be vulnerable to physical damage and smothering. In the case of designated, proposed or candidate Natura 2000 conservation sites (including potential offshore sites which may be designated in future), existing controls include the requirement for an Appropriate Assessment before consent for the proposed activity can be given.

In relation to OWF development, because of the likely distribution of these, *Sabellaria* reef is the most likely qualifying habitat to be affected by direct physical damage. *Sabellaria* is probably relatively tolerant of indirect disturbance (e.g. turbidity resulting from sediment mobilisation or scour), with high potential for recovery; but reefs are clearly susceptible to damage from direct impacts such as fishing (Holt *et al.* 1997, Jackson & Hiscock 2008). Subtidal *Sabellaria spinulosa* reefs are reported to have been lost due to physical damage in at least five areas of the northeast Atlantic. In the Waddensee, Riesen & Reise (1982) reported that extensive subtidal *S. spinulosa* reefs were lost from the Lister Ley, island of Sylt, between 1924 and 1982; they reported that local shrimp fishermen claimed to have deliberately destroyed them with "heavy gear" as they were in the way of the shrimp trawling. Reise & Schubert (1987) reported similar losses from the Norderau area, and attributed them to similar causes. Shrimp trawling still occurs in these areas and the *S. spinulosa* have not reappeared, but have effectively been replaced by mussel *Mytilus edulis* communities and assemblages of sand dwelling amphipods (Reise & Schubert 1987). In Morecambe Bay, fisheries for pink shrimp *Pandalus montagui* have been implicated in the loss of subtidal *Sabellaria* reefs in the approach channels to the Bay (Mistakidis 1956, Taylor & Parker 1993). Aggregate extraction is also clearly implicated in damage to *Sabellaria* reefs (Holt *et al.* 1997); although this activity is subject to licence controls and compared to fishing impacts, gravel extraction is likely to be more limited in extent, more controlled, and less likely to continue for very long time periods, so that although direct damage would obviously be severe, recovery from adjacent undamaged areas seems more likely.

*Sabellaria spinulosa* and *S. alveolata* (which also forms reefs) are both widely distributed, and reef-forming populations are known to be spatially patchy and temporally variable (see Appendix A3a.2 of OESEA for discussion of observed changes to the Saturn reef). Direct impact of OWF foundations will be of relatively limited spatial extent, and in view of the wide habitat tolerance of *Sabellaria* it is likely that scour protection would be as likely to support aggregations as surrounding seabed (particularly when overlain by a sand veneer). Cable placement and trenching, both within the array and shore cables, may have a greater spatial extent of disturbance, but will be of short duration and habitats will recover rapidly over buried cables. OWF development would therefore have little effect at a population level; and local disturbance may well be offset by protection from mobile fishing effects over a substantially wider area. Conversely, decommissioning plans (e.g. Thanet Offshore Wind Ltd 2007) have already conjectured that removal of foundations or scour protection may have an adverse effect on any *Sabellaria* reef aggregation which is expected to develop during the operational life of the farm; and that it will be necessary to adopt an approach to decommissioning that makes the wind farm area safe for users of the sea, whilst also maintaining the extent and distribution of any *Sabellaria* aggregations conjectured to be of importance to nature conservation.

The North Norfolk Sandbanks are currently under consideration as a candidate SAC (as of August 2010) and Dogger Bank is currently under consideration as a potential SAC (JNCC 2010). Although both are under consideration as Annex I sandbanks which are slightly covered by sea water all the time, the physical geology of the two areas is very different. The North Norfolk sandbanks as a group are the best example of tidal linear sandbanks in UK waters; sandwaves are present on the banks indicating that the surface sediment is regularly mobilised by tidal currents (JNCC 2008). The North Norfolk banks are active systems that are thought to be progressively, although very slowly, elongating in a north-easterly direction although it is difficult to demonstrate whether or not such migration occurs today and at what rate (Cooper *et al.* 2008). However, recent observations of water movement, sand wave asymmetry and sand tracers support an offshore sand transport component (Collins *et al.* 1995) with material transported offshore partly contributing to the development and maintenance of the sandbank system, and eventually dissipated into deeper waters. It has been suggested that new embryonic sandbanks are present in the swales between the banks.

In contrast, the Dogger Bank was formed by glacial processes before being submerged through sea level rise. Tidal current velocities across the Dogger Bank are considered insufficient for initiating sediment transport although large parts of the Dogger Bank are however situated above the storm-wave base: Klein *et al.* (1999) estimated that during a storm event, sediment up to medium sand was mobilised in 60m water depth at the northern slope of the Dogger Bank. The morphology of the Dogger Bank is largely controlled by the extent of the Dogger Bank Formation, a geological formation up to 42m thick that was deposited at the end of the last ice age (Cameron *et al.* 1992) and is overlain by Holocene sands of variable thickness. Coarser gravelly sand and sandy gravel substrates together with isolated patches of larger pebble and cobble-sized particles have been recorded in southern and western sections of the bank.

Hypothetically, therefore, anthropogenic structures or activities which interfered with sediment mobility could – over an extended timescale – influence the physical structure and habitat of the North Norfolk banks but would be very unlikely to significantly influence the Dogger Bank. However, scour, scour tails (as observed at Scroby Sands) and the required extent of scour protection are of limited spatial extent in relation to the overall OWF footprint (see below) and it is considered extremely unlikely that OWF development would have a significant influence on the physical habitat in either area.

## Physical damage to submerged archaeology

OWF also have the potential to damage archaeological artefacts and sites, in particular through the trenching of cables and pipelines into the seabed and through rig and other vessel anchoring. The recognition of the importance of prehistoric submarine archaeological remains has led to a number of recent initiatives.

A legal and policy framework for protection of maritime archaeology is in place. Guidance notes for the aggregates industry have been formally published (BMAPA & English Heritage 2003) covering legislation, statutory controls, possible effects of aggregate extraction, obtaining archaeological advice, application procedures, assessment, evaluation, archaeological investigation, mitigation, and monitoring. Flemming (2004b) suggested that an equivalent guide could be produced for the offshore oil and gas industry and its contractors; such a guide was published in the following year for Irish waters by Quinn (2005) but the majority of the information and advice is applicable to operations in the UK.

COWRIE (2008 and 2010) has also produced guidance on the assessment of cumulative impacts on the historic environment arising from offshore renewable energy projects. The guidance focuses on key elements of the cumulative assessment process, including an integrated approach, consideration of other actions, scoping, baseline study, impact dimensions, constraints, mitigation, monitoring and management, and communication.

## Decommissioning activities and post-decommissioning effects

The expected lifetime of turbines is 20 to 25 years and 40 years for cables and other associated infrastructure. Similar physical impacts to those outlined for the installation of OWF, sediment and habitat disturbance, are likely due to decommissioning activities. Regulations set by the DTI (2006) state that unless for good reason the whole of all disused structures and installations should be removed. Exceptions include areas where removal would cause unnecessary disturbance to benthic communities and physical features and in waters exceeding 100m depth, whereby allowing a clearance of 55m below the waterline has previously been used in the oil and gas industry. Removal of foundations by cutting below the natural seabed level should be done at such a depth that the remains are unlikely to become uncovered by currents or the migration of geomorphological features (DTI 2006).

The complete removal of buried cables may also be exempt given the spatial impact of removal on the marine environment and the financial costs involved. There may also be a case for leaving some scour protection materials in place especially if a significant marine habitat has established itself over the life of the installation. Any plan for wholly or partially removing objects must also include provision for restoring the area to the condition that is was prior to construction as part of Section 105 of the *Energy Act 2004*.

Removal of OWF may lead to varying degrees of disturbance to the seabed and associated communities especially where buried cables, foundations or scour protection are involved. Table 5.2 outlines some of the potential methods of decommissioning of OWF for different foundation types (DECC 2010q). The foundation type with the least environmental impact in terms of decommissioning are floating foundations which are simply detached from their anchors and suction caisson where water is pumped back in to the foundation which releases from the seabed to be reused without leaving anything behind. Choosing the correct removal method and most appropriate season for biological communities present will help to reduce these impacts, alongside the re-use of as much infrastructure as possible. If decommissioning activities are likely to have a significant effect on a European site designated under the EC Habitats Directive or EC Wild Birds Directive, an appropriate assessment may have to be carried out as part of the *Conservation (Natural Habitats &c.) Regulations 1994* (as amended) and the *Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007*.

Due to the likelihood that many OWF installations will not be totally removed during decommissioning post-decommissioning effects need to be taken into consideration. During decommissioning care would need to be taken to ensure that any remaining cables were buried to a significant depth so that they would be unlikely to become uncovered by sediment and current processes. This also applies to the cutting of piles and other below seabed style foundation types. Any foundations, scour protection or structures left on the seabed are likely to have similar impacts to those in operation, e.g. scour, and therefore long term monitoring could potentially be required to ensure that the environment and associated biota is not adversely impacted in the long term. Due to the infancy of marine renewable energy projects no decommissioning has yet to occur, although there are guidelines in place (DTI 2006) including a requirement to minimise environmental impacts. OWF projects are also obliged to detail future monitoring strategies for any objects either left in position or not wholly removed at decommissioned sites as part of Section 105 of the *Energy Act 2004*.

### 5.4.2.2 Other elements of the draft plan

## Oil and gas

Similar to OWF, the impact of oil and gas installations on the seabed are considered minor on a regional scale in comparison to fishing activities. At the present time and for the foreseeable future, hydrocarbon developments are also exclusively in regions dominated by faunal communities and therefore share most of the potential physical impacts with OWF, presented above. The primary issue is the placing of the infrastructure on the seabed and associated loss of habitat and installation issues described for OWF. The oil and gas industry has however increasingly adopted remotely operated vehicles (ROV) prior to installation and better navigational equipment to make it easier to avoid disturbance of vulnerable marine communities (OSPAR 2009a).

Another significant physical effect associated with oil and gas installations is the laying of pipelines. In UK waters over 34,000km of oil and gas related pipelines have been laid of which 7,718 are considered to be major trunk pipelines carrying either oil or gas (OSPAR 2009a). The physical effects of pipelines are the same as those for cabling presented in the

OWF section, with the footprint primarily being dependant on whether it is buried or not and the hydrology and sediment activity in the locality. Monitoring by service companies to check the integrity of the pipelines is common practice and therefore associated spatial environmental impacts are well surveyed.

In terms of submerged archaeology, oil and gas installations have the same potential for damage as OWF, although in addition, oil and gas and OWF activity is also recognised to present the opportunity to provide beneficial new archaeological data, for example through rig site or pipeline route mapping and sediment coring. Flemming (2004b) therefore suggested that rather than seeking to prevent or limit oil and gas activities, "it is therefore in the interests of long term preservation of the archaeological sites, and in the interests of acquisition of archaeological knowledge, that we use industrial and commercial activities as a means of identifying archaeological prehistoric sites in the offshore area".

The decommissioning of oil and gas installations is subject to the same conditions as those presented for OWF, with 122 offshore installations being brought ashore for disposal in the OSPAR region since a ban on dumping offshore installations in 1999 (OSPAR 2009a). Only 5 permits have been issued to allow parts of structures to remain in place.

## Gas storage

Gas storage projects in UK waters located in existing hydrocarbon reservoirs and using existing infrastructure are subject to the same impacts as those detailed for oil and gas installations. However, those that are located in non hydrocarbon reservoirs (e.g. salt caverns), which require excavation, may potentially have significant physical impacts on the seabed and habitats.

The Environmental Statement for the Gateway gas storage project in the Eastern Irish Sea (Gateway 2007) identified the following activities which may result in physical disturbance to the seabed:

- Drilling operations during cavern creation resulting in the discharge of cuttings
- Installation of the monopods (monopile foundations)
- Installation of pipelines/cables (including dredging, ploughing and jetting)
- Temporary presence of rigs and vessels during construction, installation and maintenance activities

The installation of foundations, pipelines/cables and the effects of structures in the water column during operation are all discussed in the OWF and Oil & Gas sections above. In terms of the discharge of cuttings, Gateway (2007) estimated that approximately 6,700 tonnes of cuttings would be produced and discharged just below the sea surface from 20 separate gas storage caverns created within the salt strata. A model used to estimate the deposition of the material on the seabed predicted that 95% (mostly particles >1mm diameter) would be deposited within 165m of the discharge point and the remaining finer particles, whilst settling up to 1.6km from the discharge point, were likely to be in such small concentrations as to be undetectable. The effect of additional suspended sediment within the water column was likely to be very temporary with high settling velocities predicted. Initial impacts on benthic habitats would be associated with smothering (shown to be significant at depths >1mm (Bakke *et al.* 1986)) but the high tidal and wave generated currents and the shallowness of the predicted depth of the cuttings (ca. 10mm) suggested that this effect will be temporary and the cuttings would become well mixed with the surrounding sediments. Further evidence of this mixing comes from wells drilled in the area (Dalton, Millom East and Millom West) by Burlington Resources Ltd (now ConocoPhilips) which reported that ROV surveys immediately after drilling operations identified no evidence of cutting piles (BRIS 2002). The effects of drill cuttings have been discussed in previous SEAs in relation to oil and gas activities and are described in Section 5.9 and 5.10 of the current Environmental Report.

In terms of the presence of rigs and vessels during the installation of gas storage sites, lift vessels and drilling rigs are likely to have the following footprint (Table 5.4) although they are only likely to be present at the site for short time periods:

Table 5.4 – Estimated footprint of rigs/vessels used for installation/drilling activities

| Rig / vessel type | Construction activity | Area of the seabed impacted per cavern | Total area of seabed impacted for all 20 caverns |
|---|---|---|---|
| Jack-up drilling rig<br>3 legs, with base of each spud can<br>approx. 10m in diameter | Drilling operations | 236m$^2$ | 4,712m$^2$ |
| Lift vessel (assumed to be equivalent to jack-up barge)<br>8 legs, with base of each spud scan<br>approx. 5m in diameter | Installation of monopod substructures | 157.1m$^2$ | 3,124m$^2$ |
| Lift vessel (assumed to be equivalent to jack-up barge)<br>6 legs, with base of each spud scan<br>approx. 5m in diameter | Installation of topsides | 157.1m$^2$ | 3,124m$^2$ |

*Source: Gateway (2007)*

As with the footprint effects associated with OWF foundations, the impact will result in the loss of benthic communities and habitats at the site. Onshore storage and terminal facilities will also be required which will have a physical footprint and impact on the onshore environment. For example, the Baird Gas Project, southern North Sea (Bacton Storage Company Ltd 2009), detailed onshore and tidal infrastructure requirements including cofferdams 10-40m wide, pipeline risers and gas compression, processing and conditioning facilities as well as the terminal itself. Decommissioning effects of gas storage projects are likely to be similar to those for OWF and oil and gas.

## Carbon dioxide storage

As with gas storage the majority of physical impacts of carbon dioxide storage projects are covered by the OWF, oil and gas and gas storage sections. The primary issue for both carbon dioxide storage in existing hydrocarbon reservoirs and those in non hydrocarbon reservoirs is the laying of pipelines and cables and the building of land based infrastructure (DECC 2010h).

## Wave

Most of the wave energy converting devices are either catenary or single point moored (Oxley 2006, Harris *et al.* 2004), with associated physical impacts on the seabed for different foundation types discussed in the OWF section. Different anchoring types for wave devices are summarised below (Harris *et al.* 2004):

- Drag embedment anchor - holding capacity is generated in the main instalment direction by the embedment of the anchor in the ground
- Driven pile or suction anchor - holding capacity is generated by forcing a pile mechanically or from a pressure difference into the ground, providing friction along the pile and the ground.
- High drilled and grouted anchor - holding capacity is generated by grouting a pile in a rock with a pre-drilled hole.
- Gravity anchor - holding capacity is generated by dead weight providing friction between seabed and anchor

The anchors used for wave devices are smaller than those deployed for OWF, with concrete gravity foundations at the Lyskil research site in Sweden being >2m in diameter (Leijon *et al.* 2008) compared to 20-50m for individual OWF installations (DECC 2010q). However, the associated impacts remain the same, just on a smaller scale depending on how many devices and arrays are deployed. A study into the effects of moored wave energy devices on soft-bottomed communities at the Lysekil research site (Langhammer 2010) from 2004-2008 showed that there was only minor direct ecological impacts of the device foundations beyond the natural level of variation, which was highly variable in space and time due to strong natural disturbances of the seabed by powerful waves. The primary issue is scour, discussed extensively in the OWF section (Section 5.4.2.1). It is however likely that only demonstrator scale wave projects will be developed within the lifetime of this report (apart from in the Pentland Firth and Orkney region) and therefore the scale of associated effects are expected to be minimal, with an overall spatial footprint of arrays of between 1 to 10km$^2$.

Some wave energy devices are shoreline based (e.g. LIMPET (Wavegen 2010)) and therefore have associated physical impacts on coastal processes and habitats. This is predominantly due to the physical footprint of the structure, which is semi-permanent/permanent and therefore unlikely to be removed after use. Wave devices work by acting as wave breakers or by removing the wave energy from the sea and have associated impacts on current and water column characteristics and sediment deposition and accretion. These physical effects of the presence of the device in the water column are discussed further in Section 5.5.2.

## Tidal stream

The devices currently in use or production have one of 4 support structure types (Rourke *et al.* 2010):

- Gravity structure
- Single monopile
- Tethered floating structure
- Tripod structure – using 3 steel monopiles

The physical effects associated with the installation, decommissioning and physical presence of a structure within the water column are all discussed within the OWF and oil and gas sections above, with cabling again being a potentially important issue as the number and extent of tidal stream deployments increase. Anchoring during installation also potentially has an impact, with hydrographical and geophysical surveys undertaken after the installation of the Stingray tidal stream device, Yell Sound, Shetland (DTI 2005b), showing a 63m long seabed scar attributed to the anchoring of one of the construction barges. Demonstrator and pre-commercial scale tidal stream projects are likely within the currency of this SEA (apart from in the Pentland Firth and Orkney region) and therefore impacts are likely to be small, with the estimated footprint of arrays between 0.5 to 5km$^2$. Dynamic effects on the physical environment associated with the movement of blades within the water column are discussed in Section 5.5.2.

## Tidal range

There are several different designs for extracting energy from tidal range; the main ones being tidal barrages and tidal lagoons. Both barrage and lagoon designs may have large physical footprints and may have significant environmental impacts on both the physical environment and associated habitats. However, mitigation measures (e.g. two way operation, regular sluicing and fish diversion) may reduce the impact.

### Tidal barrages

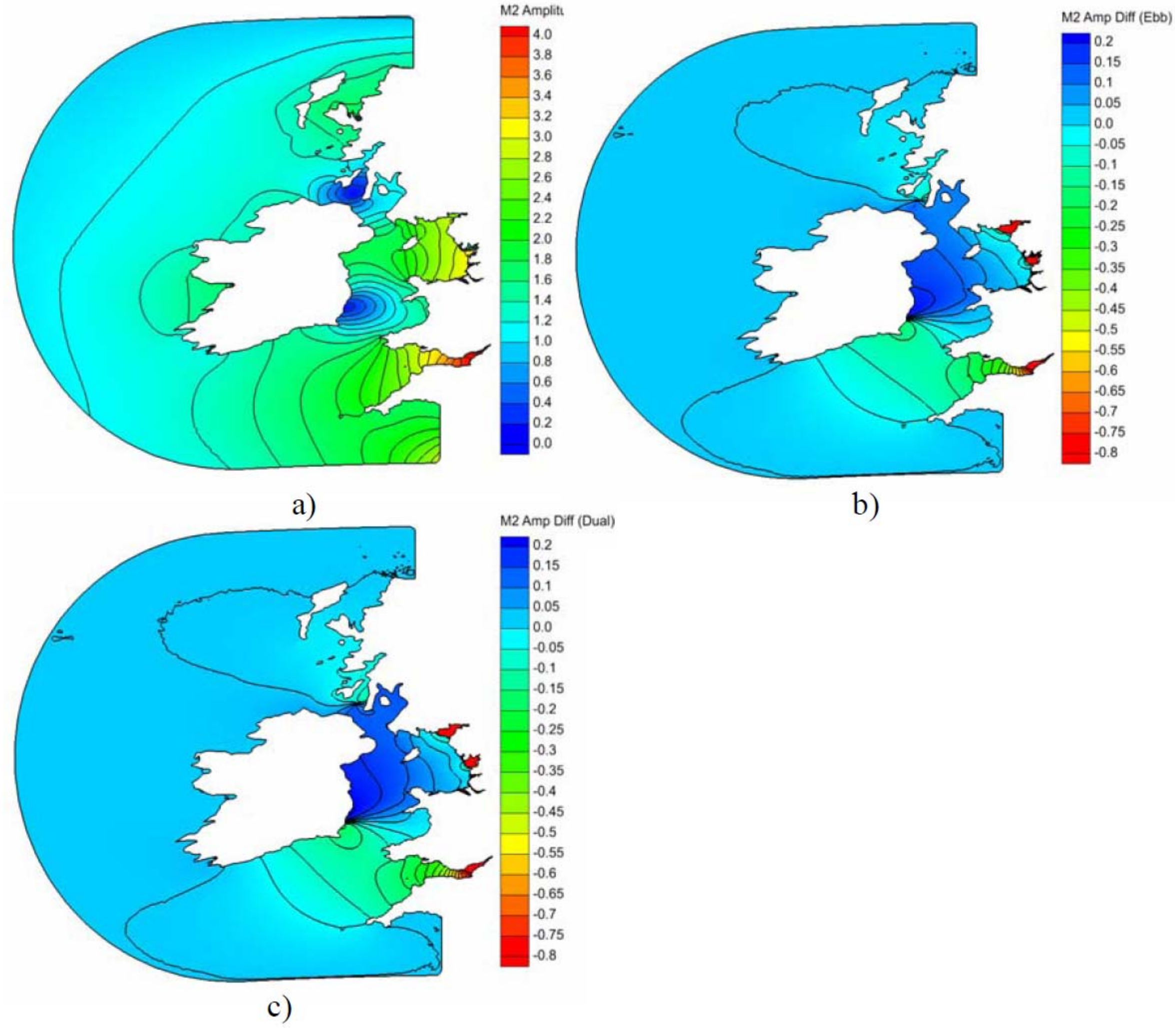
The building of a tidal barrage across a bay or estuary will permanently destroy the habitat under the physical footprint of the structure and modify others both within the wider development footprint and upstream and downstream of the facility. It may also alter tidal and residual flows and impact on the hydrography and physical characteristics of the wider region.

The previously proposed 16km long Severn Barrage from Cardiff to Western-Super-Mare was calculated to have a structural footprint of between 795,000 and 1,176,000m$^2$ (Sir Robert McAlpine Ltd 2002) although its impact would have extended to the full 480km$^2$ of the basin (DECC 2010g). This physical footprint and associated direct impact of removal of habitat are on a larger scale than any other renewable energy technology (see Table 5.2 for comparison with OWF foundation types). Physical effects of piling, seabed preparation, dredging for construction material and the actual laying of the structure on the seabed are discussed in the OWF section but may apply on a larger scale in relation to tidal barrages.

The high tidal range of an estuary is what makes it appealing as a site for a tidal range barrage. The physical presence of a barrage may inhibit the funnelling effect of an estuary which under natural conditions serves to amplify the tidal range and so the overall range of the tide both on ebb and flow may be altered. Monitoring data suggests that at the Oosterschelde tidal system, the Netherlands (Louters *et al.* 1998), the average tidal range has decreased by 12% since construction of a storm barrage, with a 50% reduction in spring tide range recorded at the La Rance tidal barrage, France (Black & Veatch 2007). Modelling work on the proposed Cardiff to Western-Super-Mare barrage (Xia *et al.* 2010a) suggested that upstream of the barrage maximum water depths could decrease by 0.5-1.5m (22% and 25% reduction at two separate modelled sites) and minimum water levels could increase by 5m, fully submerging several areas of tidal mudflats during a tidal cycle and therefore altering the ecological systems.

Similarly, modelling simulations of the effect of several tidal barrages in the eastern Irish Sea suggest that the effects of a near-field reduction in tidal amplitude could potentially be seen at far-field sites on the western side of the basin on the Irish coast (Figure 5.15, Wolf *et al.* 2009). The present situation simulated in Figure 5.15a shows large amplitudes throughout the eastern Irish Sea and in the Bristol Channel together with the two amphidromic points, one off the east coast of Ireland in the Celtic Sea and the other between the north coast of Northern Ireland and the west coast of Scotland.

Figure 5.15 – $M_2$ tidal amplitude (m) in a) present situation simulation and b) difference (m) due to 1 x DoEn ebb mode barrage simulation, c) difference due to 3 x DoEn dual mode barrage simulation




*Source: Wolf et al. (2009).*

The addition of 5 barrages (within the Severn, Solway, Morecambe Bay, Mersey and Dee estuaries) is modelled for a 1 x DoEn ebb mode barrage simulation[26] (Figure 5.15b). Figure 15b indicates a considerable decrease in amplitude behind the barrages but also the amphidromic point off the east coast of Ireland is shifted slightly. There is a small decrease in tidal amplitude seen to the south of the amphidromic point and across and up the Bristol Channel where the Severn barrage has removed some of the resonance and thus markedly lowered the tidal amplitude. North of the amphidromic point the tidal amplitude increases. In this simulation the increase along the Irish coastline is about 10-15cm but this varies depending upon the mode of operation of the barrages.

The 3x DoEn scheme[27] results in a larger volume of water passing through the barrages and, when operated in dual (ebb and flood generation) mode, preserves a larger portion of

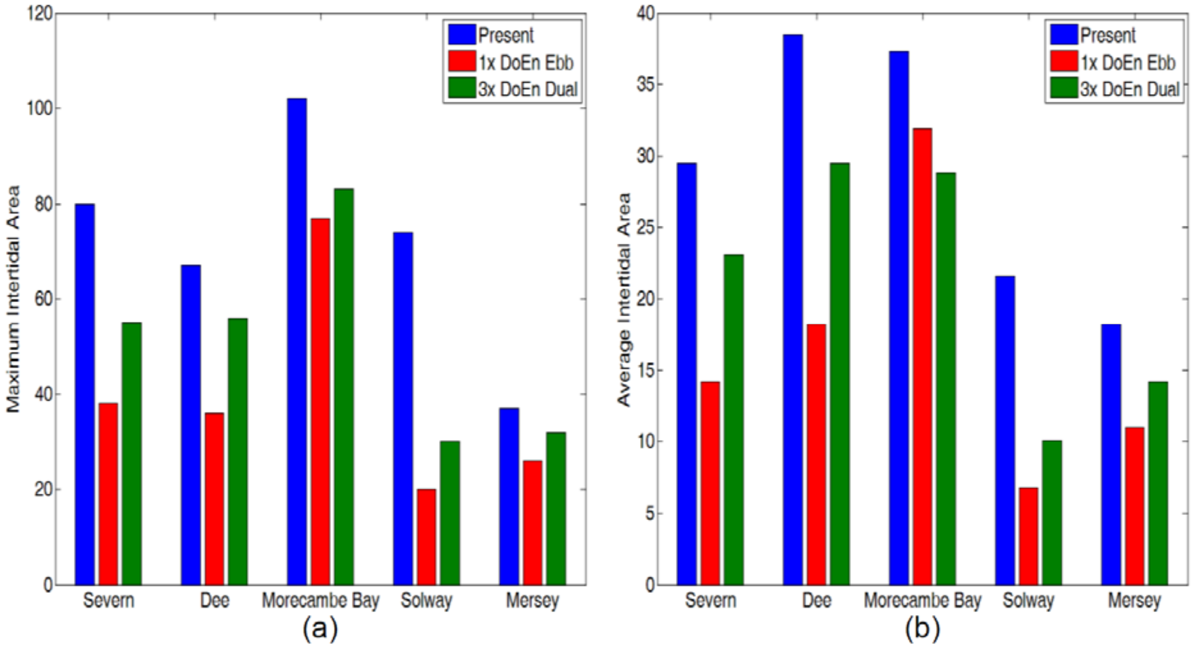
[26] This represents the schemes determined by the Department of Energy in their 1980's studies using the optimal economic cost of energy production to determine the number of turbines and sluice gates and mode of operation within each barrage (see Wolf et al. 2009).

[27] The 3x DoEn scheme is an enhanced turbine scheme whereby three times as many turbines are used than prescribed in the best economic case of the original Department of Energy studies.

the tidal range within the enclosed basins behind the barrages. This may be considered the best environmental situation, although the economics of energy production deteriorate (Burrows *et al.* 2008). The modelled changes to the $M_2$ tidal amplitude are shown in Figure 5.15c. The same qualitative pattern is seen as for the 1x DoEn schemes operating in ebb mode however the impacts are larger throughout the Irish Sea with an increase along the Irish coast of 15-20cm in tidal amplitude (up to ~10% of baseline).

The reduction in tidal range (and especially the increase in minimum tidal heights) above the barrage could result in significant changes to the positioning, width and regime of the inter-tidal zone and associated habitats (Nekrasov & Romanenkov 2010). Modelling simulations based on the construction of 5 barrages on the western coast of the UK (described above) show the projected loss of intertidal habitats associated with different barrage schemes (Figure 5.16), also given a separate value of 62% for the Severn Estuary by Warwick & Somerfield (2010). Despite the large projected losses the model shows that by using dual-operation mode (and therefore increasing the amount of water passing though the barrage, preserving a larger portion of the tidal range (3xDoEN Dual results) compared to ebb only flow (1xDoEn Ebb results)) and increasing turbine capacity three fold, up to 75% of the intertidal area can be retained, although this would increase the cost of the electricity generated (Burrows *et al.* 2008).

Figure 5.16 – Maximum (a) and average (b) percentage intertidal areas modelled for potential barrage schemes at 5 different sites around the UK




*Notes: The 1xDoEn Ebb model is based on the number of turbines and Ebb flow generation only, determined as a best economic case by Department of Energy studies. 3xDoEn Dual model is based on 3 times as many turbines as the best economic case and dual (ebb and flow) mode operation*
*Source: Wolf et al. (2009)*

The physical presence of a barrage could also reduce the propagation of saline water above the barrage, affecting the mixing of water masses. Tidal mixing results in the upwards transport of nutrients (and the near-homogenising of the temperature, salinity and dissolved oxygen content of the water column), which is important to maintaining primary production. Models based on a tidal barrage in the Sea of Okhotsk, Russia show the possible changes in the location of mixed and stratified zones, separated by tidal fronts, as a result of dam erection (Nekrasov & Romanenkov 2010), although modelling studies in UK waters have suggested that the location of tidal mixing fronts are unlikely to move significantly (within the natural variation frequency) due to barrage construction (Wolf *et al.* 2009). Similarly the presence of a barrage is likely to impact on wind induced mixing of the water column, reducing its effect and potentially further inducing stratification and a reduction in nutrient transfer to surface waters. Certain sites are naturally characterised by high turbulence within the water column, which although promoting increased mixing also reduces the water clarity, ultimately resulting in low primary productivity (e.g. Severn Estuary). The presence of a barrage could mean that for large parts of the tidal cycle the waters upstream could be fairly static, with suggestions that this could increase water clarity and therefore increase phytoplankton derived primary productivity (Underwood 2010). However, this increase in productivity is unlikely to compensate for the loss of productivity from the reduction of the intertidal zone.

Long period swell waves could also be blocked from the upstream region of a barrage (with associated decreases in erosion), although the increase in low water levels would mean that the time averaged fetch within an estuary would increase therefore increasing the impact of waves generated within the barraged area (Wolf *et al*. 2009). This has been shown to have an effect on areas of mudflats and salt marsh with an increase in erosion causing a steeper slope between salt marsh and mud flat and discouraging marsh plant colonisation (Louters *et al.* 1998). The reduction in tidal range at the Oosterschelde barrage installation has reduced the frequency of flooding above the barrage (by 70% in the high salt marsh zone) which has resulted in the loss of salt marsh and mudflat habitat due to drought (Louters *et al.* 1998) and a lack of replacement of sediment due to reduced transport levels in the water column and the settling of finer particles in deeper waters (Pethick *et al.* 2009). This reduced sediment supply to mudflats combined with an increased rate of erosion and increased wind-wave action could result in the increased loss of mudflat habitats.

The impact of a barrage on the flood risk of an estuary would likely be two fold. The presence of a barrage is suggested by modelling evidence to reduce coastal flooding risks in the Severn Estuary, even if there was a 1m rise in climate change induced sea level (Xia *et al.* 2010b), with extreme tidal flooding events largely limited to the outer reaches of the estuary and only minimal in the middle and inner estuary reaches. However, the flood risk from river overflows in the catchment above the barrage could potentially increase due to a couple of factors: raised water levels could produce a raised water table and therefore river water could potentially take longer to drain away within the lower reaches of the estuary catchment; and higher static water levels above the barrage could lower the gradient of the river entering the estuary, reducing the transport capacity of the river and causing extra mud deposition in the lower reaches which may exacerbate flooding.

It is highly unlikely that any tidal barrage would be removed at any point, with operational timescales expected to be at least 120 years, and therefore this technology has few impacts associated with decommissioning.

Large scale changes to sediment regimes, erosion and deposition, mean water heights, tidal range and current velocities (discussed further in Section 5.5.2) may affect any historical or archaeological artefacts or structures either directly through physical damage from infrastructure or indirectly through sediment erosion and deposition or submergence or emergence due to changing water levels. For example, depending on the exact siting of the previously proposed Cardiff to Western Severn barrage, 9 or 10 geological SSSIs (Pethick *et al.* 2009) could have been affected, as well as several historical monuments, wrecks and archaeological features (DECC 2010d).

## Tidal lagoons

Tidal lagoons are similar to barrages in construction impact although they do not span the whole channel width. Lagoon schemes have not had the same degree of design development as some barrage schemes. There are two distinct types; those which are coastally attached, as with the Welsh Grounds and Bridgwater Bay lagoons examined in the Severn Tidal Power Feasibility study, and offshore lagoons, such as the proposed Swansea Bay or Mersey Bay lagoons. Land connected lagoons, like barrages, result in loss of habitats because of the significant reduction in tidal range within the impounded area. Other environmental effects are similar to smaller barrages except that impacts on fish and navigation are expected to be less because they do not form a continuous barrier across an estuary. The potential environmental effects of offshore lagoons have been less well studied as the cost implications of the much deeper wall construction required for the impoundment make them more expensive than land connected options (Parsons Brinckerhoff 2010).

The Severn Tidal Power Feasibility Study indicated that for lagoons, the options having a fundamental bearing on their feasibility are their operating mode, size, alignment, and turbine capacity. Ebb and ebb flood modes were evaluated for the proposed lagoon alignments by varying the installed capacity to determine the preferable capacity for each mode. Alternative smaller lagoon sizes were evaluated to assess whether a smaller lagoon may be preferable over a larger lagoon in any respects. For the Bridgwater Bay lagoon, the preliminary optimisation found that operating in ebb flood mode with turbine capacity increased to maximise the energy extracted from the lagoon was preferable in terms of energy yield and energy cost and preferable, or equal when compared to other configurations tested, in all environmental and regional respects except for port access within the lagoon and possibly impact on fish. However, increasing turbine capacity was found to significantly increase capital cost (Parsons Brinckerhoff 2010).

Construction alternatives for lagoon impoundments were also examined with conventional rockfill embankment adopted as it provided a reasonable basis for determining the cost, programme and resource requirements for the study. A proposed scheme in Swansea Bay was estimated by the Sustainable Development Commission (2007a) to require 6 million m$^3$ of aggregate in construction. This would produce a 9km long embankment, 65-100m wide with an associated physical footprint of 585,000-900,000m$^2$. Other alternatives included: a modular precast concrete pile supported wall; a tied or braced precast wall panel system, and a sand filled geo-container construction (Parsons Brinckerhoff 2010).

Construction impacts are covered in the OWF, oil and gas and tidal barrage sections and effects of the impoundment of water, associated reduction in current velocities and sediment characteristics is discussed in Section 5.5.2.

## 5.4.3 Spatial consideration

As discussed above, the spatial footprint of OWF foundations varies by foundation type; with monopile and jacket foundations having a direct footprint (including in many cases scour protection laid to a radius of 10-20m from the pile) of around 20m$^2$ and gravity and suction caisson bases a direct footprint in the order of 300-600m$^2$ (although potentially much larger depending on local current and sediment conditions). When this is scaled up to array size the footprint of monopile and jacket foundations reaches 2,000m$^2$ for a nominal 500MW array and 100,000m$^2$ for a total 25GW development scenario. The scoured area, in the absence of scour protection, would be around 1,000m$^2$ (0.1km$^2$ for a nominal 500MW array; 4.8km$^2$ for a total 25GW development scenario). The 300MW Thanet wind farm, currently the largest operational OWF in UK waters, covers an area totalling 35km$^2$, with the 180MW Robin Rigg OWF covering 18km$^2$. The calculations of scour and physical footprint impacts suggest that the actual area impacted within the wider OWF footprint will be in the order of <0.05%, as both Thanet and Robin Rigg OWF are monopile foundations. In the worst case that four-legged jacket foundations are used, with each leg experiencing scour (or requiring scour protection) of the same magnitude as a monopile, the proportion of the seabed within the OWF array under the total "footprint" is <0.2%. For a total 25GW generation scenario, the total footprint associated with monopiles and scour is <5km$^2$ (or possibly up to 12km$^2$, if 50% of generating capacity used four-legged jacket foundations). Different foundation types are however expected to have far larger impacts over potentially greater total areas, but as such are untested within UK waters.

The anchors used for wave and tidal stream devices are far smaller than those used for OWF and currently are only being deployed in small numbers consistent with demonstrator sized installations. The scenarios presented within this report for wave and tidal stream have overall footprints of 1-10km$^2$ and 0.5-5km$^2$ respectively. As such, large spatial effects are negligible but in the future the scaling up of arrays to commercial levels could potentially impact the physical environment and associated biota on the level of OWF, as although the foundation types used are smaller they are likely to be more densely laid within an area and therefore potentially more prone to issues such as foundation to foundation scour tail effects.

Although the spatial area of seabed affected by export cables is obviously dependent on the location of OWF, wave and tidal developments, a broadly indicative area assuming a 2m corridor width, and 500MW developments at an average of 25km from shore; can be calculated as 2.5km$^2$ for the 25GW scenario. As a first approximation, the spatial area affected by intra-array cabling would equal the average turbine spacing multiplied by a corridor width of 1m; 0.002km$^2$/turbine or 10km$^2$ for the 25GW scenario. It should be noted that seabed habitat disturbance for the cable footprint would be temporary, with rapid recovery expected following trenching of the cables.

Spatial considerations for carbon dioxide storage and gas storage are linked predominantly to injections of gas into specially constructed caverns rather than existing oil and gas reservoirs. The Gateway Irish Sea project estimates the construction of 20 separate salt storage caverns, which will all require associated infrastructure and as such will impact over a larger scale than existing hydrocarbon reservoirs where there tends to be one injection site only. The spatial effect of the laying of associated pipelines in UK waters is calculated to currently cover approximately 340km$^2$ for oil and gas related pipelines (assuming a 10m wide corridor of impact alongside pipe laying operations (OSPAR 2009a)). The Baird Gas Project has an associated pipeline of 100km in length (Bacton Storage Company Ltd 2009) and the Gateway Gas Storage project estimates an 80m wide corridor that will be impacted by cable and pipeline laying equating to 1.5km$^2$ over the total 19km long route (Gateway 2007).

### 5.4.4 Cumulative impact considerations

Estimates of the intensity of trawling disturbance, and of the resilience and recovery timescale of benthic communities, vary for different parts of the UKCS, although for context previous SEAs (e.g. SEA2) included a conservative estimate of the scale of effect (assuming a fishing effort of 2,000 hours per year per 0.5º ICES rectangle, average trawl speed of 4 knots, twin scars from trawl doors, 1m scar width; neglecting clump weights used in twin-trawl gears) is of the order of several billion square metres (or thousand square kilometres) of trawl scarring per year in the North Sea.

On the basis of known fishing activities, trawl scarring is likely to be present over much of the UKCS seafloor; with the effects of scallop dredging particularly significant in shallow water (since the gear is more damaging and sensitive habitats – such as biogenic reef – may be affected). Trawling in very deep water (>1,000m) requires heavy gear, including clump weights of several tonnes, and may therefore also be more damaging than typical whitefish or *Nephrops* trawling. Trawl/dredge scarring is evident in sidescan coverage acquired from all previous SEA areas.

Eastwood *et al.* (2007) described and quantified the major sources of direct, physical pressure (not chemical or biological) from human activities in 2004 on seabed environments in UK offshore waters (England and Wales), by Regional Sea. This analysis considered oil and gas exploration and production, wind farm construction and operation, cable laying, extraction of marine aggregates, waste disposal, fishing with mobile seabed gear, and wrecks at sea arising from military activity and marine accidents. Likely and known effects of these activities were assigned to pressure categories and types using estimates of the spatial extent or the "footprint" of each activity as a proxy for direct, physical pressure. They did not however quantify the intensity of any estimated pressure (e.g. the number of times a pressure was superimposed, such as the number of passes of a trawl per $m^2$). In the case of wind farms, a buffer area corresponding to a 100m diameter was assumed to estimate the spatial extent of "abrasion" associated with scour. Aggregate extraction footprint was estimated by modelling sediment plumes; while fishing pressure was based on VMS data (i.e. excluding vessels <18m or <15m after 2005), corrected to include the entire fleet by comparison with overflight data.

Unsurprisingly, demersal trawling was estimated by Eastwood *et al.* (2007) to have affected a larger area of seabed than all other pressure types combined. The initial estimate of 13,902$km^2$ (5.4% of seabed) was adjusted to 55,504$km^2$ (21.4% of seabed) to take account of track deviation and under-representation of the fleet by VMS data, and is therefore of the same order of magnitude as (but several times larger than) the previous SEA estimate. Eastwood *et al.* (2007) rated confidence in their estimate of trawling footprint as low, since both location and extent were estimated. Sediment plumes resulting from marine mineral dredging had an estimated footprint of 2,995$km^2$, while oil and gas fixed infrastructure (platforms, wells and pipelines) accounted for 5.4$km^2$ (note the analysis excluded the major areas of North Sea development (predominantly in Scottish waters) as they only include activities in English and Welsh waters; the total figure for the North Sea therefore might be four or five times greater). A previous estimate for ICES using 1986 data, reported by de Groot (1996) estimated that 399 platforms in the North Sea (UK, Norwegian, Dutch and German sectors) covered 313$km^2$, whereas pipelines covered 8,374$km^2$, both of which appear substantially over-estimated (platform footprint may include seabed area contaminated by drill cuttings; pipeline estimate was apparently based on a 1km corridor width). Existing wind farm footprint was estimated by Eastwood *et al.* (2007) to be <0.1$km^2$, with high confidence. Currently only single turbine and demonstrator size wave and tidal stream installations have been constructed and so overall physical footprints of commercial scale arrays are difficult to detail. However, the leasing by The Crown Estate of 6 wave and 4 tidal stream commercial scale sites in the Pentland Firth and Orkney area (ranging from 50-200MW capacity) will result in the development of multi-installation arrays and associated cumulative physical impacts. The potential effect of tidal barrages on the installation of other technologies in the wider region, through changes in hydrography due to their large spatial footprint / impact, needs to be widely researched during resource investigations.

Although currently demersal trawling affects a larger area than all other activities combined (Eastwood *et al.* 2007), an increase in offshore energy installations and therefore the depth of sediment over-turned (and possibly therefore the recovery timescale) of OWF, wave and tidal stream cabling and E&P activities may become greater than many other sources of industrial seabed disturbance. Although this may be significantly reduced in areas of sediment mobility resulting from strong tidal streams and in shallower waters where periodic sediment disturbance occurs by oscillatory currents from passing waves. The scour or scour protection-related footprint of fixed installations in hydrodynamically active areas (e.g. the southern North Sea and parts of the Irish Sea) will have a duration equal to or beyond the lifetime of the development. Current spatial coverage of UK waters by multibeam data and our resulting understanding of sediment features is discussed in Section 5.5.2, but it should be added that identification of especially far field and cumulative effects of energy installations are currently limited due to poor data coverage.

### 5.4.5 Summary of findings and recommendations

Physical disturbance associated with activities resulting from proposed oil and gas licensing and OWF, wave and tidal stream leasing will be negligible in scale relative to natural disturbance and the effects of demersal fishing. The potential for significant effects, in terms of regional distribution of features and habitats, or population viability and conservation status of benthic species, is considered to be low. The potential impacts of tidal range schemes however, could be very significant with the potential loss of large areas of inter-tidal habitats and salt marshes as a result of a change in water levels and sediment transport within an estuary or river channel.

The broadscale distribution of habitats of conservation importance is relatively well mapped, and sufficient information is available to assess the probability and sensitivity of sensitive habitats in proximity of proposed activities for OWF and oil and gas. Similarly, specific projects can be assessed in terms of likelihood of significant archaeological features. In both cases, however, detailed site surveys (which are routinely acquired prior to development operations) should be evaluated with regard to environmental and archaeological sensitivities. Very little information however currently exists for the impacts of wave and tidal stream technologies, both on the physical environment and associated habitats and further research is needed into the effects of different foundation types and cumulative impacts of arrays of these devices.

# 5.5 Consequences of energy removal

## 5.5.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Energy removal downstream of wet renewable devices | | | | | X | X | X | 5.5.2 |
| | Changes to sedimentation regime and associated physical effects | | | | | X | X | X | 5.4.2.2<br>5.5.2 |

The introduction of devices that take energy from the water column will have an effect on the energy balance of the surrounding waters, with potential local and far field effects on other physical and biological processes. The inclusion of wet renewable devices (tidal stream, tidal range and wave) within this SEA has resulted in the need to assess the potential level of physical impact that energy removal associated with these devices will have and resulting impacts on habitats and biological processes. Currently the development of both tidal stream and wave technologies is in its relative infancy and therefore monitoring studies are sparse and evidence largely based on modelling simulations and a few demonstrator scale individual devices.

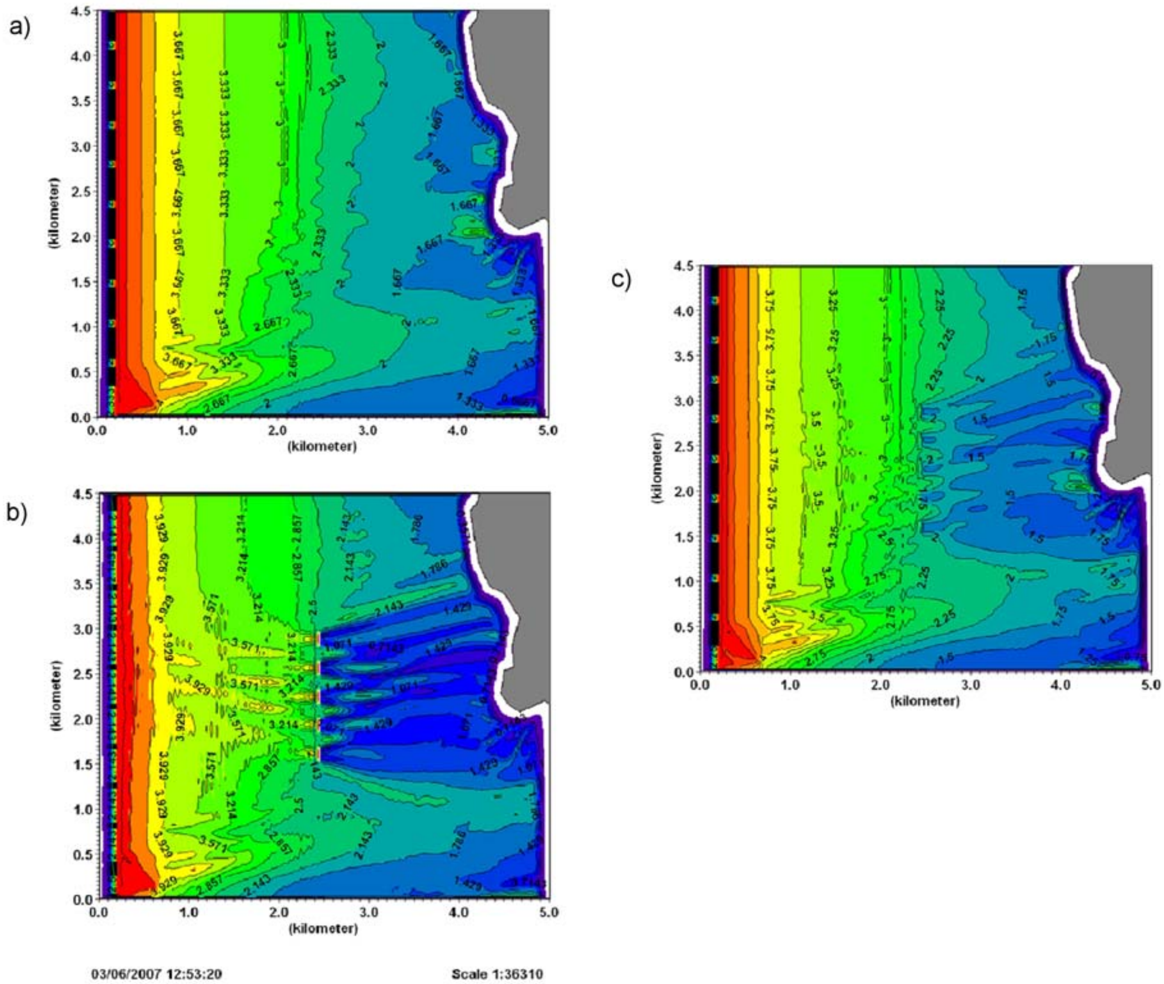
## 5.5.2 Consideration of the evidence

### Wave

Wave devices remove energy from the wave train, potentially affecting water mixing properties in the near field, sediment transport in the near and far field, wave-current interaction and current power generation capacity of neighbouring areas. Whilst wave technology is still in its infancy and little monitoring has been done on the effects of operational devices on the physical environment, several modelling studies have started to address the issues and give indications of the potential scale of the effects.

Reductions in simulated wave height immediately downstream of wave devices are modelled to be significant (e.g. around 45% for a device 10m wide and 160m long (Venugopal & Smith 2007)). However, this is not a reflection of the large absorption of energy by the device, it is predominantly due to the high level of refraction of wave energy around the structure (calculated as 70% of the wave power for long-crested waves for the Wave Dragon device type (Beels *et al.* 2010)). Variations in the reduction in wave heights (with values ranging from 13–69% reduction (Venugopal & Smith 2007)) are also modelled to occur for different porosities of devices (i.e. how much energy they absorb (Figure 5.17)). The resulting size of the wake effect of a device will be dependent on device shape and wave type, with wider but far shorter wakes observed for short-crested compared to long-crested waves. The wake effect of the device is reduced with distance due to wave diffraction and energy redistribution so that for short-crested waves modelling has shown that after 3km downstream from the device the wave height is the same as that in front of the device (Beels *et al.* 2010). For long-crested waves at 3km downstream, only 70% of the initial wave height is recorded, confirming the need for careful planning of spatial array designs to maximise power. A local increase in wave height is also seen in front of devices (Beels *et al.* 2010), due to reflection, with calculations suggesting increases of up to 31% (Venugopal & Smith 2007). Despite the high level of refraction of wave energy around devices modelling has suggested that in the far field the wave direction is not modified significantly, with differences of less than 0.5° (Palha *et al.* 2009).

Figure 5.17 – Change in modelled significant wave height at the EMEC site, Orkney with different wave device structures




*Notes: (a) no structure placed; (b) a solid structure that reflects 100% and absorbs 0% of the wave energy; (c) a structure that absorbs energy corresponding to a porosity of 0.7 and also partially reflects and transmits waves.*
*Source: Venugopal & Smith (2007)*

Further estimations of energy removal and far field effects show very small changes, with an estimated 1 to 2cm decrease in wave height at the coast 20km from the Wave Hub array (Millar *et al.* 2007), a similar value to those given for modelling studies on the Pelamis wave technology (Palha *et al.* 2009), which suggest variations of <5cm at the near-shore region. Modelling work on the effect of the Wave Dragon demonstrator (PMSS 2007) suggests that the magnitude of wave height reduction varies for different wave states, with a 2% reduction for swell waves at nearshore locations and a value of 10% for wind waves (based on a wave height of 4m). This variation is due to the design of the wave device, which absorbs more energy from short period waves than long period swell waves. In terms of a reduction in wave height both the Pelamis and Wave Hub modelling work suggests that a ~30km (20-26km for Pelamis depending on the configuration of array) section of coastline is likely to be affected by a wave array 3km in length (taking a 60° variation in wind direction into consideration). The Wave Hub project estimated near-shoreline bathymetry changes of -0.2 to +0.2 metres which would likely be indiscernible against background sediment transport and beach level changes (Halcrow 2006) and therefore it is unlikely that the small changes in wave height modelled will have significant effects on along-shore sediment dynamics, especially considering the normal values for variations due to storms and wind (EquiMar 2009). Even small changes in wave height at shorelines may, however, have a significant effect on intertidal habitats. Intertidal habitats have well defined zones of organisms which are all ecologically adapted to different levels of exposure. A significant change in mean wave weight will therefore alter the ecology of these areas. Similarly, any change in hydrodynamics may increase the drag acting on an organism or affect marine organisms that are specially adapted to cope with extreme hydrodynamic forces like breaking waves or strong currents (Shields *et al.* 2010), although this is likely to be a localised effect.

The effect on wave height has a potentially greater impact for those devices which are shore-based or situated close to land. Modelling work on the Siadar breakwater project, Isle of Lewis (Amoudry *et al.* 2009), showed that most of the wave energy will be diffracted around the structure with very little energy remaining in the lee, with a large potential for changes in shoreline and surf-zone processes and sediment accumulation. This has the potential to be a positive effect in areas with significant coastal defence issues and could possibly be used as part of a system to manage coastal erosion and coastline retreat. However, any changes to surface productivity linked to reduced turbulence or mixing of the water column will potentially alter surface productivity which may modify the food supply to benthic populations (Pelc & Fujita 2002). This is likely to be localised and the area affected is likely to vary with changing wave direction.

The changes in wave height and current velocities associated with wave devices could alter sediment transport, with potentially significant issues including: scour around the foundations of devices; fine grained sediment deposition in the lee of devices, and a change in offshore to onshore sediment transport (Boehlert *et al.* 2008). Sediment re-suspension, outside the boundaries of normal natural variations, may cause health effects in fish, with prey detection abilities of species that rely on visual cues also potentially hindered by increased turbulence (DFO 2009). There are however considerable uncertainties associated with the extent of sediment effects which will be dependent on local topography, water depth, sediment types, device type, proximity to shore and local currents.

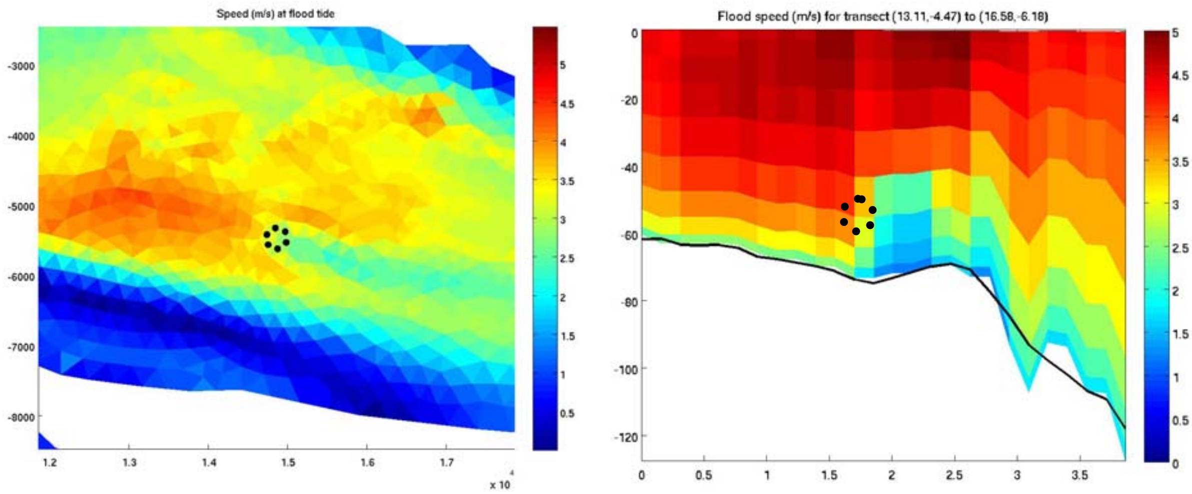
The large scale refraction of energy around a device could produce complex shadow effects, ranging in modelled spatial extent from small (~1km, Oregon Wave Energy Trust 2009) to large (20km, Millar *et al.* 2007). The limited studies to date have shown that despite a potentially large reduction in wave height and energy in the immediate lee of devices, these values do not remain reduced over long distances (with the ultimate result of limited far field effects) and as such, changes in sediment deposition and erosion may be significant close to devices but limited spatially. Modelling work has suggested significant distortion to sediment dynamics up to 50m downstream of devices (Faber Maunsell & Metoc 2007), with larger effects expected in soft sediment coastal regions. As with the spacing of turbines in OWFs careful consideration therefore needs to be given to the spatial arrangement of devices within arrays in order that shadow effects (predominantly related to changes in sediment transport and subsequent scour) do not impact on downstream devices, and large cumulative impacts and far-field effects from multiple devices does not occur.

## Tidal stream

The removal of energy from tidal currents will reduce current velocities, tidal amplitudes and water exchange in proportion to the scale of the tidal array (Sustainable Development Commission 2007c). As with wave devices, the early stage of the technology means that very little monitoring data is available, especially for commercial scale arrays and long term, far field and spatial issues. The discussion below therefore predominantly relies on modelling studies.

Tidal energy extraction from tidal stream devices has been shown to reduce the volume of water exchanged through an area over a tidal cycle, reduce the tidal range landward of an array and reduce the power density in the tidal channel itself (Bryden & Couch 2006, Polagye *et al.* 2008, Walkington & Burrows 2009). Several studies (e.g. Karsten *et al.* 2008) have shown that extracting tidal energy reduces current velocities downstream of a given device (Figure 5.18). However, there appears to be a non-linear relationship between the rate of energy extraction and the velocity reduction (Bryden & Couch 2006), due to the fact that energy extraction decreases the available energy flux and therefore diminishes the overall flow speed. Published simulation values of reductions in flow range from 56% (Vancouver Island, Canada, Sutherland *et al.* 2007), to 25% (Yell Sound, Shetland, The Engineering Business Ltd. 2005), to a 5.6% reduction in the immediate wake of a device (modelling simulation, Bryden & Couch 2006). The wide range of figures reflects the different physical settings of devices with the system response to energy extraction dependent on the geometry of the area (e.g. narrow channel, estuary, wider channel), tidal regime and non-linear turbine dynamics (Polagye *et al.* 2008).

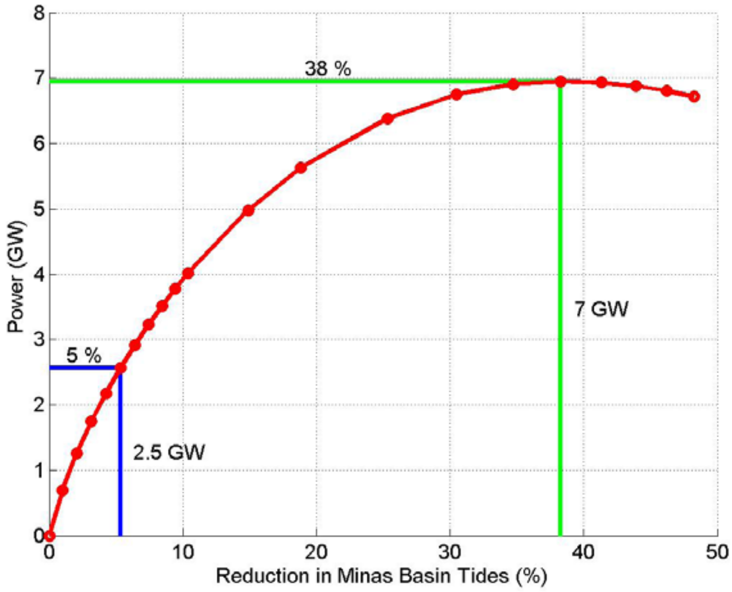
Figure 5.18 – Flow speed (left to right) in the Minas Passage, Bay of Fundy at flood tide showing the effect of a tidal stream turbine (black dotted circle) on the horizontal and vertical flow speeds




*Notes: Left hand diagram shows effect of a tidal turbine (black dotted circle) on the horizontal flow speeds of the passage, with orange-red colours indicating higher velocities. Right hand diagram shows a vertical profile through the water column, with the sea bed represented by the black line and device represented by a black dotted circle (location of turbine only; foundations and support structure not shown) and subsequent reductions in current velocity shown by yellow–blue colours.*
*Source: Karsten et al. (2008)*

A Bay of Fundy study (Karsten *et al.* 2008) estimated that extracting the full 7GW of power feasibly available from the Minas Passage through tidal turbines would reduce the tidal range by 30% (Figure 5.19). However, extracting only 2-3GW would result in only a <5% change in the tidal range. Similarly Bryden & Couch (2006) suggested that in an idealised simulation case 10% of the raw energy flux produced by the tide could be extracted without undue modifications to flow characteristics. Estimations of the limit of percentage energy extraction before any significant environmental effects occur (hereafter referred to as *acceptable EE %)* for several potential tidal stream sites around the UK were detailed by a Carbon Trust study (2005) (see Table 5.5).

Figure 5.19 – Relative change in size of the tides in the Minas Basin, Bay of Fundy with different levels of power generation




*Source: Karsten et al. (2008)*

Table 5.5 – Modelled acceptable limit of percentage energy extraction from specific UK tidal resource areas before environmental effects become significant (acceptable EE %) and associated reductions in velocity as a result of extracting this much energy.

| Site | Regional Sea | Velocity change (%) | Acceptable EE (%) |
|---|---|---|---|
| Pentland Skerries | 8 | 15 | 20 |
| Stroma, Pentland Firth | 8 | 15 | 20 |
| Duncansby Head, Pentland Firth | 8 | 15 | 20 |
| Casquets, Channel Islands | - | 10 | 8 |
| S. Ronaldsay, Pentland Firth | 8 | 15 | 20 |
| Hoy, Pentland Firth | 8 | 15 | 20 |
| Race of Alderney, Channel Islands | - | 10 | 12 |
| S. Ronaldsay, Pentland Skerries | 8 | 15 | 20 |
| Rathlin Island | 7 | 10 | 8 |
| Mull of Galloway | 6 | 10 | 12 |

*Source: Carbon Trust (2005)*

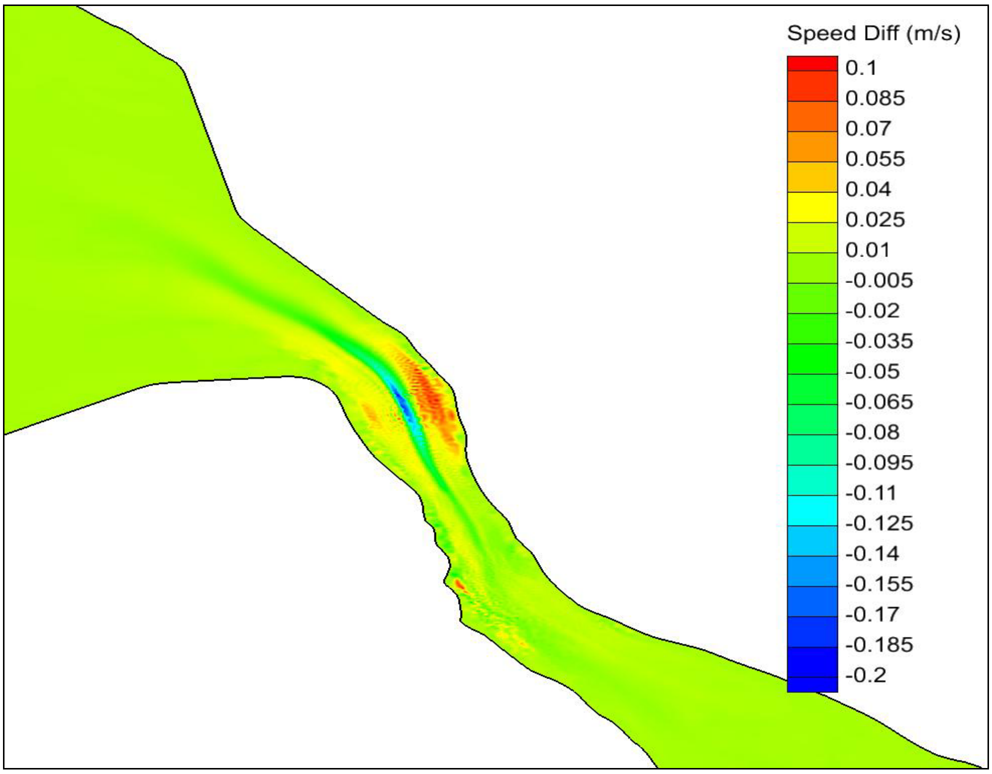
Values for the limit of acceptable EE% are shown to vary with physical location with inter island channels, open sea sites and headlands having a value of 10-20%, sea lochs a value of 50% and resonant estuaries values of <10% (Carbon Trust 2005). These values are based on theoretical modelling and therefore still have to be validated against physical measurements. The extraction of energy, especially in enclosed sites, will also modify the water levels both upstream and downstream of the device, which would potentially have the effect of moving erosion up or down the coastal height profile.

The reduction in current velocities in the wake of a device (Figure 5.18) may increase eddy formation and associated turbulence and affect both sediment deposition and erosion, and water column turbidity. This may alter benthic habitats and organisms within the water column on at least a local scale, potentially altering vertical movements of marine organisms. Craig *et al.* (2008) reported that deposition of sand may impact seagrass beds by increasing mortality and decreasing the growth rate of plant shoots. A change in velocity could also affect both the transport of larvae or young organisms to key nursery grounds (Shields *et al.* 2010) or the supply of waterborne gases, food and nutrients to organisms, although it is unlikely that this will be a spatially significant effect. Moving rotors and foils may also add to the turbulence, which may cause mixing in areas of strongly defined salinity or temperature gradients and promote both potential deposition of sediments in the areas of reduced velocity and possible re-suspension in areas of turbulence within the wake. A reduction in thermal or salinity based stratification could have an additional effect on nutrient distribution within the water column and therefore the types of biota within the immediate area. This could potentially have a knock-on effect on the food chain, with reduced stratification and increased mixing potentially affecting primary production and larval settlement, although probably on a localised scale. Alterations in turbulence may also affect the feeding behaviour of some seabirds, particularly terns (ICES 2010).

The size of the wake effect has been modelled to extend ~500m downstream of the 16m rotor diameter device in Strangford Lough (larger on flood over ebb tide), 30 times the width of the turbine blades. This effect is far smaller for the open water 11m rotor diameter Seaflow device off Lynmouth; 167m long wake effect, 15 times the blade diameter (RPS 2005b, Faber Maunsell & Metoc 2007). This highlights the variability in physical effects with geographical setting, with the most noticeable influences expected in estuarine and narrow channel conditions rather than open water or energetic channels where sediment dynamics are already strongly influenced by waves and currents.

The presence of a tidal stream device within the water column may also accelerate velocities around the structure (Figure 5.20), although in open water cases the impact on far-field areas is suggested by modelling evidence to be negligible (Walkington & Burrows 2009). Modelling of the Seagen device in Strangford Lough showed flow acceleration around the device extending 250m on either side as far as the shore (RPS 2005b). In this case the substrate, composed of rock and course sand, is unlikely to be affected but softer sediment types in other locations will experience scour and where the increased flow impacts the shore, potential erosion effects are expected (Walkington & Burrows 2009). Further wave refraction around devices also has the potential to affect coastal wave erosion especially in narrow and enclosed sites. A change in current velocities could potentially alter sediment heterogeneity or slope topography at far field sites, which in turn may influence the composition of assemblages. Any alterations to assemblages may then have an impact on the stability of sedimentary habitats (Shields *et al.* 2010), as some organisms work to stabilise sediments (e.g. *Mytilus edulis*) and some may enhance erosion rates by destabilising sediments (e.g. *Macoma balthica* and *Hediste diversicolor*). Shields *et al*. (2010) conclude that 'any ecological changes related to far field alteration of flow will ultimately depend on the sensitivity of benthic species and habitats to the alteration of energy in the environment and may, in effect, only alter species distribution with little or no overall effect to the ecosystem'. Impacts on sediment processes are therefore dependant on many site specific factors, however, in regions where these effects reverse between the ebb and flood tides, the potential for net change in sediment deposition is small, with the potential for the regime to remain stable (Faber Maunsell & Metoc 2007). Modelling evidence suggests that this is only the case in regions of tidal symmetry, as areas of tidal asymmetry experience approximately 20% more bed level change due to sediment movements (Neil *et al.* 2009) and will therefore not be expected to remain in sediment equilibrium with the presence of a tidal stream device. Neil *et al.* (2009) also suggested that the presence of a tidal stream array actually reduced the magnitude of bed level change relative to a natural system due to the general reduction in tidal velocity and hence sediment transport, although again such a response can be expected to be site specific.

Figure 5.20 – Modelled change in current speed in the Mersey Estuary due to the deployment of a 20MW tidal stream farm.




*Source: Walkington and Burrows (2009).*

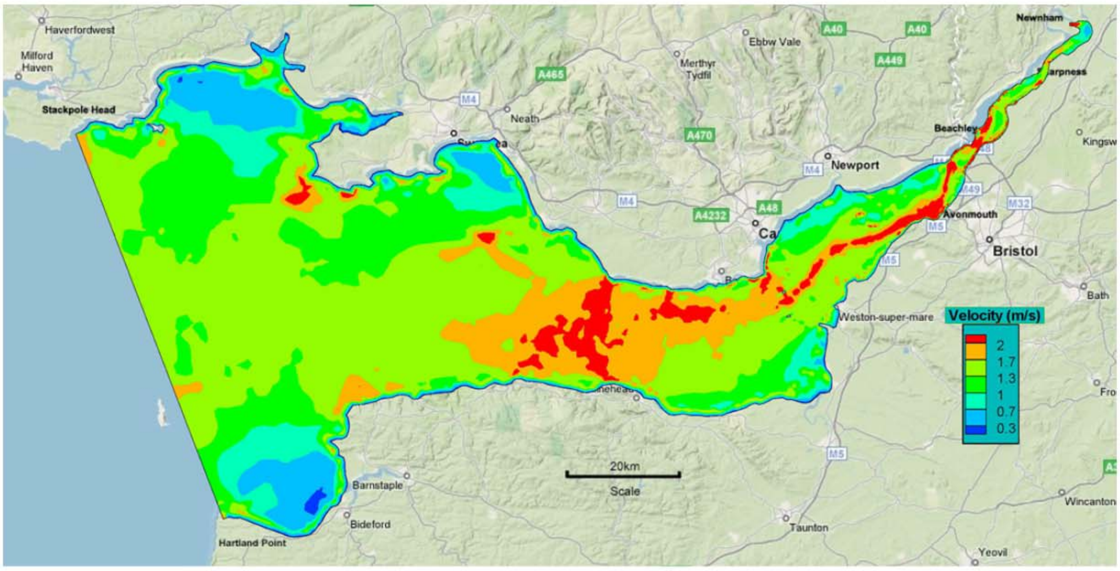
Several modelling studies have shown the relatively localised impacts of tidal turbine devices, with rapid dissipation of effects with distance (e.g. Karsten *et al.* 2008, Walkington & Burrows 2009). However, these are generally based on a small number of units, with cumulative effects from large arrays expected to extend to far greater areas, especially within enclosed and narrow areas. In reality, areas of high tidal power are often very localised and therefore there may be pressure in the future to install a large number of devices in a relatively small area. However, wake propagation is currently not well understood and there is the potential for the wake of an upstream turbine to degrade that of a downstream one (Polagye *et al.* 2008). Provisional modelling work has also shown that arrays that span the whole width of a river estuary have far larger upstream and downstream effects than only partial coverage arrays (Walkington & Burrows 2009). Again more research, both from modelling studies and monitoring of demonstrator projects is needed to determine the spatial effect and configuration of arrays.

## Tidal range

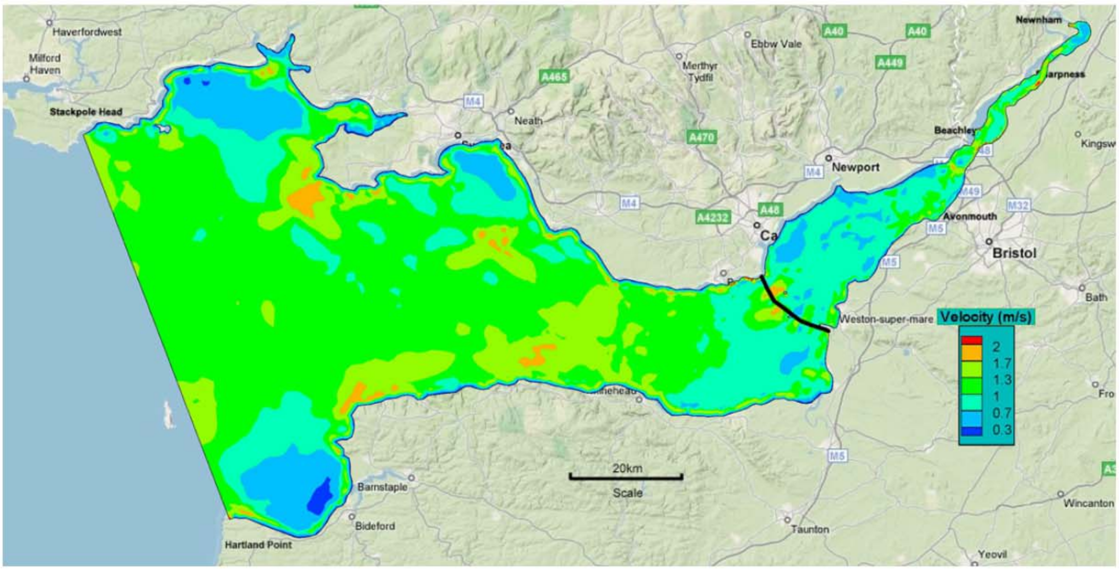
Tidal range generation designs, both barrages and lagoons, could have a large impact on the energy balance of the environment and wider region. Barrages not only remove energy from the water column at a single point but may also affect velocities across the whole channel and upstream and downstream of the installation. Section 5.4.2.2 details potential changes in water depth and resulting intertidal habitat loss associated with tidal barrages and this section considers the potential impacts and effects of both the changes in down and across-stream current velocities and sediment transport patterns as well as associated general physical impacts on habitats and biotopes.

Figure 5.21 shows the predicted changes in maximum tidal current velocities with and without a Cardiff to Western-super-Mare Severn barrage (Xia *et al.* 2010a), and illustrates the potential large impact of a barrage on the flow of water through the estuary. The figure clearly shows that upstream of the barrage there could be a significant reduction in current velocities, predominantly in the main channel, with similar reductions seaward of the barrage in the main channel and across large areas of the estuary as a whole. One of the regions evaluated for the siting of tidal stream devices is within a projected area of velocity decrease due to the construction of the barrage, highlighting the need to consider cumulative impacts of multiple energy devices on resource availability.

Figure 5.21 – Modelling comparison of maximum tidal currents both (a) without and (b) with the Cardiff to Western-super-Mare barrage.




a) without the barrage




b) with the barrage

*Source: Xia et al. (2010a)*

A 40% reduction in tidal velocity over tidal shoals and salt marshes and a 20-40% decrease of velocity in tidal channels has also been measured at the Oosterschelde storm surge barrier, Netherlands (Louters *et al.* 1998) with similar reductions measured at La Rance in France (Kirby & Retière 2009). There could be increases in velocities, in potentially complex patterns (Xia *et al.* 2010) around the barrage itself, with an obvious increase in the region of the turbines and sluices. This change could potentially enlarge turbulence and water column mixing and induce scour and coarsening of sediments around the foundations of the barrage itself, enhanced in an ebb flow only operation situation. It is expected that areas of scour associated with the spatial distribution of the turbines and sluices could subsequently become areas of sand accretion when the scour hole depth reaches a critical threshold (Louters *et al.* 1998) and therefore further change the bed topography. These changes could have significant impacts on both the substrate available for benthic communities and hydrodynamic (e.g. temperature, salinity, nutrient content and supply) conditions and may exclude several species that cannot survive the altered conditions. Any change in the nature of habitats could also alter their suitability as nursery or spawning areas for fish (ICES 2009). Areas of large tidal range also tend to be areas with high current velocities and as such are generally low in productivity, due to high suspended sediment loads, low levels of light penetration into the water column and therefore low primary productivity and dissolved oxygen concentrations. Any reduction in current velocities could therefore have a resulting increase in productivity within the water column and associated impacts on the ecosystem function as a whole.

Energy extraction and changes in current velocities could affect turbulent mixing and patterns of sediment distribution, with a large build up of sediment expected upstream of any barrage, calculated to be around 8.2M tonnes compared with 1.2M tonnes downstream for a Cardiff to Western-super-Mare barrage (DECC 2010b). Calculations suggest a reduced variability in deposited sediment mass from spring to neap tide of 3M tonnes after construction of a Cardiff to Western-super-Mare barrage compared with 5.4M tonnes under existing conditions (DECC 2010b), with rapid accumulations of up to 2m in deep channel regions. The resulting calculation of reduction in the mobile sediment load by a factor of between 2 and 3 (DECC 2010b) illustrates the large amount of sediment deposition and significant changes in bed profile, geomorphology and habitat types that could result from the construction of a barrage. Decreased velocities and increased sediment deposition upstream of a barrage could increase water clarity and increase phytoplankton derived primary production (Underwood 2010) It is likely that basin wide erosion will vastly exceed accretion (as in the Eastern Schelde, Pethick *et al.* 2009) with accretion occurring in sheltered locations, areas local to regions of erosion or tributary mouths (DECC 2010b), the barrage itself and main channels, with mudflats and sandbars experiencing high levels of flattening and erosion.

The transport of fluid mud in the Severn Estuary upstream of a barrage, which has important biological and chemical implications, could largely stop due to the reduction in current velocities. It is calculated that up to 2.5m of fluid mud could therefore be deposited in channels, which could compact to a mud bed layer about 0.3m thick (Kirby 2010). As a result of fine sediment deposition upstream of a barrage, sediment starvation may occur downstream affecting salt marsh development, allowing a further increase in erosion through greater wave propagation to the upper shore (Pethick *et al.* 2009). Presently the upper estuary has extensive sand distribution due to the high tidal flows (Underwood 2010), which could become increasingly silty with the deposition of finer sediments, changing the biotope and therefore the communities inhabiting the area. The low species richness and biomass of the present Severn Estuary, characterised by boring bivalves and species such as *Hydrobia ulvae*, *Macoma balthica* and *Nephtys hombergii* in the muds, and *Bathyporeia spp*. in the sands (Warwick & Somerfield 2010), could potentially change to one with increasing populations of deposit feeding or filter feeding invertebrates (Underwood 2010).

In the long term there is the potential for an estuary to adapt geomorphologically to a new regime and start to modify the flow conditions. Calculations of a timescale for this readjustment for the Severn Estuary place it in the order of 1,500 years (Pethick *et al.* 2009), a similar value as that given for the Oosterschelde tidal barrier (Louters *et al.* 1998), which suggests 1 or 2 magnitudes larger than the two decades it took for the system to adapt to the closure of two small dams. The huge scale of these effects and their potential complexity combined with natural variations in the physical conditions of locations means that individual estuaries / river basins could respond differently to the construction of a barrage. As a result, detailed site specific data gathering and assessment should be undertaken before any decisions on suitability of the area for construction are taken.

In terms of tidal lagoons, the effects of water impoundment are largely the same but on a smaller scale than those of tidal barrages. The proposed Swansea Bay lagoon scheme could span around 50% of the mouth of the bay severely affecting sediment transport in and out of the bay and current patterns and velocities (AEA 2007).

### 5.5.3 Spatial consideration

Power extraction has the potential to affect whole estuary / river basin systems, especially in the case of tidal barrages. In large estuaries such as the Severn this could extend to hundreds of square km (in the Severn, inter-tidal areas alone cover some $200km^2$). It is difficult to put a figure on the spatial effect of energy removal by wave and tidal stream devices as the size of any wake effect is likely to vary with technology type and local conditions and current information is predominantly based on single or demonstrator size installations and modelling evidence.

Part of the issue in identifying physical effects of energy removal from the water column relates to the spatial coverage of multibeam surveys in UK waters, shown in Figure A3b.1 in Appendix A3b. Around 85% of UK waters do not have associated multibeam data coverage (Defra 2010b) although those areas with coverage are generally classified as being of a suitable standard to support mapping to the standard required to underpin environmental and resource assessment and marine planning. Single beam coverage of UK waters is more extensive, although the resolution only really allows identification of general bathymetry and cannot be used to identify local changes in sediment patterns. The coverage of even single beam data does not encompass large parts of the coastal zone or deeper waters of especially the North Sea. This lack of detailed data of the current state and configuration of the seabed and features makes it difficult for near and far field effects of wet renewable energy devices to be ascertained.

There are a couple of initiatives tasked with compiling all available information on UK waters (e.g. 'Info HUB' created as part of the NERC MAREMAP sea-bed mapping programme and multibeam data as part of Charting Progress 2 (Defra 2010b)), although data needs to be available in the time frame of developers and as shared access. Several sources, including parts of the aggregates sector and industry, which hold large amounts of relevant data are not currently included in compilations. It can be suggested that a top-down Government lead is required on this initiative as high resolution sea-bed information underpins the understanding of a large number of the issues presented within this SEA.

### 5.5.4 Cumulative impact considerations

The impacts of multiple installations within the marine environment are not well understood. Some modelling studies have investigated the impacts of different array spacings and arrangements, predominantly on the wake effect and subsequent power availability for both wave and tidal stream technologies, with varying recommendations depending on placement, device type and physical characteristics of the site. Caution should however be taken when scaling up demonstrator sized projects to full commercial scale arrays as the effect of additional installations may not simply be additive. It is also possible that the siting and installation of one marine energy type might reduce the energy availability for other marine energy types, potentially at far field sites. One example is the Puget Sound, USA where modelling has suggested that extracting power from near to the outlet to the Pacific Ocean (with the strongest current speeds) could reduce the tidal range in all the other basins in the estuary. Power extraction from the Tacoma Narrows (further upstream, with lower current speeds and therefore lower power generation capacity) would not significantly affect the range in other basins apart from the main basin (Polyagye *et al.* 2008), leaving more areas available for subsequent energy generation schemes.

The potential trade-off between power generation and environmental costs is also an issue with the scaling up of arrays. For tidal stream technologies commercial feasibility studies have proposed array layouts of regular rows of turbines spread across a channel, with the highest possible blockage ratio (ratio of device swept area to channel cross-section area) desirable for maximum power generation (Garrett & Cummins 2007). However, environmental impact studies have shown that across stream 'blocking' layouts have the greatest potential environmental impact (Walkington & Burrows 2009). Conversely, isolating clusters of turbines in particular areas of a tidal channel may be desirable environmentally but could reduce power generation by diverting high speeds around the cluster. The extent of any cumulative effects of multiple devices on organisms and benthic communities is not entirely understood, although the sensitivity of individual species to minor changes in hydrography suggests that at local scales any impacts may be extensive.

Despite the current lack of available data on cumulative effects of energy removal, NERC in collaboration with Defra have allocated £2.3m to fund research into the environmental benefits and risks of up-scaling marine renewable energy schemes on the quality of marine bioresources (including biodiversity) and biophysical dynamics of open coasts. In December 2010 the NERC/Defra 'sandpit' workshop, designed to develop interdisciplinary research proposals, will aim to generate proposals with the following potential topics:

- understanding the exciting science challenges in relation to the spatial arrangement, connectivity, and potential whole system benefits (e.g. the use of fisheries protection zones, marine protected areas etc.);
- identifying optimal design, scale and connectivity of marine renewable arrays to ensure these deliver potential gains for marine bioresources (including biodiversity) and for coastal defence;
- considering the options for establishing enhanced bioresources and biodiversity within marine renewable energy schemes, and the environmental benefits and risks of these on the physical, chemical and biological dynamics of open coasts;
- exploring the long-term sustainability of tidal, wave, and wind renewable energy in the context of a changing marine climate and the biodiversity impacts;
- exploring the socioeconomic impacts or benefits from delivering a sustainable, environment-enhancing supply of energy from the marine environment from a range of sources (tidal, wave, wind) through appropriate partnerships and novel technologies;
- considering the options for restoring and or enhancing ecosystem services and biodiversity with the development of marine renewable energy.

### 5.5.5 Summary of findings and recommendations

The impacts of the removal of energy from the natural marine systems are reasonably well understood for tidal barrages but are far less predictable and appreciated for wave and tidal stream devices. Tidal barrages may have far reaching, large scale impacts that potentially change the energy balance, physical hydrography and associated ecology of the estuary / river basin permanently. For this reason and because individual estuary/embayments are so different it is recommended that detailed site specific data gathering and assessment is required before decisions can be taken on the acceptability or otherwise of a development. Although information is scarce, both tidal stream and wave devices are thought to have significant localised effects that are detectable but unlikely to be highly significant at distance from the installations. Significant uncertainty arises when considering commercial scale arrays of these devices as current information is based on modelling studies or demonstrator scale deployments.

Further information and especially field based measurements and observations are therefore required for all aspects of tidal stream and wave technologies. Current technological developments mean that there is a great variety of designs of wave and tidal stream devices, which will all have differing impacts. The variety of potential physical locations for such designs also needs to be further investigated.

The lack of multibeam survey data for 85% of UK waters means that it is difficult to ascertain the spatial extent of effects from devices. As part of Charting Progress 2 a collation of available data was made, but some data sets from commercial and government departments are not currently shown. A recommendation would be that increased spatial coverage of UK waters by multibeam surveys and a single repository for the data was made available so that the full spatial extent of effects can be realised. This collation of seabed information underpins the wider understanding of a large number of the effects discussed within this SEA.

## 5.6 Physical presence - ecological implications

### 5.6.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Potential for non-native species introductions in ballast water discharges or spread through "stepping stone" effect | X | X | X | X | X | X | X | 5.6.2.4 |
| | Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities | X | X | X | X | X | X | X | 5.6.2 |
| | Collision risks to birds | | | | X | X | | X | 5.6.2.2<br>5.6.3 |
| | Collision risk to marine mammals, fish and large water column animals | | | | | X | X | X | 5.6.2.2<br>5.6.3 |
| | Barriers to movement of birds (e.g. foraging, migration) | | | | X | | X | | 5.6.2.1 |
| | Barriers to movement of fish and marine mammals | | | | X | X | X | X | 5.6.2.1 |
| | EMF effects on sensitive species | | | | X | X | X | X | 5.6.2.5 |

Physical presence of offshore infrastructure and support activities may potentially cause behavioural responses in fish, birds and marine mammals. Previous SEAs have considered the majority of such responses resulting from interactions with offshore oil and gas infrastructure (whether positive or negative) to be insignificant; in part because the total number of surface facilities is relatively small (of the order of a few hundred) and because the majority are at a substantial distance offshore, in relatively deep water. This assessment is considered to remain valid for the potential consequences of future Rounds of oil and gas licensing, including for gas storage and carbon dioxide storage. However, the large numbers of individual surface-piercing structures in OWF developments, the presence of rotating turbine blades and considerations of their location and spatial distribution (e.g. in relation to coastal breeding or wintering locations for waterbirds), indicate a higher potential for physical presence effects. There may also be potential impacts associated with the presence of submerged tidal stream devices, tidal range developments and wave energy converters.

The screening, assessment workshop and consultation processes within the SEA process identified the following broad categories of potential physical presence effect:

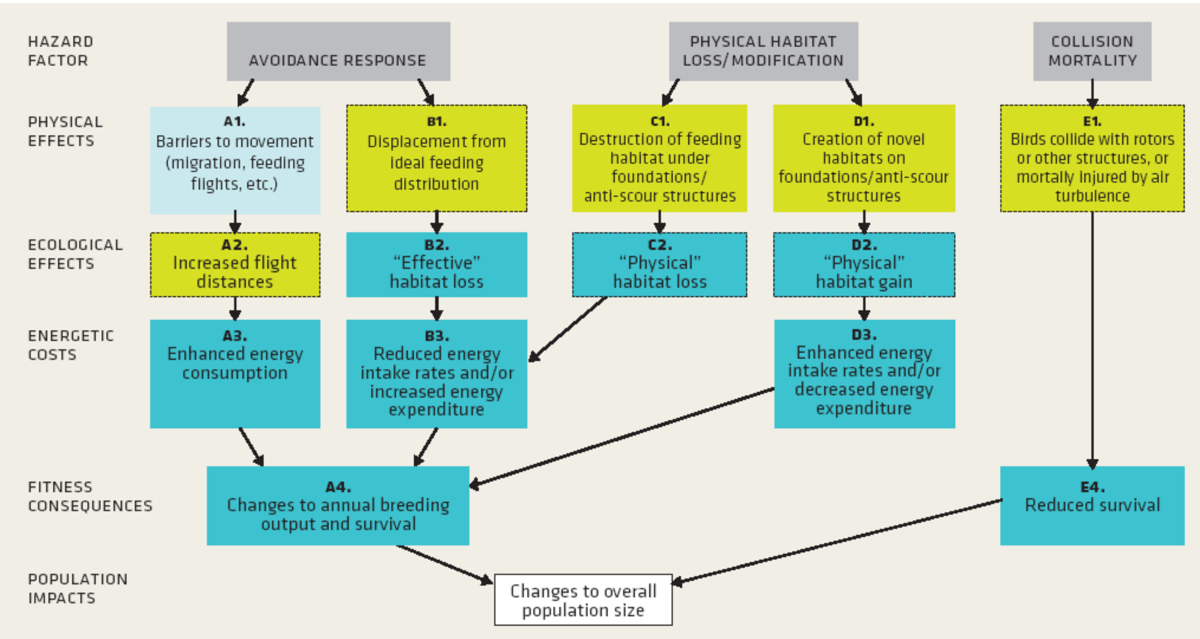
- Displacement and barrier effects – distributional effects associated with displacement from ecologically important (e.g. feeding, breeding) areas; or with disturbance of regular movement (e.g. foraging, migration) of receptor species: principally fish, birds and marine mammals
- Collision risk – in part based on experience with onshore wind turbines, the risk to birds, marine mammals and fish (and potentially bats and insects) of collision with aerial

structures (including turbine blades associated with offshore wind) and submerged structures (turbines and other infrastructure associated with tidal stream and wave devices). Also within this category, there is a potential risk of interaction with gas flares, or fixed structures

- The disturbance effects of light, particularly where this may interact with barrier or collision risks
- Fouling - the presence of artificial substrate for colonisation by plant and epifaunal species
- Stepping stones – the potential for artificial substrates, or effects on natural habitats (such as localised warming) to facilitate colonisation by non-indigenous species
- Electromagnetic fields (EMF) – although indirectly related to the physical presence of structures, EMF has been identified as a potential source of effect resulting from marine electricity transmission.

These potential effects, particularly displacement, do not represent simple causative relationships, with assessment in many cases complicated by subtle and unpredictable interactions between functional ecological processes (e.g. between behavioural modification and energetic cost); feedback processes (for example Maclean *et al*. (2007a) note that mortality resulting from wind farm collisions may reduce competition for resources, thus reducing the rate of natural mortality); the importance of stochastic events, particularly to small populations (also noted by Maclean *et al*. 2007a); habituation; and the presumed functioning of processes which are difficult or impossible to measure. Figure 5.22 illustrates the "Danish model" describing the three major hazard factors (grey boxes) to birds from offshore wind farms, showing their physical and ecological effects on birds, the energetic costs and fitness consequences of these effects, and their ultimate impacts on the population level (white box). The light green boxes indicate potentially measurable effects, the dark blue boxes indicate processes that need to be modelled.

Figure 5.22 – "Danish model" flow chart for the three major hazard factors to birds




*Source: Dong Energy et al. (2006) (a similar chart is used by Fox et al. 2006)*

There is also a considerable range in the quantity of, and confidence in, information relating to these issues. Some (e.g. displacement and collision risks for birds) have been subject to a considerable research effort, although this is largely predictive; others (fouling) have been extensively monitored over a substantial time period; and some are relatively speculative. Furthermore, some receptors (birds and marine mammals) are the focus of considerable attention from a range of NGO and conservation organisations with occasional lack of distinction between conservation, welfare and ethical concerns. Research on the potential impacts of tidal stream and range, and wave devices is still at a preliminary stage focussed on demonstrator scale projects. It is likely that licensing of areas for tidal stream and wave activities in this licensing round will be at a demonstrator scale consisting of a small number of devices rather than full development arrays. Potential development scenarios used to inform the SEA are described in Section 2.5.4 and include: for tidal stream, a maximum array capacity of 30MW occupying 0.5-5km$^2$; for wave, a maximum array capacity of 30MW occupying 1-10km$^2$, and for tidal range, a minimum tidal range of 6m. This assessment aims to draw balanced conclusions based on credible scientific evidence, while recognising that some precautionary concerns are valid given current uncertainties and information gaps.

## 5.6.2 Consideration of the evidence

### 5.6.2.1 Displacement and barrier effects

#### Offshore wind farms

In relation to birds, the potential displacement and barrier effects of OWF have been extensively recognised (Percival 2001, Exo *et al*. 2003, Drewitt & Langston 2006, Fox *et al*. 2006, Stienen *et al*. 2008, Norman *et al*. 2007) although there remains little convincing data for significant effects. Garthe & Hüppop (2004) suggest that both birds on migration and those resting or foraging locally could potentially be affected: at sea, this therefore includes both migrating birds, from the smallest songbirds to large birds such as cranes and birds of prey, and seabirds during their local movements (Exo *et al*. 2003). Despite the concern, and construction of a number of OWF developments, the evidence base for biologically meaningful displacement or barrier effects is relatively sparse.

At Tunø Knob in the Danish Kattegat, Guillemette *et al*. (1998, 1999), demonstrated a decrease in the number of common eiders and common scoters in the development site in the two years following construction. Although eider numbers subsequently increased, supporting the view that the decline following construction was not due to the wind farm, there was only a partial recovery for common scoter. It is also possible that the increase in eider numbers post-construction may have occurred as a result of increased abundance of mussels or due to birds habituating to the wind farm. This work is subject to a number of caveats regarding its application to other developments, in particular relating to the small size of the wind farm (ten 500kW turbines) and the small size of the flocks studied (Drewitt & Langston 2006). Later work reported by Larsen & Guillemette (2007) concluded that eiders reacted strongly to the presence of wind turbines, with the number of flying birds significantly related to flight corridor location and position of a decoy group. That behavioural reaction was interpreted to be a consequence of this species' high speed and low-manoeuvrability flight occurring within the vertical height range of the wind turbines.

Predictive modelling of common scoter distribution in Liverpool Bay (Kaiser *et al*. 2006) suggested that under some circumstances a significant adverse effect on common scoter mortality would occur; specifically, in the predicted presence of a wind farm on Shell Flat in combination with others in the region, and on the assumption that the radius of the buffer zone around them all extends to 2km. However, only in the scenarios in which a 2km buffer zone around the Shell Flat location was included did the model predict that common scoter would be excluded from a number of grid cells in which the model predicted they would otherwise feed heavily. The model may underestimate the magnitude of this effect, but nonetheless, a significant effect is predicted. However, this cumulative adverse effect may be negated if: i) the radius of the buffer zone is smaller than 2km, ii) common scoter redistribute to currently unused but apparently profitable feeding areas within Liverpool Bay or iii) common scoter feed during the hours of darkness as well as during daylight. The proposal to construct the Shell Flat wind farm has subsequently been withdrawn.

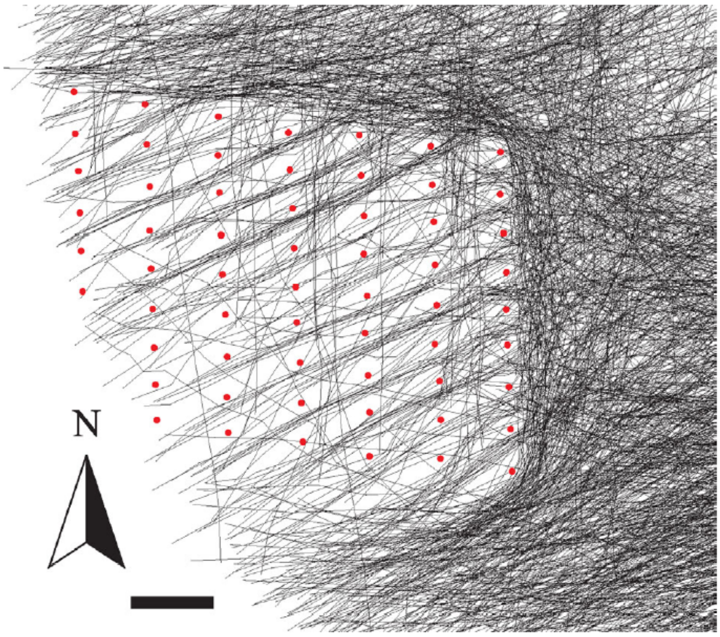
Studies using aerial surveys carried out before, during and following construction at Horns Rev OWF found that divers, gannets, common scoters, guillemots and razorbills occurred in lower numbers than expected in the wind farm area, and the zone within 4km of it, following construction (Petersen *et al*. 2004). Divers and common scoters showed almost complete avoidance of the Horns Rev wind farm area in the first three years post construction (DONG *et al*. 2006), although as proportions of the total numbers present in the wider area, the displaced birds were relatively few. Conversely, gulls and terns showed a preference for the wind farm area following construction. Subsequent surveys indicate that common scoters may now be distributed in comparable densities inside and outside the development; and the possibility cannot be excluded that changes in food availability rather than displacement by disturbance led to the observed changes in distribution (Petersen *et al*. 2006). It is also possible that these changes reflect habituation to wind farm presence and associated activities.

Barrier effects of birds altering their migration flyways or local flight paths to avoid a wind farm are also a form of displacement (Drewitt & Langston 2006). This postulated effect is related to the possibility of increased energy expenditure when birds have to fly further, as a result of avoiding a large array of turbines, and the potential disruption of linkages between distant feeding, roosting, moulting and breeding areas otherwise unaffected by the wind farm.

Radar studies at Nysted offshore wind farm, in the western Baltic, indicated a high degree of avoidance by large waterbirds (mostly eider) during migration, at least in fair weather (Desholm & Kahlert 2005; Figure 5.23). There was a significant ($P<0.001$) reduction in migration track densities within the wind farm area post-construction (40.4% ($n=1,406$) of flocks entered the wind farm area prior to construction of the wind farm (2000-2002) compared with 8.9% ($n=779$) during initial operation (2003)). Significant differences were also observed between the avoidance response during daylight and at night. The practical problems in demonstrating effects (or lack of effects) with statistical rigour was shown by long-tailed duck monitoring at Nysted, where data from only two (consistent) baseline years in 2001 and 2002 would suggest a dramatic displacement of birds from the OWF in 2003 out to almost 15km (Kahlert *et al*. 2004). However, the baseline data from 2000 showed that the bird distribution during 2003 fell within the variability of the baseline sampling.

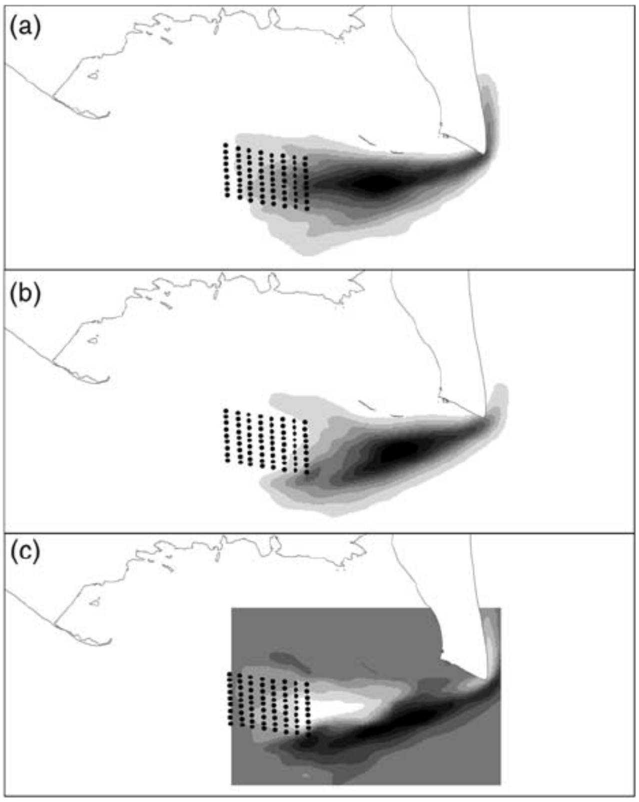
More recent analysis of flight trajectories of migrating common eiders passing through the Nysted wind farm area pre- and post-construction indicated the curvature of eider trajectories was greatest post-construction and within 500m of the wind farm, with a median curvature significantly greater than pre-construction, suggesting that the birds adjusted their flight paths in the presence of the wind farm (Masden *et al.* 2009). The response of eiders to the wind farm and the differences in space use are illustrated in Figure 5.24.

Figure 5.23 - Westerly oriented flight trajectories during the initial operation of the wind turbines at Nysted OWF. Black lines indicate migrating waterbird flocks, red dots the wind turbines. Scale bar, 1000m.




*Source: Desholm & Kahlert (2005).*

Figure 5.24 - Kernels of space use by eider across the study area (a) pre-construction, (b) post-construction, and (c) the difference in space use between (a) and (b). Darker colour represents greater use. Dots denote the wind turbines.




*Source: Masden et al. (2009).*

Post-construction, the space used by eiders was reduced in the area of the wind farm when compared with that pre-construction, and there was a corresponding increase in the use of surrounding areas, particularly to the south. The additional distance travelled as a consequence of the wind farm's presence was ca. 500m and trivial compared with the total costs of a migration episode of 1,400km. However, construction of further wind farms along the migration route could have cumulative effects on the population, especially when considered in combination with other human actions (Masden *et al.* 2009)

Other studies in Denmark (Christensen *et al*. 2004, Kahlert *et al*. 2004) and the Netherlands (Winkelman 1992a, b, c, d), have produced limited evidence to show that nocturnally migrating waterfowl are able to detect and avoid turbines, at least in some circumstances, and that avoidance distances can be greater during darker nights when visibility of navigation and aviation lights is greater (Dirksen *et al*. 1998, 2000).

Overall, although measurable changes in the local distribution of two waterbird species – eider and common scoter – have been reasonably well characterised in Danish studies; and displacement of divers and possibly auks also shown (at Horns Rev), it is not clear to what extent this is a permanent effect (within the lifetime of the development), with habituation or other recovery mechanisms clearly implicated at Horns Rev. Neither is it clear whether any of the observed displacement, or deviation of migratory flightpaths, are biologically meaningful, in terms of population dynamics at a local or biogeographic population level (or would be meaningful even with a substantial increase in the number of OWF developments). Drewitt & Langston (2006) noted that a review of the literature suggests that none of the barrier effects identified so far have significant impacts on populations (although they were able to speculate on specific locational or cumulative circumstances where this might occur).

Displacement caused by OWFs during migration or daily foraging trips may have an energetic cost which under certain circumstances may be significant. Speakman *et al.* (2009) modelled the impact on energy expenditure (and hence fat utilisation) of migrating common scoter, red-throated diver, whooper swan and sandwich tern having to deviate around a single wind farm facility, and found it to be trivial. For most species it would result in depletion of less than 2% of their available fat reserves, even if the birds travelled 30km out of their way to avoid the facility.

However, the impact on birds having to make regular deviations around a facility located between roosting and feeding sites, or between nesting and feeding sites was more significant. An extra 15km of flying each day would increase daily energy demands by between 4.8 and 6%. This would require birds to increase their daily foraging effort by the same extent or cut back other components of their energy budgets. Such effects, if prolonged, could have a mortality impact. Directly modelling this impact is complex because the ways that birds respond to such increases in energy demand are not yet fully understood, and birds are known to have great flexibility in their responses to variation in their energy demands (Speakman *et al.* 2009).

Similarly, Masden *et al.* (2010) considered the potential energetic costs to seabirds forced to commute around offshore wind farms on a regular basis. For a given distance, species have different levels of basic energy expenditure for flight and thus different species suffer proportionally more or less energetic penalties for each extra kilometre of flight caused by avoidance of objects such as wind turbines. Cormorants and auks undertake a few short provisioning flights and hence experienced the greatest additional costs when performing many foraging trips per day and travelling large additional distances. In contrast, northern fulmar and northern gannet undertake few but long foraging trips and are adapted to using efficient gliding flight, so the extra costs of additional distance are relatively small, although both species may have difficulty provisioning chicks in low-wind or strong head-wind conditions due to the high energetic cost of flapping flight (Furness & Bryant 1996). Gulls (lesser black-backed and black-legged kittiwake) show similar patterns despite their shorter and more frequent provisioning trips, suggesting a more energy efficient wing loading in these species. Finally, although common tern required the least energy when ecology and foraging characteristics were assumed constant across all species, it was the most affected by the additional distance when foraging ecology was considered species-specific. A common tern typically completes 12 foraging trips per day and therefore would interact with the wind farm and incur the additional distance, 24 times per day (Masden *et al.* 2010).

Following a review of Round 1 and Round 2 windfarm applications, as well as other recent developments in the monitoring and assessment of bird numbers at offshore sites, Maclean *et al.* (2009) provided recommendations on carrying out ornithological impact assessments, including determining displacement effects. They recommended that the best way to quantify the potential magnitude of disturbance would be to determine peak densities within the windfarm footprint and buffer area and then to assume that, as a worse-case scenario, all birds are displaced. The magnitude of the impact can then be determined by quantifying the proportion of the regional, national or international populations hosted by the windfarm footprint and buffer zone. In the absence of more detailed research on displacement of the species in question, a 4km buffer could be used (Maclean *et al.* 2009).

Displacement will affect different bird species in different ways, and will be dependent largely upon the availability of suitable feeding habitat in the areas to which they are displaced. Thus species with very specific habitat requirements are likely to be more vulnerable to the effects of displacement than habitat generalists. The use of a habitat flexibility score (Table 5.6) devised by Garthe & Hüppop (2004) could be used to derive sensitivity to displacement (Maclean *et al.* 2009).

Table 5.6 - Sensitivities of individual species due to flexibility in habitat use

| Sensitivity due to habitat flexibility | Species |
|---|---|
| Very high | Red-necked grebe |
| High | Divers, scoters, cormorant, great-crested grebe |
| Medium | Eider, common tern, Arctic tern, little gull |
| Low | Sandwich tern, great black-backed gull, auks, great skua, black-headed gull, kittiwake |
| Negligible | Gannet, lesser black-backed gull, herring gull, fulmar |

*Source: Maclean et al. (2009) adapted from Garthe & Hüppop (2004).*

Maclean *et al.* (2009) indicate that barrier effects are complex to quantify and there is an urgent need for more detailed research to assess the impacts barrier effects have on species survival and population sizes. The magnitude of impacts should be determined by considering a combination of the number of birds likely to be flying through the windfarm and the extent to which the windfarm is likely to act as a barrier. Maclean *et al.* (2009) proposed that the magnitude of impact could be assessed using the following criteria (Table 5.7).

Table 5.7 - Criteria used to determine one of the components of the magnitude of impact due to barrier effects

| Magnitude of impact | Definition |
|---|---|
| Very high | (i) windfarm is located between breeding site and key foraging area of a species flying through the site in nationally or internationally important numbers and/or (ii) is located close to key stopover, breeding or wintering site of species flying through the site in nationally or internationally important numbers and/or (iii) is located along the migration route of a species flying through the site in internationally important numbers. |
| High | (i) windfarm is located close to key stopover, breeding or wintering site of species flying through the site in nationally important numbers and/or (ii) is located along the migration route of a species flying through the site in nationally important numbers. |
| Medium | (i) windfarm is located between breeding site and key foraging area of a species flying through the site in regionally important numbers and/or (ii) is located close to key stopover, breeding or wintering site of a species flying through the site in regionally important numbers and/or (iii) is located along the migration route of a species flying through the site in regionally important numbers |
| Low | (i) windfarm is located between breeding site and key foraging area of any other species and/or (ii) is located close to a key stopover, breeding or wintering site of any other species and/or (iii) likely to be located on a migration route of any other species. |
| Very low | None of above. |

*Source: Maclean et al. (2009).*

The impact on survival of a given barrier and concomitant deviation in flight will differ between species. Large, bulky species with small wing areas (i.e. those which have high wing-loadings) will be more adversely affected that those that do not. Using body mass and wing-length ratios, Maclean *et al*. (2009) devised sensitivities to barrier effects for different species (Table 5.8).

Table 5.8 - Sensitivities of individual species to barrier effects

| Sensitivity to barrier effects | Species |
|---|---|
| Very high | Black-throated diver |
| High | Red-throated diver, cormorant, geese, auks |
| Medium | Ducks |
| Low | Fulmar, skuas, gulls |
| Very low | Gannet, terns, passerines |

*Source: Maclean et al. (2009).*

Speculative concerns have been raised in relation to possible barrier effects of offshore developments (in particular seismic surveys discussed further in relation to noise in Section 5.3.2.1) in relation to marine mammals; there is no meaningful evidence base for assessment of this. Migration, as an organised seasonal behavioural pattern comparable to that of birds, is probably limited in marine mammals to movements of sperm whales and possibly baleen whales along the continental shelf margin and the main investigative approach is through passive acoustic monitoring (using SOSUS arrays). Following the work sponsored through AFEN in the 1990s (e.g. Charif & Clark 2000), further studies were commissioned as part of the SEA programme. The initial report of an assessment of a 10 year dataset (Charif & Clark 2009) indicates the consistent presence of blue, fin, and humpback whales with annual cycles of occurrence of sounds from all three species at Atlantic SOSUS stations. These cycles are apparently consistent with seasonal migrations between high latitudes in summer and lower latitudes in winter.

## Wave and tidal stream

The area of seabed impacted directly during the construction of wave and tidal stream devices may be small, limited to impacts from cabling and anchorage (Langhamer & Wilhelmsson 2009). Nevertheless, some devices, such as oscillating wave converters, will require a fixed base. This is similar to the impacts suggested during wind turbine construction; however, the construction and decommissioning of the devices themselves differ substantially and loss of habitat throughout these phases is likely to be less extensive (Grecian *et al.* 2009). Disturbance and removal of habitat may lead to displacement of animals from the vicinity of the development site (e.g. birds may avoid areas containing manmade structures (Petersen *et al.* 2006, Larsen & Guillemette 2007)).

The presence of wave and tidal stream devices and infrastructure could cause loss of habitat during device operation, with estimations of the size of physical impacts of devices and arrays discussed in Section 5.4.2.2. Devices may exclude fish from suitable feeding habitats by providing a physical or perceptual barrier, or producing noise that results in avoidance behaviour. Exclusion may limit other device interactions, such as collisions, but will also limit the available habitat, with associated effects on feeding and breeding success, stress on individuals and energy budgets. Whilst it is considered that alternative feeding areas may be available to these species, the device may create a net loss of feeding area and removal of food resource, depending on the means of securing the device to the seabed. Wave devices which either float on the surface or are stable in the water column and anchored to the sea bed are likely to have less of an impact than pile-driven devices (Mueller & Wallace 2008, Inger *et al.* 2009). There may also be a knock-on effect on adjacent fish populations arising from increased competition for prey species in adjacent areas (AECOM & Metoc 2009).

Environmental monitoring of the Seagen tidal stream turbine in Strangford Lough (installed in July 2008) has been carried out since 2005. The potential for displacement and barrier effects to marine mammals has been investigated by passive acoustic monitoring with a number of T-PODs deployed within the narrows and inner Lough. A decline in the overall detections of harbour porpoises within the narrows was recorded which may indicate that the animals now pass through the narrows more quickly and/or quietly. However, detailed analysis of individual T-POD's data indicated that only those on the east side of the narrows show a decline, with the site to the west remaining constant and the site to the north showing a significant increase in detections. Despite the apparent changes in porpoise detection to the east of the narrows no significant difference between detections during SeaGen operation and non-operation has been observed within the Lough, indicating that SeaGen is not causing a barrier effect (Royal Haskoning 2010a). Further monitoring between March and October 2010 highlighted a significant decrease in Detection Positive Days (DPD) at the eastern pod locations within the Narrows. It is not clear whether this represents a shift in the route used through the Narrows or whether the findings could be a result of changes in the locations of the eastern PODs. The results from a TPOD in the inner Lough have shown a decline in the number of DPDs during the operational phase when compared with the baseline findings (Royal Haskoning 2010b).

Aerial surveys have shown no significant changes in seal use of haul out sites since installation of SeaGen. The Sea Mammal Research Unit (SMRU) deployed successfully a series of tags on harbour seals between 30th March and 9th April 2010 to provide details of seal movements in relation to the Strangford Lough narrows and wider coastline. The tracks showed a large amount of individual variability with some individuals remaining within the Lough and Narrows, and others making long journeys to and from the Lough. Comparison between the harbour seal transit rates during operation and non-operation of SeaGen throughout the deployment period in 2010 showed no statistically significant difference when considering all the seals together. Further investigation of the effect of operation and non-operation of SeaGen indicated that some individual seals did appear to transit less during operation. The extent of the reduction is between 10% and 50%, with an average of around 20%. It is unclear at this stage whether this is biologically significant, particularly due to the small number of seals tagged (4) (Royal Haskoning 2010b).

Wave and tidal stream development resulting from implementation of the plan are likely to be restricted to demonstrator scale projects consisting of a small number of devices and it is therefore unlikely that displacement will represent a significant strategic impact. However, given that suitable areas for exploitation of the tidal stream resource may be restricted to localised areas such as tidal straits and channels, the potential for barrier effects and displacement is perhaps greater and should be assessed comprehensively at the project-level. For example, the maximum area occupied by a tidal stream array envisaged by the SEA scenarios (Section 2.5.4) is approximately 5km$^2$ which could represent a significant potential barrier in a tidal strait or channel.

## Tidal range

Topic papers on migratory and estuarine fish produced as part of the DECC Severn Tidal Power feasibility study (DECC 2008b, 2010g) indicated that the placement of a tidal range scheme within the Severn Estuary could result in effects to fish passage and movement both for the seasonal migration of diadromous species and the daily movement of estuarine species. In a high tidal range and strong excursion environment such as the Severn Estuary, upstream migrants are likely to use tidal stream transport as a mechanism of moving up the estuary. A tidal range scheme across the estuary could alter this tidal regime and potentially as a result, the mechanism and rate of upstream movement of migratory fish. Furthermore, migratory fish are likely to change their behaviour as they move into the estuary from coastal waters, through the main estuary and into the inner estuaries and freshwater environments. Changes to the tidal and freshwater patterns as a result of a structure may further the negative impacts to migratory behaviour and resultant impacts upon individuals and populations. Such changes to migratory movement may result in delay and increased passage time which subsequently has the potential to result in further effects including increased predation and extended exposure to any changes to water quality (DECC 2008b, 2010g).

The effect of changes to quality or loss of access to the intertidal habitat (including duration of exposure, discussed further in Section 5.4.2.2) may have a negative effect on the waterbird species which use these areas for feeding. For example, the potential loss of (and associated changes to) intertidal habitat resulting from the largest of the Severn Estuary tidal power options, the Brean Down to Lavernock Point Barrage option (B3), was proposed to represent the principal effect for waterbird receptors. The main, initial effect could follow construction and implementation of the option, when an estimated 51% of the intertidal could be lost (based on area exposed at lowest astronomical tide and not including intertidal areas of sub-estuaries); an additional 7.4% decrease in the extent of the intertidal was predicted over the operational phase. The predicted level of 2.0Mm$^3$ of maintenance dredging per year may also affect intertidal habitat quality (by exposing mudflats to erosion and affecting the maintenance or development of invertebrate communities). This effect was identified as a likely significant negative effect under the B3 option for 30 waterbird receptors, including the overall waterbird assemblage, as the scale of (both immediate and long-term) habitat loss and the changes to the intertidal exposure period were predicted to outweigh any positive changes in the quality of intertidal habitat (DECC 2010g).

Energy generation using barrage systems that generate power on both ebb and flood tides could reduce considerably the changes in exposure of the intertidal area and so reduce the potential impacts on the bird community (ICES 2010).

### 5.6.2.2 Collision risk of birds, marine mammals and fish

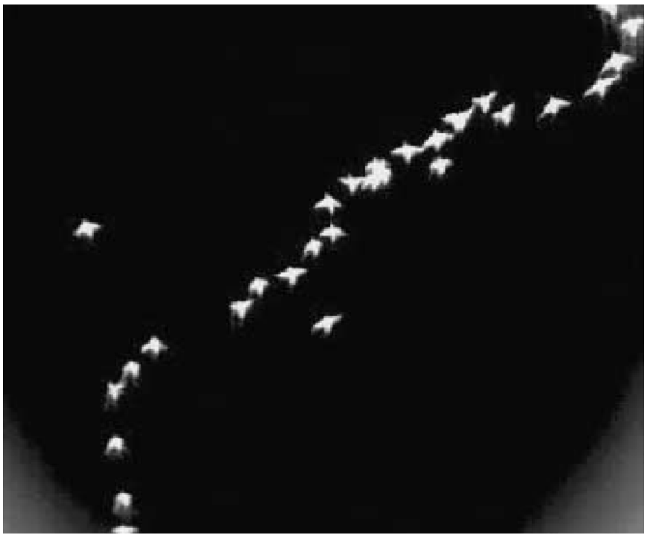
#### Offshore wind farms

Collision risk has received considerable attention in relation to both onshore and offshore wind farm development, with substantial effort expended both in empirical studies (e.g. mortality counts; infrared monitoring) and predictive modelling. This subject has been comprehensively reviewed (Desholm *et al*. 2006, Drewitt & Langston 2006) and detailed discussion of the evidence base is provided by these sources.

Collision risk mortality depends on a range of factors related to bird species, numbers and behaviour, weather conditions and topography and the nature of the offshore structure itself, including the use of lighting. The review of the available literature by Drewitt & Langston (2006) indicated that, where collisions have been recorded, the rates per turbine are very variable with averages ranging from 0.01 to 23 bird collisions annually; the highest figure is the value, following correction for scavenger removal, for a coastal site in Belgium and relates to gulls, terns and ducks amongst other species (Everaert *et al*. 2001). In contrast, visual observations of eider movements in response to two small, relatively near-shore wind farms (seven 1.5MW and five 2MW turbines) in the Kalmar Sound, Sweden, recorded only one collision event during observations of 1.5 million migrating waterfowl (Pettersson 2005). Drewitt & Langston (2006) also note that although providing a helpful and standardised indication of collision rates, average rates per turbine must be viewed with some caution as they are often cited without variance and can mask significantly higher rates for individual turbines or groups of turbines.

Hüppop *et al*. (2006a) note the problems of quantifying collision rate by carcass collection offshore, and Chamberlain *et al*. (2006), in a review of collision risk modelling, point out that calculation of post-construction mortality rates has typically relied on corpse searches (Langston & Pullan 2003), using tideline searches for off-shore and coastal wind farms (e.g. Winkelman 1992a, Painter *et al*. 1999). There are potential biases in estimating mortality in this way due to searching efficiency, corpse removal by scavengers, injured birds leaving the area before death, ‘obliteration’ of birds struck by turbine blades (especially smaller species) and, for coastal locations, corpses sinking or being washed out to sea. Adjustments to mortality rates have been made to try and compensate for these factors by some authors (e.g. Winkelman 1992a, Painter *et al*. 1999). Desholm *et al*. (2006) review possible technical developments in remote techniques, including thermal imaging (Figure 5.25).

Figure 5.25 - Thermal image recorded by TADS and showing a flock of common eiders passing the field of view at a distance of ca. 70m



*Source: Desholm et al. (2006)*

Collision Risk Modelling (CRM) has been extensively used for both onshore and offshore sites globally, including a range of UK offshore developments (Table 5.9); although not always consistently and with appropriate input data. For example, Chamberlain *et al*. (2006) present a critical review of collision risk modelling for the Kentish Flats OWF, where, using survey data and an avoidance rate of 0.9998 taken from Winkelman (1992c), Gill *et al*. (2002) estimated mortality rates for terns, divers, gannets and black-headed gull. The estimated avoidance rate was used for all groups, even though it was derived for passerines only (Winkelman 1992c). Chamberlain *et al*. (2006) considered this inappropriate when all species considered at Kentish Flats were considerably larger and have very different flight characteristics from passerines. Furthermore, despite the authors' statement that the avoidance rate used is 'the worst case scenario', it produces one of the lowest collision rates presented in the source reference. For example, application of the maximum estimated nocturnal mortality for gulls resulted in over an eight-fold increase in mortality rates. This Kentish Flats study would have been a good candidate for presenting a range of avoidance rates, rather than a single (and arguably inappropriate) rate.

In reviewing OWF monitoring data compiled as part of FEPA licence conditions, CEFAS (2010) indicated that methods to investigate barrier effects or collision risk (e.g. motion sensitive still/video cameras, infra-red cameras, thermal imaging, X-band radar), have been left to the developer to devise, and are generally site specific and not comparable. Broadly this monitoring has generally found little significant effects, but this may be because the monitoring techniques are less well developed. The review recommended that standardised methodologies be developed for all aspects of ornithological monitoring to provide guidance to developers (CEFAS 2010).

Table 5.9 – Collision Risk Modelling (CRM) predictions taken from various UK Round 1 & 2 Environmental Statements (see also notes overleaf)

| Location | Species/Taxa | Collision (mortality) rate (in units of number/time) for whole development |
|---|---|---|
| Sheringham Shoal - north Norfolk coast[1] | Sandwich tern<br>Common tern<br>Gannet<br>Little gull<br>Lesser Black-backed gull | $23/y_a$ $12/y_b$ $6/y_c$<br>$3/y_a$ $1/y_b$ $1/y_c$<br>$31/y_a$ $16/y_b$ $8/y_c$<br>$8/y_a$ $4/y_b$ $2/y_c$<br>$33/y_a$ $16/y_b$ $8/y_c$ |
| Kentish Flats - Outer Thames Estuary[2] | Divers<br>Divers | $0.52/y_d$<br>$0.01/y_e$ |
| Greater Gabbard - Outer Thames Estuary[3] | Red – throated diver<br>Lesser Black-backed gull<br>Great Skua | $0.048/d_d$<br>$0.076/d_d$<br>$0.052/d_d$ |
| Gunfleet Sands - Outer Thames Estuary[4] | Divers | $1.69/y_f$<br>$0.34/y_b$<br>$0.03/y_g$<br>$0.003/y_h$ |
| Lincs - Greater Wash[5] | Pink-footed goose<br>Red-throated diver<br>Gannet<br>Little gull<br>Common gull<br>Lesser Black-backed gull<br>Common tern<br>Guillemot | $4668/y_d$ 317[6]$/y_f$ $93/y_a$ $47/y_b$ $23/y_c$ $4.7/y_g$ $0.93/y_e$<br>$77/y_d$ $4/y_f$ $2/y_a$ $1/y_b$ $0/y_c$ $0.1/y_g$ $0.02/y_e$<br>$427/y_d$ $21/y_f$ $9/y_a$ $4/y_b$ $2/y_c$ $0.4/y_g$ $0.09/y_e$<br>$74/y_d$ $0/y_f$ $1/y_a$ $1/y_b$ $0/y_c$ $0.1/y_g$ $0.01/y_e$<br>$2137/y_d$ $107/y_f$ $43/y_a$ $21/y_b$ $11/y_c$ $2.1/y_g$ $0.43/y_e$<br>$1710/y_d$ $85/y_f$ $34/y_a$ $17/y_b$ $9/y_c$ $1.7/y_g$ $0.34/y_e$<br>$114/y_d$ $6/y_f$ $2/y_a$ $1/y_b$ $1/y_c$ $0.1/y_g$ $0.02/y_e$<br>$3/y_d$ $0/y_f$ $0/y_a$ $0/y_b$ $0/y_c$ $0/y_g$ $0/y_e$ |
| Thanet - Outer Thames Estuary[7] | Red-throated diver<br>Fulmar<br>Gannet<br>Common tern<br>Sandwich tern<br>Kittiwake<br>Common gull<br>Herring gull<br>Lesser Black-backed gull<br>Great Black-backed gull<br>Gull sp.<br>Auks | $1/y_b$<br>$0/y_b$<br>$1/y_b$<br>$0/y_b$<br>$1/y_b$<br>$1/y_b$<br>$17/y_b$<br>$49/y_b$<br>$32/y_b$<br>$1/y_b$<br>$23/y_b$<br>$0/y_b$ |
| Walney - East Irish Sea[8] | Lesser Black-backed gull | Worst case scenario<br>$572.02/y_f$ $114.4/y_b$ $11.44/y_g$ $1.14/y_h$<br>Base case scenario<br>$438.96/y_f$ $87.79/y_b$ $8.78/y_g$ $0.88/y_h$ |
| Beatrice - Moray Firth[9] | Kittiwake<br>Great Black-backed gull<br>Herring gull<br>Fulmar<br>Gannet<br>Tern sp. | $47/y_i$ $23/y_f$ $9/y_a$ $5/y_b$ $2/y_c$<br>$28/y_i$ $14/y_f$ $6/y_a$ $3/y_b$ $1/y_c$<br>$10/y_i$ $5/y_f$ $2/y_a$ $1/y_b$ $1/y_c$<br>$1.6/y_i$ $0.8/y_f$ $0.3/y_a$ $0.2/y_b$ $0.1/y_c$<br>$24/y_i$ $12/y_f$ $5/y_a$ $2/y_b$ $1/y_c$<br>$2.0/y_i$ $1.0/y_f$ $0.4/y_a$ $0.2/y_b$ $0.1/y_c$ |
| Dudgeon - Greater Wash | Sandwich tern<br>Common tern<br>Razorbill<br>Lesser black-backed gull<br>Gannet | $75/y_a$<br>$2/y_a$<br>$<1/y_c$<br>$54/y_b$<br>$217/y_J$ |

*Notes to Table 5.9: Probability of avoidance $_a$ 98% $_b$ 99% $_c$ 99.5% $_d$ Based on no avoidance $_e$ 99.98% $_f$ 95% $_g$99.9% $_h$ 99.99% $_i$ 90%$_.$ J 97%*

*[1]Two precautionary assumptions are used in impact assessment. First, the annual mortality was calculated with the worst case 108 × 3MW layout (Rochdale Envelope). Second, a precautionary avoidance rate of 98% was used.*

*[2] Collision mortality analysed using Scottish Natural Heritage (SNH) model (SNH 2000). Collision risk model used makes no allowance for either avoidance behaviour or the orientation of turbines in relation to flight direction.*

*[3] Estimation of risk of collision uses SNH Collision Risk Model (CRM). This model assumes no avoidance action is taken by birds.*

*[4] Collision rates calculated using the SNH CRM.*

*[5] Collision rates calculated using the CRM developed by SNH and BWEA (Percival et al. 1999, SNH 2000).*

*[6] This figure assumes that pink-footed geese are active at night (night activity constituting 75% of daytime activity levels). If they are treated as entirely diurnal then at 95% avoidance 192 collisions are predicted.*

*[7] Results for worst case scenario, (60 turbines), as they have the greatest combined rotor swept volume.*

*[8] Collision rates calculated using the SNH CRM.*

*[9] Collision rates calculated using the SNH CRM using four different scenarios for flight height distribution and flight speed – results given above are for "most applicable" (Model C, uniform height distribution, flight speed affected by wind for kittiwake; Model D, skewed height distribution and constant speed for great black-backed gull, herring gull, fulmar, gannet and tern sp.).*

The main conclusions which can be reached from Table 5.9 are, firstly, that numerical predictions are highly sensitive to assumptions on avoidance rates; and that secondly, excluding scenarios with zero avoidance, the maximum predicted collision rates for any species are of the order of a few tens (per year, per development). Maclean *et al.* (2009) propose that for CRM a combination of published estimates of avoidance rates are used for species for which sufficient published information exists, and precautionary avoidance rates dictated by flight manoeuvrability and the extent to which birds are likely to avoid the windfarm altogether are used for other species (Table 5.10).

Table 5.10 - Choice of lower avoidance rates for different species and taxon, based on published avoidance rates and flight manoeuvrability

| Avoidance rate | Species |
|---|---|
| 99.0% | Terns, divers, cormorant, ducks, geese, grebes, puffin |
| 99.5% | Auks, gulls, gannet |
| 99.9% | Fulmar, shearwaters |

*Source: Maclean et al. (2009).*

Since the publication of OESEA in 2009, a number of other studies examining the potential interaction of bird species with offshore wind farms have been commissioned on behalf of the DECC SEA process (see Appendix 3a.7).

A collaborative study between the British Trust for Ornithology and the University of Amsterdam is tracking several lesser black-backed gulls and great skuas during a complete annual cycle, to examine the interaction between these two species and wind farm development zones. Foraging ranges are being mapped and information on flight heights gathered.

An RSPB-led, EU INTERREG and NERC funded study, conducted in collaboration with Birdlife International is tracking five species of seabirds: fulmar, shag, kittiwake, guillemot and gannet from several UK breeding colonies. A complimentary SEA funded RSPB study, has tagged gannets from Bempton cliffs, which will help identify important foraging areas for gannets from the Bempton and Flamborough SPA. In July 2010, 14 satellite tags were fitted to adult gannets breeding at the site. The tags collected data for up to one month during the chick rearing stage and the information will help identify important foraging areas.

Preliminary results indicate that most foraging trips are within 100km of the coast, with some overlap of the Hornsea offshore wind zone. A few tracks reach the Dogger Bank and some extend southwards.

A COWRIE-commissioned satellite-tracking study has indicated that whooper swans migrating from southeast England (Wildfowl and Wetland Trust Welney site) generally migrate north along the east coast of Britain whereas those from northwest England and southwest Scotland (Martin Mere and Caerlaverock WWT sites) followed the western coastline (Griffin *et al.* 2010a) en route to Icelandic breeding grounds. The study found that the potential for overlap between whooper swan migration routes and proposed offshore windfarm sites was greater for swans migrating along the west coast of Britain than for those migrating along the east coast of Britain. The authors suggest that potential differences in collision risk arising from the installation of wind farms within these two migratory corridors could be assessed by continuing the long-term study of whooper swan survival rates for birds wintering at these WWT sites over the next 5-10 years, during which time many of the proposed windfarms will become operational (Griffin *et al.* 2010a).

DECC has funded an extension to the whooper swan tagging study into migration routes in relation to wind farm footprints, carried out by WWT. The work includes analyses of existing GPS and conventional satellite tracking data for four key species (whooper swan, Svalbard barnacle goose, Greenland white-fronted goose and light-bellied brent goose) in relation to offshore wind farm locations along their migration flyways. An interim report (Griffin *et al.* 2010b) indicates that of the seven whooper swans tracked in 2010, tracks for six birds appeared to cross five different operational or potential offshore wind farm areas (Ormonde, Robin Rigg, Solway Firth, Islay and Argyll Array). The Kintyre, Islay and Argyll Array sites appear to have the greatest potential to occur on the migration routes of brent geese leaving or arriving in northeast Ireland although no tracks actually crossed the sites. Of 22 Svalbard barnacle goose producing GPS satellite tracks across the North Sea, 17 passed across, or less than 20km from, proposed offshore wind farm areas, either in spring and/or autumn. Twelve extrapolated GPS tracks for ten different birds passed through more than one wind farm footprint with eight tracks passing through both the Firth of Forth and Forth Array; two tracks through both the Firth of Forth and Neart na Gaoithe; one track through both the Firth of Forth and Inch Cape; and one track through/adjacent to the Moray Firth and Beatrice. On reaching and moving up the coast of Norway, the migration route of the Svalbard barnacle goose narrows so that most birds pass within a 10km corridor, a corridor within which many offshore and small island wind farms are planned or are operational. Griffin *et al.* (2010b) suggest there is significant potential for the combination of inshore or offshore wind farms along the international flyway having a cumulative effect on the Svalbard barnacle goose population.

## Wave and tidal stream

Wilson *et al.* (2007) reviewed the risks of injurious collision that wave and tidal stream devices may pose to marine mammals, fish and birds as part of the Scottish SEA of marine renewable energy (Faber Maunsell & Metoc 2007). More recently, as part of the Marine Renewable Energy Strategic Framework for Wales (MRESF), the collision risk of marine mammals (WAG 2010), fish (ABPmer 2010) and diving birds (RPS 2010) with wave and tidal stream devices in Welsh waters was evaluated. The potential impacts of wave devices on marine birds were also reviewed by Grecian *et al.* (2010) with ICES (2010) also providing advice on collision risk as part of a general review of environmental interactions with marine renewable devices.

## Fish

Fixed submerged structures (such as vertical or horizontal support piles, ducts & nacelles) are likely to attract marine life in the manner of artificial reefs or fish aggregating devices. Collisions are most likely in high flow environments where flows can combine with swimming speeds to produce high approach velocities with consequently reduced avoidance or evasion response times (Wilson *et al.* 2007). ABPmer (2010) indicate that the opportunity for fish to engage in long range avoidance is likely to be a function of the source levels of underwater noise associated with wave and tidal devices, background noise levels and the particular hearing sensitivities of different fish species. They suggest that hearing sensitive fish (e.g. herring) may be able to detect and avoid individual operational tidal stream devices at distances between approximately 120-300m (depending on water depth) even when background noise levels are comparatively high. For wave energy devices, source noise levels are estimated to be lower with a consequent reduction in detection distance (35-200m).

The extent to which fish might exhibit close range evasion of wave and tidal stream devices is a function of the visibility of the devices, device structure (and speed of moving parts such as turbine blades), the visual acuity and maximum swimming speeds of different fish species. There are very few direct observation studies on the near-field interaction of fish with wave or tidal stream devices and it remains unclear how fish might respond on encountering such devices (ABPmer 2010). A study of fish behaviour around the Roosevelt Island tidal energy project in New York city's East River (Verdant Power 2008), found that densities observed in and around the turbines were generally low (range of 16-1,400 fish per day, average 330); the fish were predominantly small but still swam faster than the turbines rotated; and fish movement tended to be restricted to the direction of the tide and during slack water when the turbines were non-operational. Most fish were observed inshore and not in the zones occupied by the turbines. The potential collision risk of the Roosevelt Island tidal stream devices for diving birds was also reported to be small (Verdant Power 2008).

## Birds

RPS (2010) indicates that for diving birds an assessment of collision risk from marine renewables should take into account a range of parameters including: dive depth and duration; dive entry and shape, prey type and foraging range (Table 5.11). The bird species listed are relevant to Welsh waters but the majority are found throughout the UK.

Table 5.11 - Summary of dive depth behaviour[1]

| Species | Mean dive depth | Maximum dive depth[2] | Dive duration | Dive entry and shape | Prey type | Mean foraging range |
|---|---|---|---|---|---|---|
| Manx shearwater | 14m (wedge-tailed shearwater)<br>15m (Audubon's shearwater)<br>21m (black-vented shearwater) | 66m (wedge-tailed shearwater)<br>35m (Audubon's shearwater)<br>52m (black-vented shearwater)<br>67m (sooty shearwater) | <20s (Audubon's shearwater) | Plunge diver | Pelagic | 172km |
| Common scoter | 3m – 20m (England/Wales) | - | - | Surface diver | Benthic | 4.5km |

| Species | Mean dive depth | Maximum dive depth[2] | Dive duration | Dive entry and shape | Prey type | Mean foraging range |
|---|---|---|---|---|---|---|
| Northern gannet | 5m (Newfoundland)<br>20m (Shetland/Orkney) | 22m (Newfoundland)<br>34m (Shetland/Orkney) | 1s – 8s (Shetland)<br>8s – 38s (Shetland/Orkney) | Plunge diver. Deep, extended U-shaped dives and rapid, shallow V-shaped dives (Shetland/Orkney) | Pelagic | 62km |
| Great cormorant | 6m (France) | 32m (France) | Mean 40s/max. 152s (France) | Surface diver | Pelagic and benthic | 25km |
| Razorbill | 50% dives <15m (Baltic)<br><20m during night (Baltic)<br>25m – 30m (Norway)<br><35m (Iceland) | 41m (Iceland)<br>43m (Baltic)<br>120m (Newfoundland) | - | Surface diver. V-shaped dives (Baltic)<br>W- and U-shaped dives (Labrador) | Pelagic | 48km |
| Common guillemot | 10m (50% dives <6m and 90% dives <22m) (Norway)<br>80% dives <50m | 37 (Norway)<br>50m (Norway)<br>53m (Scotland)<br>138m (Newfoundland)<br>180m (Newfoundland) | Mean 39s/max. 119s (Norway) | Surface diver. U-shaped (mean bottom dive duration of 19s) (Norway) | Pelagic | 122km |
| Red-breasted merganser | - | - | - | Surface diver | Pelagic | - |
| Great northern diver | - | 60m (Lake Superior) | - | Surface diver | Pelagic and benthic | 4km[3] |
| Sandwich tern | - | - | - | Plunge diver | Pelagic | 14.7km |
| Common tern | - | - | - | Plunge diver | Pelagic | 8.7km |
| Little tern | - | - | - | Plunge diver | Pelagic | 4.1km |
| Northern fulmar | 3m (Shetland) | 4m | Max 8s (Shetland) | Plunge diver | Pelagic | 69.4km |
| Arctic tern | <0.20m | <0.35m | - | Plunge diver | Pelagic | 11.8km |
| Atlantic puffin | 75% dives <10m (laboratory)<br>25m – 30m (Norway) | 68m (Newfoundland) | 60% <40s (laboratory) | Surface diver | Pelagic | 30.6km |
| Balearic shearwater | 6m (Balearic Islands) | 26m (Balearic Islands) | Mean 18s/max. 66s (Balearic Islands) | Plunge diver. V-shaped dives (Balearic Islands) | Pelagic | 29.3km |
| Greater scaup | 1m – 5m | 10m | 14s (laboratory) | Surface diver | Benthic | - |
| Common eider | - | 42m (Canada) | - | Surface diver | Benthic | 9.3km |
| Common goldeneye | - | 4m | - | Surface diver | Pelagic and benthic | - |
| Red-necked grebe | - | - | Mean 25s/max. 50s<br>Mean 29s/max. 42s | Surface diver | Benthic | - |

| Species | Mean dive depth | Maximum dive depth[2] | Dive duration | Dive entry and shape | Prey type | Mean foraging range |
|---|---|---|---|---|---|---|
| Slavonian grebe | - | 3m | - | Surface diver | Pelagic and benthic | - |
| Black-necked grebe | - | - | - | Surface diver. Often skimming, occasionally diving | Pelagic and benthic | - |
| European shag | 33m – 35m (Scotland) 55% time 25m – 34m (Scotland) 10m – 43m (Scotland) Forages most frequently in water depths 21m – 40m (Scotland) | 43m (Scotland) | 97s (Scotland) | Surface diver. Almost vertical descent and ascent | Pelagic and benthic | 6.5km |
| Black-throated diver | 3m – 6m | 20m (Baltic) | Mean 45s/max. 120s | Surface diver | Pelagic | 4km[3] |
| Red-throated diver | - | 21m | - | Surface diver | Pelagic and benthic | 4km[3] |
| Sooty shearwater | - | 68m (Pacific) | - | Plunge diver | Pelagic | - |
| Roseate tern | - | - | - | Plunge diver | Pelagic | 12.3 |
| Great crested grebe | - | 30m | - | Surface diver | Pelagic | - |

*Note: [1]Available data mostly refer to breeding birds, on breeding grounds, during the summer. It may therefore not be relevant to extrapolate these findings to non-breeding birds, other foraging grounds or behaviour during different seasons. [2]Location of observations in brackets. [3]Mean foraging range described for diver species.*
*Source: RPS (2010).*

Mean and maximum dive depths provide information on the water column bands commonly occupied by each species. This precautionary approach of considering maximum as well as mean dive depth is necessary given the many knowledge gaps in diving behaviour, prey species preferences and habitat variability along the UK coast.

Data on dive duration reflect dive depth as well as swimming patterns, and thus indicate the degree of lateral movement that birds may undertake. Black-throated diver *(Gavia arctica)*, for example, have been recorded spending up to two minutes foraging underwater to a comparatively moderate depth of up to 20m. The lateral movements of this species are substantial and highlight the need to incorporate lateral movement and dive duration into underwater collision risk assessments (RPS 2010).

Dive shape will influence risk by affecting the time spent within particular bands of the water column, and thus the likelihood of the species encountering devices positioned at particular depths. Risk will be also be affected by entry to the water. Northern gannet, for example, enter the water at considerable speeds with a very small margin for error in relation to underwater structures; surface divers on the other hand exhibit a slower and more controlled pursuit behaviour which likely puts them at lower risk (RPS 2010).

Prey type is a factor influencing the level of risk, whereby diving bird species can be broadly distinguished as either pelagic or benthic foragers. For renewable devices positioned in water deeper than the diving capabilities of benthic foragers, underwater risk to these species will be negligible, for example common eider forage on molluscs on the seabed at depths of up to 42m, therefore beyond this depth the species may be tentatively excluded from any risk assessment (RPS 2010).

The risks posed by marine renewable devices in a particular area of open water are dependent on the foraging ranges of each species, especially the mean range within which most birds from a particular population will be expected to forage. For example, care should be taken to ensure devices are only located within the foraging ranges of birds from major colonies and SPA-designated areas if it can be established that the sites in question are of little importance or where risks to these species are assessed to be low. Placing devices within important foraging areas may mean that species are at elevated risk of collision with or entrapment within structures, construction and operational disturbance and indirect effects such as displacement of prey (RPS 2010).

Risk of collision is expected to be minimal as for many species of sea birds, including gulls, terns, kittiwakes, fulmars and skuas, their normal depth range would not allow them to encounter operating turbines. For some deep diving species, e.g. auks, shags, there is the chance of an encounter as these species regularly dive to depths of 45-65m. The critical issue is the relative swimming speed of the bird, and the ability to sense and respond to the turbine. A typical swimming speed for these species is of the order of $1.5ms^{-1}$. For comparison, the tip turning at 15rpm would be moving faster than this and so potentially be difficult for a bird to avoid. The possible interactions are further complicated by the possibility that diving birds may respond to the moving blades as potential prey and be attracted to their vicinity. Further work is needed to elucidate the scale of this phenomenon and to develop mitigation measures i.e. painting the blades (ICES 2010).

### Marine mammals and others

Mooring equipment such as anchor blocks and plinths are likely to function like other natural or artificial seabed structures and hence pose few novel risks for vertebrates in the water column. Cables, chains and power lines extending up through the water will have smaller cross-sectional area than vertical support structures and so produce reduced flow disruption and fewer sensory cues to approaching animals (e.g. marine turtles, marine mammals). Instead of being swept around these structures, animals are more likely to become wrapped around or entangled in them (Wilson *et al.* 2007).

Semi-aquatic species (e.g. seals and birds) may use floating devices as landing/roosting/breeding or haul-out sites and risks of injury may be associated with getting onto/off the structures and any contact with exposed, moving or articulated parts. While cetaceans do not haul-out, they do regularly surface for air and collisions could either occur with animals swimming into them or the structures pitching down onto breathing animals in heavy seas. Collision risks for surfacing mammals and birds will depend on how aware they are of the presence of the surface structures (Wilson *et al.* 2007).

There remain large information gaps concerning the collision risk of marine mammals with structures such as tidal stream devices. The literature reviewed suggests that the probability of cetaceans failing to detect and avoid a large static structure is considered to be extremely low, particularly for species that echo-locate and are agile and quick moving. The exact placement of tidal farms for species that frequent particular areas, either through site fidelity or seasonally, should be considered in mitigation. Feeding and breeding sites in particular for marine mammal species should be avoided when tidal farm sites are selected (ICES 2010).

An active sonar system is operated from the Seagen tidal turbine in Strangford Lough providing real time sub-surface sonar imagery of marine mammals and other large marine animals e.g. basking sharks within 80m of the SeaGen turbine. Between March and September 2010, the active sonar system recorded 612 targets of which 227 triggered precautionary turbine shutdowns as a result of large animals coming within 50m of the turbine (although 22 shutdowns were believed not to be marine mammals on closer inspection, Royal Haskoning 2010b). Monitoring indicates that both marine mammals and 'other' targets move past the turbine in close proximity; however, due to the requirement for precautionary turbine shutdowns information on how marine mammals interact with the turbine during operation is not collected, although avoidance is expected. A programme of weekly shoreline surveillance, covering the Strangford Narrows and immediate coastline, has found no evidence of seal carcasses showing signs of possible interaction with the turbine (Royal Haskoning 2010).

Few studies have quantified how collision risk might vary with environmental conditions, particularly during bad weather when animals may be at greater risk due to reduced visibility and manoeuvrability. Further work is required to quantify the potential collision risks posed by these devices, and how risk may vary between species and environmental conditions, allowing mitigation of any effect to be incorporated at an early stage in the process (Grecian *et al.* 2010).

Given that licensing of wave and tidal stream development resulting from the plan will likely be at a demonstrator scale rather than full development arrays, the potential collision risk of wave and tidal stream devices to birds, fish and marine mammals is not considered significant. There is a general shortage of data on the interaction of these animals with wave and tidal stream devices and this situation will have to be improved prior to the deployment of development arrays. ABPmer (2009) indicated with respect to marine mammals and turtles, that an array of devices may represent a significant obstacle with significance dependent on the spatial confines of the array e.g. whether it spans across the entire mouth of a harbour, and the functional use of the area by marine mammals e.g. foraging or migration route.

WAG (2010) provides a thorough desk-based examination of factors which may influence collision risk between devices and marine mammals; discussions are consistent with the earlier work by Wilson *et al*. (2007) in contribution to the Scottish marine renewables SEA. They conclude that a detailed assessment of the risks posed by tidal turbines is hampered by major knowledge gaps in all areas. It is noted that areas of high tidal energy are apparently important for different species of cetaceans and seals; better understanding of their distributions and densities in these environments, including knowledge of diving behaviour, is important for assessing encounter probability. Better understanding of sensory and motor capabilities and behaviour is important for quantifying evasion, quantifying collision risk and devising effective mitigation strategies. Improved understanding of the biology of marine mammals in these areas and the use they make of these special habitats is necessary for assessing the biological significance of any impacts.

WAG (2010) review a number of different approaches to mitigation. At the planning stage, developments could be sited in lower density, less sensitive areas, while within sites it may be possible to locate turbines at spots where collision risks are lower. Locating turbines at depths which are less-utilised by marine mammals might be a practical option for some devices at some deep water sites. Measures may be taken to improve the visual detection by making structures more conspicuous underwater, although it was noted that water clarity is typically low. Making devices a stronger echolocation target and locating them in areas with lower levels of masking background noise may improve their acoustic detectability. Active noise sources to warn or deter animals may be useful, though these also raise concerns of habitat exclusion and habituation. In extreme cases, it might be necessary to monitor for marine life continuously and stop or slow blades when detections are made in high risk locations.

A recent report on seal mortalities in UK waters (Thompson *et al*. 2010c) indicates that a number of severely damaged seal carcasses have been found on beaches in eastern Scotland (St Andrews Bay, Tay and Eden Estuaries and Firth of Forth), along the North Norfolk coast in England (centred on the Blakeney Point nature reserve), and within and around Strangford Lough in Northern Ireland. All the seals had a characteristic wound consisting of a single smooth edged cut that starts at the head and spirals around the body. The fatal injuries are consistent with the seals being drawn through a ducted propeller such as a Kort nozzle or some types of Azimuth thrusters (rather than a large open propeller).

Ducted propellers and azimuth thrusters are used for the dynamic positioning of vessels. These boats maintain their position by altering the speed and direction of their thrust. This can involve an almost stationary vessel repeatedly starting or reversing its rapidly rotating propellers which may increase the opportunities for animals to approach propellers and be drawn into them. Such systems are common to a wide range of ships including tugs, self propelled barges and rigs, various types of offshore support vessels and research boats. These vessel types would likely be used to undertake and support activities associated with the implementation of the draft plan/programme.

Thompson *et al. (*2010c) propose that the seals are responding inappropriately to some aspect of the operation of these devices. The localisation in space and time of these events makes it unlikely that the seals are being hit as a result of random coming together of swimming animals and fast moving vessels. The concentration of carcasses in each locality suggests that the vessels must be either stationary or slow moving but operating their propellers, such as when using motors for dynamic positioning. This suggests that some aspect of the operation of these devices is attracting the seals to within a danger zone from which they do not appear to be able to escape. Developing any mitigation measure will require that the attractive mechanism be identified and understood.

Two possible/likely mechanisms would be attraction to concentrations of food associated with the vessel and an inappropriate response to an acoustic signal from the motor/ship/propeller. An acoustic cue is suggested by the fact that all seals killed during summer month have been female harbour seals which are thought to be attracted by underwater calls of breeding males. Juvenile grey seals which are the main victims during winter months in Norfolk and Scotland have also been shown to be attracted by conspecific calls with a pulsing rhythmic pattern. A range of future research requirements are detailed by Thompson *et al.* (2010c), and discussed in Section 5.6.6 below.

## Tidal range

The Severn Tidal Power Feasibility Study indicated that fish passage through tidal range schemes, in particular turbine passage could be the primary source of fish injury and mortality and consequently make the greatest contribution to overall effects upon fish populations within the Severn Estuary. Injuries could lead to the direct mortality of fish or fish could suffer delayed and indirect mortality sometime after passage (DECC 2008b, 2010g).

The collision risk represented by tidal range schemes is primarily to migratory diadromous and estuarine fish passing through the turbines within the barrage or lagoon. Given the likely large scale of any tidal range scheme and its apparent visibility, they are unlikely to represent a significant collision risk to birds and marine mammals although placement within estuarine areas across bird migration or foraging routes could represent a significant risk particularly during periods of poor visibility or weather.

### 5.6.2.3 Effects of offshore lighting

## Oil and gas, gas storage and carbon dioxide storage

The potential effects of light on birds have been raised in connection with offshore oil and gas over a number of years (e.g. Weise *et al*. 2001). As part of navigation and worker safety, and in accordance with international requirements, drilling rigs and associated vessels are lit at night and the lights will be visible at distance (some 10-12nm in good visibility). The attractive effect of lights on seabirds on cloudy nights is enhanced by fog, haze and drizzle (Weise *et al*. 2001). Bruderer *et al*. (1999) noted that the switching off and on of a strong searchlight beam can influence the flight behaviour of migrating birds.

While well-defined preferred migratory corridors are still unknown, the cuneiform southernmost part of the North Sea (Regional Sea 2 and 3) is an important funnel for seabird migration with an estimated 1-1.3 million seabirds possibly using the route annually (Stienen *et al*. 2008). Large numbers of species such as great skua and little gull, as well as terns and lesser black-backed gull, can use the Strait of Dover to exit the North Sea.

Hüppop *et al*. (2006a) have studied the migration of terrestrial birds across the German Bight, noting that each year during the migration periods several hundred million birds of roughly 250 species (dominated by passerines) cross the North and Baltic Seas on their journeys between their breeding grounds in northern Asia, North America and especially in Scandinavia and Finland, and their winter quarters, which lie between Central Europe and southern Africa, depending on the species. They report on remote observations, including those of ‘invisible’ bird migration from the FINO 1 research platform, using ship radar, thermal imaging, video and a directional microphone from October 2003 onwards. While providing considerable data regarding the seasonal and diurnal variability in migrating bird numbers, and on the altitude of migrating birds, they also report that a total of 442 birds of 21 species were found dead at FINO 1 (which has no rotating turbine blades, but has a metmast and navigation lights) between October 2003 and December 2004; of which 245 individuals (76.1% of the 332 birds examined) had outwardly apparent injuries. Over 50% of the strikes occurred on just two nights, both characterised by periods of very poor visibility with mist or drizzle and presumably increased attraction of the illuminated research platform. In the second of these nights the thermal imaging camera revealed that many birds flew “obviously disorientated” around the illuminated platform.

## Offshore wind farms

Although to date there has been little observational data reported in relation to light effects from OWF developments, similar observations of behavioural responses and mortality of migratory birds have been reported from lighthouses, gas platforms in the southern North Sea (Hope Jones 1980, “Green light paper”) and are commonly observed from vessels of all sizes. It is unclear to what extent relative risks are presented by rotational machinery, gas flares or fixed structures; to what extent natural mortality during offshore migration is increased (or decreased) by the presence of offshore structures; or how significant such mortality is in the context of overall adult mortality in migratory species. Dierschke *et al*. (2003, cited by Hüppop *et al*. 2006a) assumed that "an increase of the existing adult mortality rate by 0.5–5%, depending on the individual species, seems to be acceptable for the 250 bird species regularly migrating across the German sea areas" (it is unclear whether this relates to total annual mortality rate, or mortality during migration). For the "several hundred million" migratory population, this would equate to greater than (roughly) one million fatalities per year; a casualty rate which might be expected to be observable as dead birds in the vicinity of installations; the absence of such observations suggests that a casualty rate on this scale does not occur in reality.

## Wave and tidal stream

There is very little information on the potential ecological impact of lighting on wave and tidal stream devices. Some installations are totally submerged while others may only protrude slightly above the sea surface. Lighting patterns will be based on IALA Recommendation 0-139 on the marking of man-made offshore structures. Navigational lights associated with devices may attract foraging nocturnal birds at night although any attraction would likely be short-lived if not associated with any foraging benefits for the birds (ABPmer 2009). Given the likely demonstrator scale of development rather than large scale arrays, it is unlikely that lighting will have a significant ecological impact.

## Tidal range

Lighting over the estuary during construction and operation of a potential Severn tidal range scheme could possibly represent a barrier to the migration and movement of fish in transit through and residing within the estuary (DECC 2010g).

### 5.6.2.4 Artificial reef effects - fouling, stepping stones & fish aggregation

## Fouling

The physical presence of structures in the sea provides hard surfaces for biological colonisation. The development and succession of this fouling growth on North Sea production platforms was summarised by Whomersley & Picken (2003) and similar patterns can be expected in the majority of Regional Seas. Fouling on OWF foundations appears to be generally similar, with dominant species depending on the geographical location (and scour and salinity regime) (e.g. Schröder *et al*. 2006, DONG Energy *et al*. 2006, and Linley *et al*. 2008). However, Wilhelmsson & Malm (2008) found that Baltic Sea turbine foundations differed significantly from adjacent boulders in terms of assemblage composition of epibiota and motile invertebrates although the reasons for this are unclear. Fouling growth can result in a number of subtle ecological impacts (e.g. enrichment) in the immediate vicinity of the structure but these are not regarded as significant effects. There has been considerable speculation that increased numbers of crabs, and perhaps lobsters, on and around OWF foundations, especially where scour protection is used, may lead to increased opportunities for pot fisheries (see Linley *et al*. 2008). The practicalities of fishing around turbines, the relatively large distances between turbines, and the distance offshore of most Round 3 developments suggest that this may be limited.

Langhamer *et al.* (2009) demonstrated that wave power foundations served as colonisation platforms with a higher degree of coverage of sessile organisms on vertical rather than horizontal surfaces possibly related to lower sedimentation levels on vertical surfaces. Sessile assemblages on marker buoys (used as indicators of fouling patterns on wave power buoys) were dominated by the blue mussel, *Mytilus edulis*. The filamentous red algae *Ceramium* sp., barnacles, and the sea star *Asterias rubens* were also frequently recorded. The buoys had been submerged for between one and three years, but the total fouling biomass did not seem to increase significantly with time. Furthermore, the high variation in biomass on the buoys was due to their exposure to wind and waves. The dominating blue mussels rapidly reach a constant biomass, as a result of the counteraction of colonisation/growth by dislodgement of lumps of blue mussels due to gravity and wave action (Lachance *et al.* 2008). The authors indicated that cleaning of wave power buoys may not sufficiently enhance the performance of devices to be cost effective, and thus, any positive effects of enhanced biomass of certain species and biodiversity through fouling could in this respect be maintained if desired. Fish abundance was low compared to other more complex structures in shallower water in adjacent areas (e.g. Wilhelmsson *et al.* 2006) and there was no significant difference recorded between fish and shellfish abundance at foundation sites and control areas (Langhamer *et al.* 2009).

## Stepping stones

The deliberate and accidental placement of hard substrates in the marine environment where the seabed is predominantly sand and mud will allow the development of "island" hard substrate communities and there is a possibility that a substantial expansion of the number of hard surfaces (such as OWF foundations, wave and tidal stream infrastructure and cable armouring) could provide "stepping stones" allowing species with short lived larvae to spread to areas where previously they were effectively excluded. However, such "islands" are widespread and numerous in continental shelf areas, for example on glacial dropstones and moraines. A strategic review of OWF monitoring data associated with FEPA licence conditions (CEFAS 2010) indicated that the long term effects of epifaunal colonisation will require monitoring and/or further research to address issues of concern, such as their potential as 'stepping-stones' for invasive species. The review concluded that epifaunal colonisation of monopiles could result in a localised increase in species diversity, but whether this was a 'beneficial' impact as was often predicted, was debatable and highly subjective as the colonising species were different from the original community.

The review recommended that benthic monitoring associated with OWF development should link with national monitoring programmes (such as National Marine Monitoring Programme - NMMP), to support the interpretation of any community change by informing on whether similar change has been noted regionally or historically. The review highlighted the potential benefit of the Regional Environmental Assessments conducted by the aggregate industry which are designed to inform site-specific issues to be addressed within EIAs and assess the impacts of aggregate extraction on a regional scale. The use of such a tool independently or in collaboration, could be beneficial to the offshore wind farm construction and renewable energy industries in the future. These could possibly be based around The Crown Estate Round 3 proposals for Zonal Assessment Plans (CEFAS 2010).

## Fish aggregation

Many fish species are known to aggregate around structures in the sea, including oil and gas platforms and pipelines, probably as they provide shelter from currents and wave action and safety from predators, but possibly also in some cases due to increased feeding opportunities. It is generally considered that such aggregation represents minimal increase in overall biomass of fish in an area. Aggregation is seen not only in midwater fishes (see photo as Figure 6 in Schröder *et al.* 2006) but also many demersal species such as most gadoids, and to some extent flatfish such as plaice and dab. It is reasonable to assume that fish will also aggregate around turbine foundations, although present evidence as to the extent to which it occurs is limited. A gill netting survey at the Svante Wind Farm, Sweden, found higher numbers of cod within two hundred metres of an operating turbine compared to the surrounding open waters, and higher still when the turbines were not operating (Westerberg 1999). Diver held video surveys of the North Hoyle OWF piles found extremely high densities of juvenile whiting, apparently feeding on dense populations of amphipods amongst the fouling biota on the piles (Bunker 2004). It is generally agreed that fish aggregation probably represents a very minor effect.

The CEFAS (2010) review of OWF monitoring indicated that fish monitoring data was not providing results sufficient to impart definitive cause and effect conclusions such as on the potential for fish aggregation effects. The review recommended a more targeted approach to monitoring, including monitoring over several sites to give better spatial coverage and giving a greater importance to temporal variability.

#### 5.6.2.5 Electromagnetic fields (EMF)

A review (Gill *et al*. 2005) of the potential effects of electromagnetic fields on electrically and magnetically sensitive marine organisms focussed on the electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments. The results demonstrated that the EMF emitted by industry standard AC offshore cables produced a magnetic (B) field component and an induced electric (iE) field component in the marine environment. Although submarine power cables are fully electrically insulated it is the fluctuating magnetic field which induces the electric field in the environment (CMACS 2003). An electric field is also generated by the movement of water or objects (e.g. an animal) through the magnetic field in the same way that movements through the natural (geomagnetic) field of the earth induce an electric field.

The review of material on electrosensitive species showed that many fish and a number of other species found in UK waters are potentially capable of responding to anthropogenic sources of E and B fields. Certain fish species, including common ones such as plaice, are understood to be both magnetically and electrically sensitive and a range of other species, notably cetaceans and many Crustacea, to be magnetically sensitive. Recent studies have also identified responses to electric fields in some species of pinnipeds (PSC 2009); results are discussed further below.

Most attention has focused on elasmobranchs (sharks, skates and rays) which have specialist electro-receptive organs and are capable of detecting very small electric fields of around 0.5μV/m (Gill 2005). This group includes rays, some of which are commercially fished and have suffered severe population declines in recent years (Myers & Worm 2003), usually linked to overfishing (e.g. Walker & Hislop 1998, Rogers & Ellis 2000).

Potential impacts could result from repulsion effects, leading to exclusion of animals from an area of seabed (e.g. for elasmobranchs in the presence of relatively high electric fields); attraction effects, for example causing elasmobranchs to waste time and energy resources foraging around electric fields mistaken for bioelectric fields of prey organisms; and disruption to migrations for magnetically sensitive species such as eels and salmonids that may use the earth's geomagnetic field for navigational cues. However, it is not known whether interactions between the fish and the artificial E or B fields will have any consequences for the fish. The information available on magnetosensitive species is limited, but it does suggest that potential interactions between EM emissions, of the order likely to be associated with wind farm cables, and a number of UK coastal organisms could occur from the cellular through to the behavioural level.

The conclusion of most project-specific environmental impact assessments is that whilst there could be an interaction between these species and the sub-sea cables used the result is unlikely to be of any significance at a population level. Gill *et al*. (2005) highlighted the lack of evidence supporting such conclusions but it was evident that the industry does try to take into consideration the potential environmental effects of EMFs, but it is hampered by a lack of information and understanding. It is clear from the review of industry based material that the issue of electromagnetic (both B and iE field) effects on electrically and magnetically sensitive species has not been addressed in a consistent manner and that there is a lack of clear scientific guidance on the significance of effects (if any) on receptor species. Various recommendations were made by Gill *et al*. (2005) for further work; initially to identify if the species most likely to interact with EMFs responded to fields of a magnitude and character associated with power transmission and to then definitively determine whether these species would be affected.

Recent advances in understanding include measurements of EMF at offshore wind farm locations which confirm that EMFs are emitted and, for standard 50Hz AC cabling used in Round 1 developments, that iE fields are likely to lie in the range of potential attraction to elasmobranchs (0.5-100μV/m (Gill & Taylor 2002). Higher fields, potentially of a magnitude that could be repulsive to elasmobranchs, have not been measured but could occur where cables lie in close proximity (a few metres) and fields are additive (Gill *et al*. 2005). Importantly, results of the most recent work for COWRIE (Gill *et al*. 2009) suggest that low level electrical fields of a magnitude and character produced by offshore wind farms did cause a change in swimming behaviour of fish in experimental mesocosms. This suggests that the mechanism for an impact to occur is present but does not yet demonstrate that any impacts will occur; a similar conclusion drawn by Öhman *et al*. (2007) from field observations. Field measurements of EMF at offshore wind farms sites showed that there were both magnetic and electric field emissions associated with the main feeder cables to shore and these EMFs were comparable, and in some cases, greater than the EMF produced in an experimental mesocosm study. The zone of EMF that was potentially within the range of detection of the elasmobranchs spanned several hundred metres (Gill *et al.* 2009).

The work by Gill *et al*. (2005) also highlighted that while cable burial is important to isolate marine organisms from the very highest electric and magnetic fields no significant benefits are likely to be accrued by burying cables to greater depths than traditionally achieved for cable protection purposes (1-3m).

Work on EMF undertaken by Bochert & Zettler (2006) in connection with the FINO 1 test platform concluded that none of the fish (flounder) and several invertebrate species tested responded by attraction or avoidance when exposed to static artificial magnetic fields, although further studies were recommended. The authors did not consider effects of induced electrical fields or AC magnetic fields on the test species although oxygen consumption in two prawn species did not vary significantly between 50Hz AC, static and control magnetic fields.

Recently, studies of deterrents to seal predation on salmon fisheries have identified strong responses to electric fields in certain pinniped species (PSC 2009, Burger 2010). In 2007, the Pacific Salmon Commission (PSC), and collaborators, conducted a series of tests to assess how Pacific harbour seals (*Phoca vitulina richardsi*) respond to very low electric fields and determine whether this technology could be used to deter seal predation on salmonids. Results from tests on captive and wild animals in aquarium and river environments respectively indicated that seals avoided an electrified zone of voltage gradient <0.32V/cm at surface with a maximum pulse width of 1 millisecond (ms) and frequency of 2.25Hz (Cave *et al*. 2008, cited in PSC 2009).

PSC (2009) report an extension of these experiments, with three different configurations (arrays) of electrodes tested across the width of the lower reaches of a river known to be a preferred foraging area for seals. Arrays included 3 and 4 cable configurations running perpendicular to the bank and an array of 17 elements oriented parallel to the bank spanning the width of the river. For each configuration, tests commenced at the lowest pulse width setting (1ms) and ramped up by 1ms increments to a maximum of 5ms (17 element array only). At the lower pulse width settings (1-2ms), seals that successfully passed through the array were not harmed or exposed to excessive stress. At pulse width settings in the mid range (3ms), seals displayed more distinctive behavioural responses (avoidance of short-term discomfort or pain) while at the highest pulse width settings (4-5ms) seals exhibited more physiological responses (involuntary muscle contractions). In further field studies, seals were deterred from foraging in a test fishing gill net in a river habitat by using a pulsed, low-voltage DC electric gradient (Forrest *et al*. 2009). These levels did not seem to affect the behaviour of salmonid fish, and catch rates of salmon were shown to be higher at nets protected by an electric field.

Burger (2010) report results from experiments on the responses of captive Californian sea lions (*Zalophus californianus*) to electric fields, with a view to wider applications as deterrents to predation in salmonid fisheries. A pulsed DC electric field was generated within a freshwater test pool (conductivity of 509µS/cm). Sea lions were able to detect an electric gradient introduced at a frequency of 2Hz at pulse widths that ranged from 0.08-0.29ms. Strong deterrence reactions without and with food present were exhibited at pulse widths from 0.08-0.32ms and 0.16-0.44ms respectively, both with a voltage gradient of 0.6V/cm.

WAG (2010) review the studies on harbour seals in relation to potential effects from buried cables associated with marine renewable energy devices. Estimates of the electrical fields that will be generated in seawater from buried power cables bringing power ashore from marine renewable devices are orders of magnitude lower than those shown to induce responses in seals; therefore, it appears that there is no basis for expecting such strong exclusion effects demonstrated in those studies. Furthermore, consideration must be given to the differences in the environments where exclusion responses were observed and the marine environment relevant to this assessment. PSC (2009) noted that the impact of the electric field on seal behaviour deteriorated as river depth increased due to a weakening in the electric field strength at the water surface over the array, with seals often observed passing through the array during high tides.

Despite this, certain caveats should be considered. Firstly, the seal exclusion trials used short pulse length electrical fields, and it was shown that seal sensitivity increased as pulses lengthened; seals might therefore be more sensitive to a continuous electrical field. Secondly, seal sensitivity and responsiveness to lower level electrical fields have not been studied and there may be effects at levels below those tested. It is not know why seals are apparently so sensitive to these electrical fields, whether they have specially adapted electrically sensitive organs, or if this is of any biological significance to them. WAG (2010) suggests the risk that electrical fields from power cables could affect seal behaviour must remain as a precautionary concern, and recommend that the issue should be more fully explored. The authors noted that they are unaware of any attempts to test for sensitivity to electrical fields in cetaceans.

To date, efforts have focused on the 50Hz AC systems used throughout all UK and most other offshore renewables projects. Longer export cable distances, bigger wind farms and technological advances mean that High Voltage Direct Current (HVDC) cables may be used in future, including for Round 3 wind farms. Although (static) magnetic fields will still be produced in the marine environment this technology offers potential advantages in that fewer cables may be required and bipole systems should retain electrical fields within the cables. It should be noted that an electrical field would be induced when water, or animals, move through the magnetic field, as also occurs with AC systems. There are various environmental concerns about monopole HVDC systems but it is considered unlikely that such solutions would be used.

In summary, further research is required to investigate the potential significance (if any) of artificial electric and magnetic fields for marine organisms. Evidence should begin to accumulate from environmental monitoring at existing UK and other wind farms over the next 1-2 years and, together with more academic work, should help inform planning and design of projects. Attention to this issue should be proportionate to the potential for impacts, e.g. careful consideration should be given to mitigation and monitoring where there are important areas for key species such as elasmobranchs. Boehlert & Gill (2010) indicate that before-and-after baseline assessment of EMFs associated with cable networks within an array of devices in addition to the main cables to shore is needed. Furthermore, there needs to be greater research effort to determine the detectability by potential receptors of a range of fields emitted; the response and potential biological significance of detection, if any, also remains to be determined.

The potential for EMF effects associated with wave and tidal stream devices are likely to be similar to OWF given the requirement for inter-field and export cabling. However, given the likely demonstrator scale of these activities, the magnitude of cabling and resultant potential EMF effects is likely to be reduced compared to OWF.

## 5.6.3 Spatial consideration

### Offshore wind farms

Given that the major potential receptors identified above were birds, the spatial distribution of potential effect is clearly strongly related to the distribution and relative sensitivities of individual bird species. The use of vulnerability indices for assessment of oil spill risks to birds is well established (see previous SEAs), and a similar approach has been developed by Garthe & Hüppop (2004) for scaling possible adverse effects of marine wind farms on seabirds. Their species sensitivity index (SSI) (also referred to as a Wind Farm Sensitivity Index, WSI) for seabirds was based on nine factors (see below). Each factor was scored on a 5-point scale from 1 (low vulnerability of seabirds) to 5 (high vulnerability). Five of these factors could be dealt with by real data but four (flight manoeuvrability, nocturnal flight activity, disturbance by ship and helicopter traffic and flexibility in habitat use) could only be assessed by subjective considerations using expert review. Species differed greatly in their individual sensitivity index scores. Black-throated diver and red-throated diver ranked highest (= most sensitive), followed by velvet scoter, sandwich tern and cormorant. The lowest values were recorded for little auk, European storm petrel and northern fulmar.

Garthe & Hüppop (2004) have mapped SSI scores for German areas of the North Sea and Baltic Sea, finding that coastal waters in the south-eastern North Sea had values indicating greater vulnerability than waters further offshore throughout the whole year. This exercise does not include all species found around the UK and has not yet been carried out for UKCS areas, although Langston (2010) considers that the SSI could provide a useful measure to assist in prioritising bird species for assessing the risks applicable to the UK's Round 3 offshore wind farm programme, and has included the individual sensitivity index scores from Garthe & Hüppop (2004) in a tabular assessment of UK species (see Table 5.12). Langston (2010) notes that the scores used for the UK represent an initial assessment that is not a substitute for updated baseline data collection, detailed EIA, and targeted research, but is intended to make best use of available information until these sources improve that knowledge base.

Derived from the frequency distribution of the SSI, Garthe & Hüppop (2004) suggest a 'level of concern' and a 'level of major concern' that could act as a basis for the selection of marine wind farm locations.

Table 5.12 - Species-specific Sensitivity Index and other information pointing to focal species in relation to proposed wind farms. Species listed in order of declining SSI.

| Species | Collision[1] | Displacement[1] | Barrier[1] | Habitat / prey[1] | SSI[2] | GB/UK min%[3] | Overall risk[4] | OVI[5] |
|---|---|---|---|---|---|---|---|---|
| Black-throated diver | * | *** | ** | ** | 44 | * | *** | 29 |
| Red-throated diver | * | *** | ** | ** | 43.3 | ** | *** | 29 |
| Velvet scoter | * | ** | ** | ** | 27 | * | ** | 21 |
| European shag | * | ** | ** | ** | 26.3 | ** | ** | 24 |
| Sandwich tern | ** | * | * | ** | 25 | ** | ** | 20 |
| Great cormorant | ** | * | ** | ** | 23.3 | ** | ** | 20 |
| Slavonian grebe | * | ** | ** | ** | 23.3 | * | ** | |
| Black guillemot | * | ** | ** | ** | 22 | * | ** | |
| Bewick's swan | *** | * | * | - | 21.7 | ** | *** | |
| Dark-bellied brent goose | ** | ** | * | - | 21.7 | ** | ** | |
| Red-breasted merganser | * | * | ** | ** | 21 | * | ** | 21 |
| Common eider | * | * | ** | ** | 20.4 | * | ** | 16 |
| Great black-backed gull | ** | * | * | * | 18.3 | ** | ** | 21 |
| Common scoter | * | ** | ** | ** | 16.9 | * | ** | 19 |
| Whooper swan | *** | * | * | - | 16.7 | * | *** | |
| Glaucous gull | ** | * | * | * | 16.7 | | * | |
| Northern gannet | ** | * | * | * | 16.5 | *** | *** | 22 |
| Razorbill | * | ** | ** | ** | 15.8 | * | ** | 24 |
| Goldeneye | * | * | ** | ** | 15.8 | * | ** | 16 |
| Atlantic puffin | * | ** | ** | ** | 15 | * | ** | 21 |
| Common tern | ** | * | * | ** | 15 | * | ** | 20 |
| Pink-footed goose | ** | ** | * | - | 15 | *** | *** | |
| Greylag goose (Iceland) | ** | ** | * | - | 15 | *** | *** | |
| Greylag goose (NW Scotland) | ** | ** | * | - | 15 | *** | *** | |
| Greater scaup | * | ** | ** | ** | 15 | | | |
| Iceland skua | ** | * | * | * | 15 | | * | |
| Lesser black-backed gull | ** | * | * | * | 13.8 | *** | *** | 19 |
| Arctic tern | ** | * | * | ** | 13.3 | * | ** | 16 |
| Bean goose | ** | ** | * | - | 13.3 | * | ** | |
| Long-tailed duck | * | ** | ** | ** | 13.1 | * | ** | 17 |
| Little gull | * | * | * | * | 12.8 | ? | ? | 24 |
| Balearic shearwater | * | * | | ** | 12.5 | ? | **? | |
| Great skua | ** | * | * | * | 12.4 | *** | *** | 25 |
| Common guillemot | * | ** | ** | ** | 12 | ** | ** | 24 |
| Common gull | * | * | * | * | 12 | * | ** | 13 |
| Great shearwater | * | * | | | 11.9 | ? | ? | |
| Herring gull | ** | * | * | * | 11 | * | ** | 15 |
| Manx shearwater | * | * | | ** | 10.1 | *** | *** | 23 |
| Arctic skua | ** | * | * | * | 10 | * | ** | 24 |
| Pomarine skua | ** | * | * | * | 10 | ? | **? | |

| Species | Collision[1] | Displacement[1] | Barrier[1] | Habitat / prey[1] | SSI[2] | GB/UK min%[3] | Overall risk[4] | OVI[5] |
|---|---|---|---|---|---|---|---|---|
| Leach's storm petrel | * | * | | ** | 9 | * | ** | |
| European greater white-fronted goose | ** | ** | | - | 8.3 | * | ** | |
| Sooty shearwater | * | * | | | 8.3 | ? | ? | |
| Black-legged kittiwake | ** | * | * | * | 7.5 | * | * | 17 |
| Black-headed gull | * | * | * | * | 7.5 | * | * | 11 |
| Little auk | * | ** | ** | ** | 7 | ? | **? | |
| European storm petrel | * | * | | ** | 6 | * | ** | 18 |
| Northern fulmar | * | * | * | ** | 5.8 | * | * | 18 |
| Great northern diver | * | *** | ** | ** | ns | ** | *** | 29 |
| Roseate tern | ** | * | * | ** | ns | * | ** | |
| Little tern | * | * | * | ** | ns | * | ** | 19 |
| Mediterranean gull | ** | * | * | * | ns | * | * | |
| Light-bellied Brent goose | ** | ** | * | - | ns | ** | ** | |
| Greenland greater white-fronted goose | ** | ** | * | - | ns | *** | *** | |
| Barnacle goose (nearctic) | ** | ** | * | - | ns | *** | *** | |
| Barnacle goose (Svalbard) | ** | ** | * | - | ns | *** | *** | |
| Light-bellied brent goose (Svalbard) | ** | ** | * | - | ns | ** | ** | |
| Light-bellied brent goose (Canada) | ** | ** | * | - | ns | *** | *** | |
| Cory's shearwater | * | * | | | ns | ? | ? | |
| Long-tailed skua | ** | * | * | * | ns | ? | **? | |

*Notes:*

1. *Assessment based on combination of experience from operational wind farms, Garthe & Hüppop 2004, King et al. 2009: *low risk,**moderate risk, ***high risk, – not dependent on marine foraging habitat.*
2. *ns = no Species-specific Sensitivity Index (SSI) score presented in Garthe & Hüppop 2004; NB this score takes account of SPEC status. King et al. 2009.*
3. *The minimum % of the relevant biogeographical population breeding in Britain, is taken from Mitchell et al. 2004; UK non-breeding population estimates are from Baker et al. 2006 as a % of European populations from BirdLife International 2004, converted accordingly: * <25%; ** 25 – 50 %; *** > 50%.*
4. *Overall risk taken as the highest score across the table for each species. Species for which the UK has a high % of the population score*
5. *High risk of impact because of the potential consequences for the population. JNCC Offshore Vulnerability Index (OVI) (Williams et al. 1994)*

*Source: Langston (2010).*

The SSI of Garthe & Hüppop (2004) is calculated as:

$$\text{SSI} = \frac{(a+b+c+d)}{4} X \frac{(e+f)}{2} X \frac{(g+h+i)}{3}$$

where the nine vulnerability factors are:

a= flight manoeuvrability
b= flight altitude
c= percentage of time flying
d= nocturnal flight activity
e= sensitivity towards disturbance by ship and helicopter traffic
f= flexibility in habitat use

g= biogeographical population size
h= adult survival rate
i= European threat and conservation status

The Offshore Vulnerability Index (OVI) developed by JNCC and used to assess the vulnerability of bird species to surface pollution, considers four factors (Williams *et al.* 1994):

OVI = 2a + 2b + c + d

where,
a= the amount of time spent on the water
b= total biogeographical population
c= reliance on the marine environment
d= potential rate of population recovery

Although the factors used in the two indices are different, there is a significant correlation between the two ($P<0.01$), with the main differences being in fulmar, kittiwake, great and arctic skuas, guillemot and razorbill; all of which score relatively higher in OVI than in SSI (Table 5.12); and diver species which score relatively highly in SSI. In view of this, it is considered that the OVI maps (Figures 5.26 and 5.27) developed for the UKCS based on the European Seabirds at Sea (ESAS) database will give a rough indication of spatial sensitivity with regard to OWF development, pending further consideration of the usefulness of producing SSI-based maps, and the inclusion of species not in the OVI e.g. geese species. Figures 5.26 and 5.27 indicate clear spatial (geographical) differences in bird sensitivities. It is noted that the inclusion of aerial bird distribution data will also have an influence on final sensitivity mapping, particularly for nearshore areas.

As a complementary approach, Table 5.13 provides a preliminary list of species of greatest concern in relation to Round 3 wind leasing and extension areas to R2 sites, derived from Langston (2010). This was based on proximity to nearest major breeding colonies (most are SPAs) and likely foraging range for seabirds (RSPB 2000, Stroud *et al*. 2001, McSorley *et al*. 2003, Mitchell *et al*. 2004, Guilford *et al*. 2008) and, for non-breeding seabirds and waterbirds, based on the onshore SPA network, offshore distribution (non-breeding) including marine IBAs (Stroud *et al*. 2001, Skov *et al.* 1995), and migration (Wernham *et al*. 2002). The compilation of Langston (2010) has here been revised to group by Regional Sea. Note that this list relates mainly to water depths <60m.

Figure 5.26 - Overall vulnerability to surface pollutants

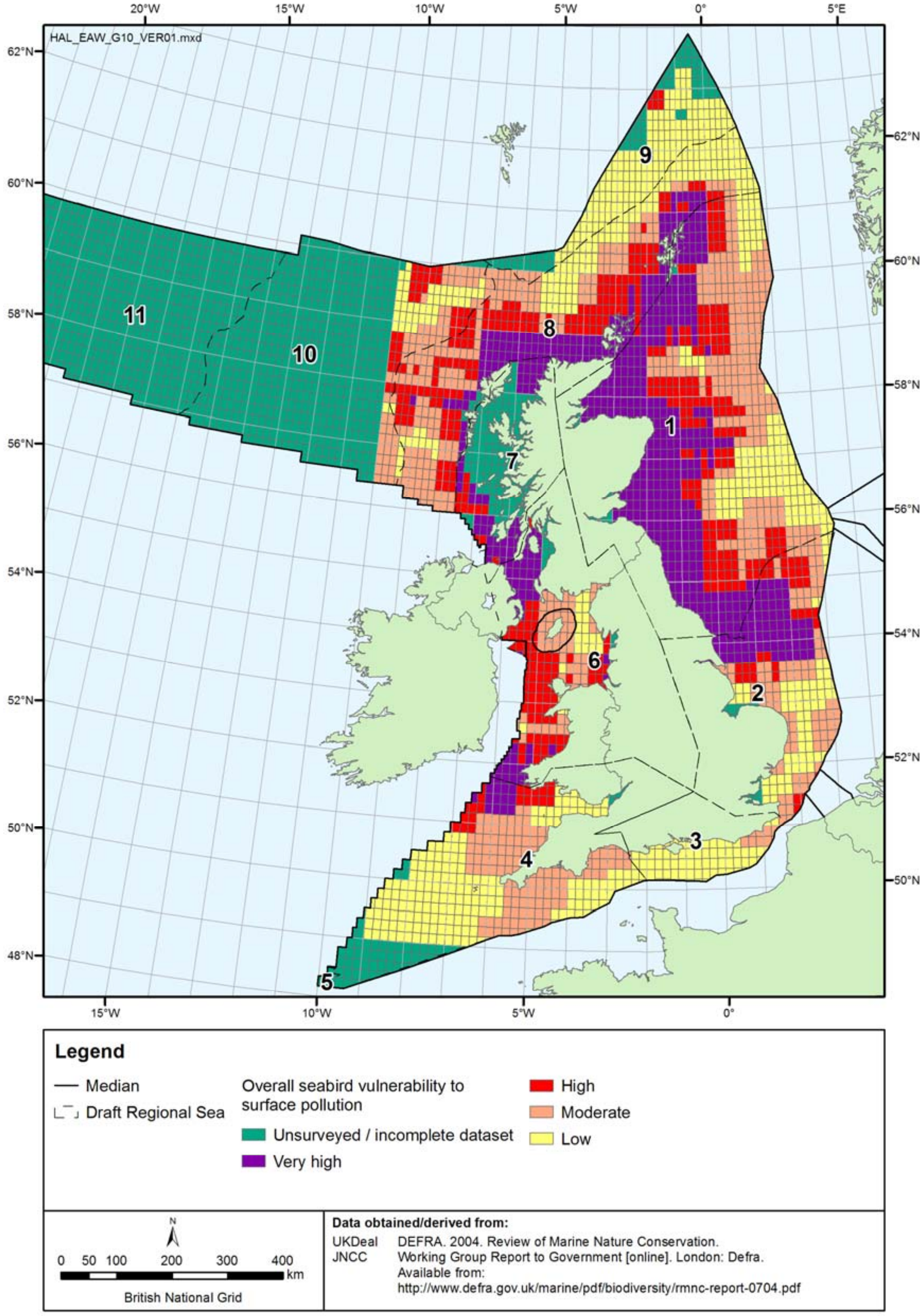


Figure 5.27 – Seasonal vulnerability of seabirds to surface pollution (expressed as numbers of months in which very high vulnerability is present, data gaps for seabird vulnerability are also shown)

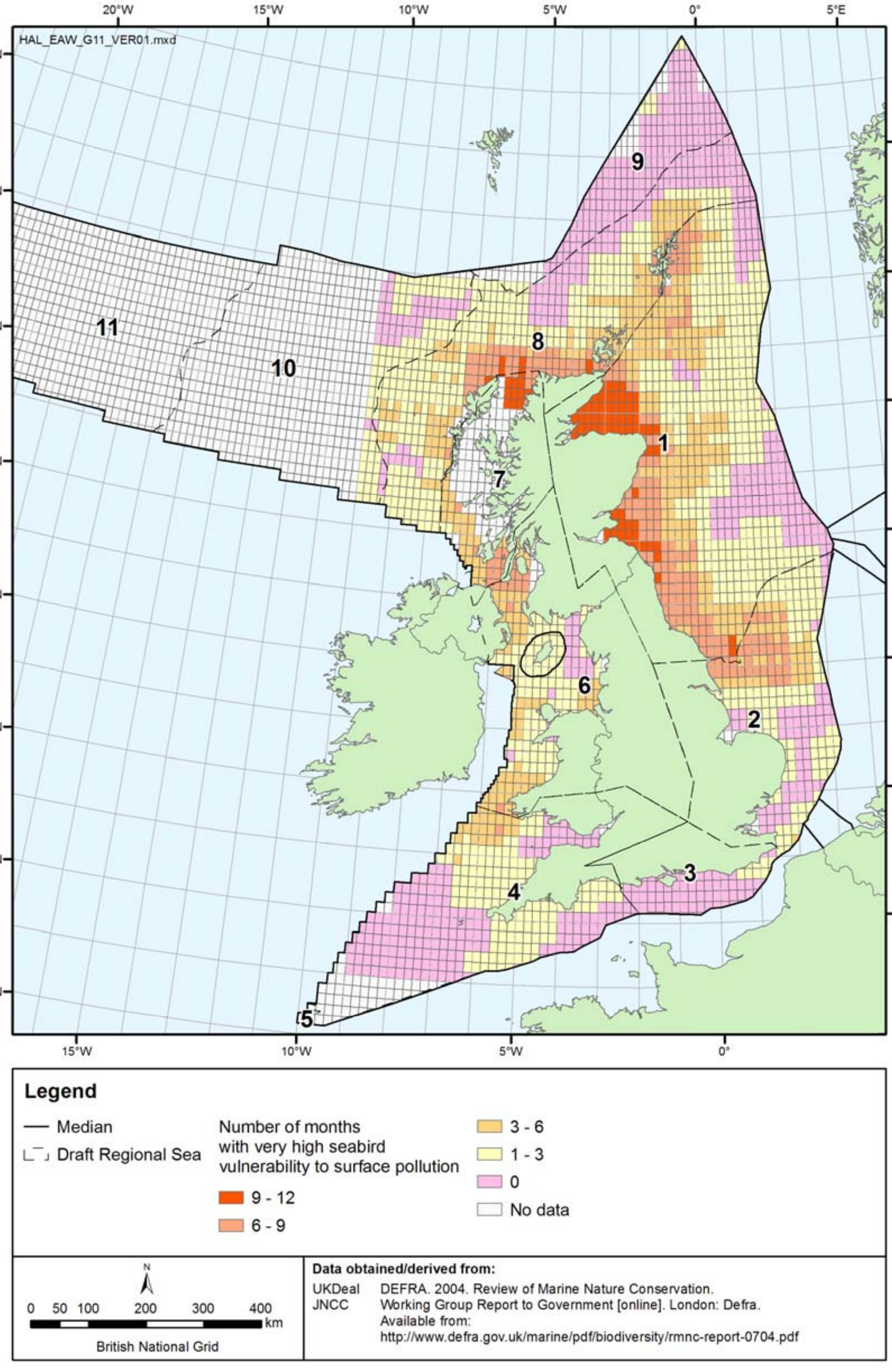


Table 5.13 – Priority species, and key risks, in relation to Round 3 Crown Estate development zones and extension areas to R2 sites

| Regional Sea (CE zone/R2 sites) | Potential collision | Potential displacement |
|---|---|---|
| **Regional Sea 1** | | |
| **Moray Firth**<br>(CE zone 1) | Northern fulmar<br>Northern gannet<br>Arctic skua<br>Great skua<br>Great black-backed gull<br>Black-legged kittiwake<br>Whooper swan<br>Pink-footed goose<br>Barnacle goose (Svalbard) | European storm petrel<br>European shag<br>Auks |
| **Firth of Forth**<br>(CE zone 2) | Northern gannet<br>Black-legged kittiwake<br>Arctic skua<br>Herring gull<br>Little gull<br>Terns<br>Sandwich tern<br>Arctic tern<br>Migrating waterbirds | Manx shearwater (passage)<br>Auks |
| **Regional Sea 2** | | |
| **Dogger Bank**<br>(CE zone 3) | Northern fulmar<br>Northern gannet<br>Gulls<br>Black-legged kittiwake<br>Migrating waterbirds | Auks |
| **Hornsea**<br>(CE zone 4) | Northern gannet<br>Little gull<br>Black-legged kittiwake<br>Migrating waterbirds | Auks |
| **East of Norfolk & Suffolk**<br>(CE zone 5) | Lesser black-backed gull<br>Little gull<br>Migrating waterbirds | Auks<br>Divers |
| **Greater Wash**<br>(R2) | Sandwich tern<br>Common tern<br>Pink-footed goose<br>Migrating waterbirds | Auks |
| **Greater Thames**<br>(R2) | Northern gannet<br>Lesser black-backed gull<br>Common tern<br>Migrating waterbirds | Auks<br>Red-throated diver |
| **Regional Sea 3** | | |
| **Hastings**<br>(CE zone 6) | Mediterranean gull<br>Little gull<br>Terns<br>Migrating waterbirds | |
| **West Isle of Wight**<br>(CE zone 7) | Mediterranean gull<br>Sandwich tern<br>Common tern<br>Migrating waterbirds | Balearic shearwater |

| Regional Sea (CE zone/R2 sites) | Potential collision | Potential displacement |
|---|---|---|
| **Regional Sea 4** | | |
| **Bristol Channel**<br>(CE zone 8) | Northern gannet<br>Lesser black-backed gull<br>Herring gull | Manx shearwater<br>Balearic shearwater<br>European storm petrel<br>Auks |
| **Regional Sea 6** | | |
| **Irish Sea**<br>(CE zone 9) | Little gull<br>Terns | Manx shearwater<br>Great cormorant<br>Auks |
| **Liverpool Bay**<br>(R2) | Lesser black-backed gull<br>Herring gull<br>Little gull<br>Arctic tern<br>Whooper swan<br>Pink-footed goose<br>Migrating waterbirds | Great cormorant<br>Auks<br>Red-throated diver<br>Common scoter |

*Source: Langston (2010).*

Combining the assessment of spatial distribution of "priority" species with the assessment of sensitivity (as SSI) would indicate that:

- In Regional Sea 1, fulmar, kittiwake and European storm petrel are of relatively low SSI; auks, gannet, gulls, Manx shearwater, terns and migratory waterbirds are of moderate sensitivity; the species of greatest sensitivity in the area are shag and sandwich tern.

- In Regional Sea 2, the most sensitive species are divers and gannets (mainly distributed along the Flamborough front); and, to a lesser extent, auks in the outer Thames and along the East Anglian coast; sandwich tern in the Greater Wash, and migrating waterbirds.

- In Regional Sea 3, terns in particular sandwich tern are the highest sensitivities with migratory waterbirds, gull species and Balearic shearwater of moderate sensitivity.

- In Regional Sea 4, gannet, lesser black-backed and herring gull, shearwaters and auks are all of moderate SSI. European storm petrel are of relatively low sensitivity. .

- In Regional Sea 6, cormorants are of high sensitivity with terns, auks and Manx shearwater of moderate sensitivity. In Liverpool Bay, red-throated diver and cormorant are of high sensitivity with common scoter, auks, gulls and waterbirds, including swans and geese of moderate sensitivity.

## Wave, tidal stream and tidal range

There is very little information on the potential sensitivity of birds to wave and tidal stream devices. As described previously, RPS (2010) reviewed the risk to diving birds of underwater marine renewable devices in Wales. This report indicated that there will likely be considerable overlap between the proposed location of wave and tidal stream devices and seabird foraging areas. Tidal stream devices in particular will be proposed for areas favoured by diving birds, which preferentially forage in regions of high tidal activity.

Most seabird species will potentially be at risk from wave devices located at or near the surface. However, the degree of risk posed by such devices will depend on the extent and nature of moving parts. By contrast, submerged wave devices and tidal devices will only pose a risk to those species capable of diving to the depths at which the devices are installed. Wave devices located on the shoreline will probably pose the least risk, since these areas are typically of limited use for bird activity, either for resting or foraging. Any risks they do pose could probably be minimised through the use of mesh to prevent birds becoming trapped within any enclosed chambers.

Tidal devices will only be sited at very specific locations, as determined by the available tidal resource. Therefore, the range of diving species potentially at risk from any particular development will also be limited by proximity to seabird breeding colonies, as well as species specific diving ability in relation to tidal flow rates. A further aspect to consider will be seabird prey preferences, since rapid tidal flows are also likely to favour certain prey types (e.g. stronger swimming fish species).

RPS (2010) provided an overall assessment of risk for a range of seabird species to marine renewable devices in Welsh waters based on their ecology (Table 5 in RPS 2010). No species were assessed as being at high risk from marine renewable developments in Welsh waters. Seven species were assessed as being at medium risk (Manx shearwater, northern gannet, great cormorant, razorbill, common guillemot, European shag and Atlantic puffin). The populations of all other species (listed in Table 5.11 above) were considered to be at low risk of impacts. Not all of the seven medium risk species will be equally at risk for all possible developments, this will only be determined through site and device specific assessment.

A basic strategic analysis of SPAs in England and Wales and the bird species they support was used to identify those sites which support internationally important species which may be vulnerable to the presence of wave and tidal stream devices (i.e. those species identified as medium risk above) (Table 5.14).

Table 5.14 – SPAs and associated bird species potentially vulnerable to wave and tidal devices

| Special Protection Areas | Diving birds protected by SPA designation |
|---|---|
| **Wales** | |
| Ynys Seiriol / Puffin Island SPA | Cormorant |
| Glannau Aberdaron and Ynys Enlli/Aberdaron Coast and Bardsey Island SPA | Manx shearwater |
| Skokholm and Skomer SPA | Razorbill, puffin and Manx shearwater |
| Grassholm SPA | Gannet |

Potentially vulnerable areas where tidal stream development may represent a collision risk to diving birds will likely be restricted to areas where tidal currents are greater than approximately $2m/s^{-1}$ and hence exploitable by current technologies (see Figure 2.6). Within these vulnerable areas, the depth of deployment will be a key factor determining whether diving birds will be exposed to the devices.

Similarly, the scenarios developed for the current SEA (Section 2.5.4) indicate that potential tidal range projects are likely to be restricted to areas where the tidal range is sufficiently large (>6m) (see Figure 2.7). Those bird species at most risk from tidal range schemes are likely to be waterfowl which rely on intertidal habitats for feeding which may be significantly impacted by such schemes. Those SPAs and associated waterfowl species potentially vulnerable to tidal range schemes in England and Wales are detailed in Table 5.15 (does not include the Severn Estuary which was covered by a separate SEA).

Table 5.15 - SPAs and associated waterfowl species potentially vulnerable to tidal range devices

| Special Protection Areas | Waterbirds protected by SPA designation |
|---|---|
| **England** | |
| Duddon Estuary SPA | Sandwich tern, knot, pintail, redshank |
| Morecambe Bay SPA | Sandwich tern, ringed plover, curlew, dunlin, grey plover, knot, oystercatcher, pink-footed goose, pintail, redshank, shelduck, turnstone, bar-tailed godwit |
| Ribble and Alt Estuaries SPA | Ruff, bar-tailed godwit, Bewick's swan, golden plover, whooper swan, ringed plover, sanderling, redshank, whimbrel, black-tailed godwit, dunlin, grey plover, knot, oystercatcher, pink-footed goose, pintail, redshank, shelduck, teal, wigeon, scaup, common scoter, curlew, lapwing |
| Mersey Narrows and North Wirral Foreshore pSPA | Redshank, turnstone |
| Mersey Estuary SPA | Golden plover, redshank, ringed plover, dunlin, pintail, shelduck, teal, lapwing, great crested grebe, grey plover, curlew, black-tailed godwit, wigeon |
| The Dee Estuary SPA | Bar-tailed godwit, pintail, knot, oystercatcher, turnstone, redshank |
| Thames Estuary and Marshes SPA | Avocet, dunlin, knot, black-tailed godwit, grey plover, redshank, ringed plover |
| The Wash SPA | Bewick's swan, bar-tailed godwit, pintail, wigeon, gadwall, pink-footed goose, turnstone, dark-bellied brent goose, goldeneye, sanderling, dunlin, knot, oystercatcher, black-tailed godwit, common scoter, curlew, grey plover, shelduck, redshank |
| Humber Estuary SPA | Avocet, bar-tailed godwit, golden plover, ruff, dunlin, knot, black-tailed godwit, shelduck, redshank |
| **Wales** | |
| Traeth Lafan / Lavan Sands, Conway Bay SPA | Oystercatcher, curlew |
| Bae Caerfyrddin/ Carmarthen Bay SPA | Common scoter |

As mentioned, marine mammals and fish may also be vulnerable to displacement and collision risk from wave, tidal stream and tidal range devices. The following strategic analysis of Special Areas of Conservation identifies those sites and species potentially vulnerable to such devices. The scope of analysis for wave devices includes all SACs in England and Wales territorial waters and UK offshore waters; for tidal stream, those areas of England and Wales and offshore waters where tidal currents are greater than approximately $2m/s^{-1}$, and for tidal range, those areas of England and Wales where the tidal range is sufficiently large (>6m) (does not include the Severn Estuary which has been covered by a separate SEA, DECC 2010g) (Table 5.16).

Table 5.16 – SACs and associated marine mammal and fish species potentially vulnerable to wave, tidal stream and range devices

| Special Areas of Conservation | Relevant marine mammal and fish species protected by SAC designation |
|---|---|
| **Wave** | |
| Berwickshire and North Northumberland Coast SAC | Grey seal |
| Humber Estuary SAC | Lamprey species, grey seal |
| The Wash and North Norfolk Coast SAC | Harbour seal, otter |
| North Norfolk Coast SAC | Otter |
| Isles of Scilly Complex SAC | Grey seal |
| Lundy SAC | Grey seal |
| Severn Estuary/Môr Hafren SAC | Lamprey species, twaite shad |
| Carmarthen Bay and Estuaries/Bae Caerfyrddin ac Aberoedd SAC | Lamprey species, shad species, otter |
| Pembrokeshire Marine/Sir Benfro Forol SAC | Grey seal, lamprey species, shad species, otter |
| Cardigan Bay/Bae Ceredigion SAC | Bottlenose dolphin, lamprey species, grey seal |
| Pen Llyn a`r Sarnau/Lleyn Peninsula and the Sarnau SAC | Bottlenose dolphin, otter, grey seal |
| Dee Estuary SAC | Lamprey species |
| Solway Firth SAC | Lamprey species |
| **Tidal stream** | |
| Lundy SAC | Grey seal |
| Pembrokeshire Marine/Sir Benfro Forol SAC | Grey seal, lamprey species, shad species, otter |
| Cardigan Bay/Bae Ceredigion SAC | Bottlenose dolphin, lamprey species, grey seal |
| Pen Llyn a`r Sarnau/Lleyn Peninsula and the Sarnau SAC | Bottlenose dolphin, otter, grey seal |
| **Tidal range** | |
| Humber Estuary SAC | Lamprey species, grey seal |
| The Wash and North Norfolk Coast SAC | Harbour seal, otter |
| Carmarthen Bay and Estuaries/Bae Caerfyrddin ac Aberoedd SAC | Lamprey species, shad species, otter |
| Dee Estuary SAC | Lamprey species |

A recent Whale and Dolphin Conservation Society review identifying critical habitats for cetaceans made a number of recommendations for Marine Protected Areas (Clark *et al*. 2010). Of relevance to the analysis above, they recommended that MPAs should be considered (or have existing protection extended) for the following areas of coastal Wales:

- northern Pembrokeshire and southern Cardigan Bay; Lleyn Peninsula and Bardsey Island; and, north and west Anglesey – harbour porpoises
- Bardsey Island – Risso's dolphins
- Cardigan Bay – bottlenose dolphins

The potential of this area for future wave and tidal stream development means that the potential for interaction between marine mammals and renewable devices should be an important consideration for any future development in these areas.

## 5.6.4 Controls and mitigation

The following provides details of potential mitigation measures, primarily at the project level which could be implemented to minimise or avoid potentially significant ecological effects associated with the physical presence of infrastructure associated with implementation of the draft plan.

| Sources of potentially significant effect | Potential mitigation measures |
|---|---|
| Potential for non-native species introductions in ballast water discharges or spread through "stepping stone" effect | Possibility of effects mitigated by adherence to recent ballast water guidance |
| Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities | Enforce speed limits for vessels used in support activities and establish a code of conduct to avoid disturbance if entering areas of high animal abundance. |
| Collision risks to birds | Design device for minimal impact<br>Avoid siting devices in particularly sensitive areas e.g. migration routes, feeding, breeding areas<br>Do not undertake installation activities at night when birds are more vulnerable to collisions.<br>Increase device visibility, or use of acoustic warning devices.<br>Tidal turbine blades should not be shiny, as diving birds may mistake them for fish.<br>Use of protective netting or grids |
| Collision risk to marine mammals and fish | Design device for minimal impact<br>Do not site devices in particularly sensitive areas e.g. migration routes, feeding, breeding areas<br>Increase device visibility, or use of acoustic deterrent devices<br>Use of protective netting or grids<br>Seasonal restrictions could be placed on operation to avoid impacting on marine mammals at vulnerable times such as breeding season.<br>The use of acoustic deterrents such as pingers or acoustic harassment devices.<br>Protect against entrapment by incorporating escape hatches into device design. |
| Barriers to movement of birds (e.g. foraging, migration) | Consider siting wind turbines close together to minimise the area accommodated by a wind farm; grouping turbines to avoid alignment perpendicular to main flight paths; providing corridors (up to a few kilometres wide) between groups of turbines to allow passage by birds. |
| Barriers to movement of marine mammals | Avoid sensitive areas<br>Avoid placement of devices within constrained areas where array could completely block or cause a significant perceptual barrier to marine mammals |
| EMF effects on fish | Cable export design to minimise EMF fields<br>Cable burial to minimise the field strength at the seabed. |

*Sources: Faber Maunsell & METOC (2007), AECOM & Metoc (2009).*

## 5.6.5 Cumulative impact considerations

The physical presence of anthropogenic structures in the marine environment is not expected to increase significantly following further oil and gas, gas storage and carbon dioxide storage licensing. The development of more offshore wind farms will greatly increase the number of structures present; the potential for cumulative effects from such a physical presence requires consideration. The potential presence of wave, tidal stream and tidal range devices and schemes in coastal and offshore waters will add to the potential for cumulative impacts although it is likely that the majority of these will consist of small, demonstrator scale projects rather than large arrays.

## Birds

Considering the evidence presented in Section 5.6.2 and 5.6.3 above, the greatest potential for cumulative impacts resulting from the physical presence of OWFs and wave, tidal stream and tidal range devices and schemes is with regard to birds. The potential for birds to be impacted cumulatively through collision, displacement and barrier effects in relation primarily to OWF has received considerable attention in recent years; methods of assessing such potential effects have been the subject of a number of studies and workshops, and are continuing to be developed.

In terms of assessing the overall conservation significance of the relatively small observed and predicted number of bird collision fatalities (in relation to total population sizes), in a wider context NRC (2007) have considered whether and to what degree they are ecologically significant and how the number of turbine-caused bird deaths compares with the number of all anthropogenic bird deaths in the United States. NRC (2007) concluded that bird deaths caused by wind turbines are a minute fraction of the total anthropogenic bird deaths – less than 0.003% in 2003 of a total that Erickson *et al*. (2005) estimate "may easily approach 1 billion birds per year." Although this assessment is US-specific and almost exclusively for land birds, the major causes of anthropogenic bird mortality – collisions with buildings and overhead power lines, and predation by domestic cats – are probably equally relevant to the UK and other European countries. Similarly, of the Baltic/Wadden Sea population of common eider (235,000 birds) that passes the Nysted offshore wind farm, modelling has shown with 95% certainty that 0.018-0.02% would collide with the turbines (less than 1 bird/turbine/year) (Desholm *et al.* 2006). Set in this context, the evidence for migrating passerine bird mortality from collision with the FINO-1 platform (Hüppop *et al*. 2006b), and by extension to major UK offshore wind farm development, is unlikely to result in cumulative impacts of concern for biogeographic populations of such species. For migrating waterbirds and seabirds commuting between nests and foraging areas, inappropriately sited wind farms could result in cumulative effects of concern.

At a national (and potentially biogeographic) level, Maclean *et al*. (2007a) have reviewed the relevance and practicality of population viability analysis (PVA) as a method of assessing the impact of OWFs on bird populations. PVA is defined as the process of determining the probability that a population will persist over a specified time period; in the context of cumulative impact assessment (CIA) for OWFs, it may be used as a tool to answer the broad question: "do several OWFs acting in combination with each other (and non-OWF-related pressures) have a deleterious effect on bird populations?" (Maclean & Rehfisch 2008). Maclean *et al*. (2007a) recommended its use as "a robust framework for taking a scenarios-based approach in which likely impacts are determined using upper- and lower-bound estimates of unknowns" – while cautioning against its application without critical assessment.

Following this study, it was agreed at a COWRIE workshop on the cumulative impact of OWFs on birds that PVA should form the basis for assessing whether the magnitude of any change in population was likely to be significant (Norman *et al*. 2007). Although there are some concerns over the information dependency and assumptions inherent in population modelling, further development of PVA is supported for a range of key sensitive bird species (red throated diver, common scoter, gannet, lesser black-backed gull and common tern). In addition, a PVA study for the pink-footed goose population potentially affected by wind farms off the East Anglian coast and eastern Irish Sea has been completed, funded by DECC (WWT Consulting 2008). This concluded that with an additional annual mortality of 1,000 birds per year, the increase in the risk of population decline below the specific thresholds used was less than 2%. However, if 10,000 birds are killed each year the risk of significant population decline increases considerably (e.g. 18% risk of decline below 100,000 within 25 years).

Norman *et al*. (2007) noted that existing guidelines relevant to cumulative impact assessment (CIA) on birds were insufficiently focussed, with various versions open to interpretation. In response, a draft discussion paper on developing guidelines for ornithological CIA (Maclean & Rehfisch 2008) was prepared in contribution to a further COWRIE workshop in October 2008. Following this, guidance on ornithological CIA for offshore wind farm developers (King *et al.* 2009) was produced.

King *et al.* (2009) noted that CIA was particularly relevant in relation to Round 3 given that the nine development zones will contain multiple projects each comprising hundreds of turbines. The Crown Estate has identified unresolved cumulative impacts on birds as a key issue and has promoted their early identification as a way of expediting the consenting process in relation to Round 3 (The Crown Estate 2008a). Zonal development should in theory permit a more strategic approach to the identification and assessment of cumulative impacts compared to previous rounds of development.

King *et al.* (2009) made a number of recommendations on the methods and techniques which could be applied to CIA of offshore wind farms (based on Maclean & Rehfisch (2008)) including:

*Selection of species for consideration*

- Production of a list of species potentially at risk of cumulative impacts in Round 3
-

*Selection of projects for consideration*

- Projects that have been consented but which are yet to be constructed
- Projects for which application has been made
- Projects that are reasonably foreseeable
- Non-wind farm projects subject to EIA
- Existing projects which have yet to exert a predicted effect (i.e. an effect that is not covered in the baseline).

*Consideration of relevant population and reference area*

- The default boundary of the CIA study area for defining regional populations should be considered as the relevant Round 2 strategic area, Round 3 zone or equivalent, unless there is reliable evidence to support the definition of an alternative discrete biogeographic region e.g. area incorporating onshore breeding colony; Regional Sea etc.
- Depending on the reference population(s) identified, impacts may need to be considered at different population scales at different times of year.

For collision risks and displacement, the effects should be assessed by summing the impacts from each component project. In some cases, further population modelling may be required. Disturbance and barrier-effects accrue in a non-linear manner and these should, therefore, firstly be considered in a qualitative manner making best-use of available information. Significance of a cumulative impact on a species should include a consideration of its life history parameters. Alternately, consideration should be given to life history parameters and habitat/resource use flexibility when defining a species' sensitivity with long-lived species and specialists considered more sensitive (King *et al.* 2009).

Considering the recommendations of King *et al.* (2009), particularly those relating to appropriate spatial scales for ornithological CIA, it is not thought possible at present to conduct a CIA of the offshore wind and marine renewable elements of the draft plan/programme in relation to birds. However, the information presented above identifies key areas and sensitivities of birds in relation to OWF and marine renewable (although limited) development; consideration of this information, in combination with the findings and recommendations below, will assist in the appropriate siting of OWFs wave and tidal devices and minimising the risk of cumulative effects arising. It is recommended that such assessments follow a single set of guidelines (e.g. King *et al.* 2009) supported by the regulatory authorities. While CIA will need to consider potential cumulative impacts in relation to all other ongoing or proposed developments, particular attention will need to be given to any proposed developments within territorial waters of Scotland and Northern Ireland; the scope of functional units must consider such developments. The proposed demonstrator scale of marine renewable development likely to result from the draft plan will ensure that the increment to cumulative impacts on birds is not significant at a strategic level over the 3-5 year lifetime of the plan.

### Other potential cumulative effects

Considering the very minor effects identified relating to fouling and fish aggregation, significant cumulative effects seem unlikely. Such effects have been experienced over many decades in relation to offshore oil and gas infrastructure, with no evidence of cumulative effects identified to date. Potential cumulative impacts influenced by lighting on offshore wind turbines and other infrastructure relate to bird collision risk; the influence of lighting on this risk should be considered in estimations of collision rates (see above).

Further research is required to investigate the potential significance (if any) of artificial electric and magnetic fields for marine organisms. In the absence of information on the significance of EMF effects, very little can be done to assess the potential for cumulative impacts resulting from EMF. As described in Section 5.4.2.1, an approximation of the area affected by inter-array and export cabling for R3 is 40km$^2$ (8,000km of cables (The Crown Estate 2010) with a 5m wide cable corridor). Such an area represents a tiny fraction of the UKCS seabed, and appears trivial in comparison to the area which is subject to disturbance by demersal fishing gear. However, it is prudent to consider important areas for key species of concern such as elasmobranchs, along with the development of the evidence-base for the ecological significance of EMF effects given the cabling requirements of marine renewable devices.

## 5.6.6 Summary of findings and recommendations

Overall, the assessment outlined above concludes that the available evidence from existing OWF developments suggests that displacement, barrier effects and collisions are all unlikely to be significant to birds at a population level. There are some important uncertainties in relation to bird distribution (and temporal variability), the statistical power of monitoring methods (Maclean *et al*. 2007b), and the sensitivity of this conclusion to modelling assumptions (notably avoidance frequency in modelling of collision risk; and several important factors in modelling of population dynamics).

The potential application of a Species Sensitivity Index (SSI) for wind farms (Garthe & Hüppop 2004) is noted; and it is recommended that consideration is given to the practicality and utility of the development of UK-specific individual Species Sensitivity Indices (SSI) and its mapping in UK waters. King *et al.* (2009) have produced a provisional list of species potentially susceptible to cumulative impacts for Round 3 development zones compiled using European Seabirds at Sea (ESAS) data (Tasker *et al.* 1986; 1990) and information on SPA features presented in Stroud *et al*. (2001). The recent aerial bird survey data should be incorporated in the distributional database used to map the SSI (if progressed) and an updated version of the Offshore Vulnerability Index (OVI) to surface pollutants. The existing initiatives to develop Population Viability Analysis for sensitive species should also be progressed. Both of these topics will be of strong relevance for site-specific environmental assessment of potential Round 3 and future developments.

It is not considered possible at present to conduct a CIA of the offshore wind element of the draft plan/programme in relation to birds. The recommendations of King *et al.* (2009) and their proposed approach to CIA is also recommended - including the spatial scale of a Round 3 strategic zone level and/or a corresponding functional unit, and the use of PVA (where possible) as a measure of significance.

A large proportion of the bird sensitivities identified are concentrated in coastal waters. Therefore, as part of a precautionary approach for ecological receptors, it is recommended that the bulk of new OWF generation capacity should be sited away from the coast, generally outside 12 nautical miles (this recommendation also contributes to minimising adverse effects on a range of other users of the maritime area). Potential marine renewable development resulting from the implementation of the plan may be within 12 nautical miles of the coast. Given the likely demonstrator scale of this development over the lifetime of the SEA (3-5 years), it is unlikely to represent a significant cumulative impact to coastal receptors.

Although there has recently been significant survey in coastal waters, the lack of modern data on waterbirds in offshore areas is noted. Developers need to be aware that access to adequate data on waterbird distribution and abundance is a prerequisite to effective environmental management of activities for example in timing of operations, and oil spill contingency planning. An important gap in understanding of relevance to wind farm siting and the siting of wave and tidal stream devices is the marine areas routinely used by breeding birds for foraging, in particular those adjacent to SPAs. To give a specific example, the East Caithness cliffs SPA holds a seabird assemblage of international importance which during the breeding season regularly supports 300,000 individual seabirds including guillemot, razorbill, kittiwake, herring gull, shag (all at numbers of European importance) as well as puffin, great black-backed gull, cormorant and fulmar. The Smith Bank, some 20km from the cliffs, is generally sandy and recorded as having high densities of sandeels and seabirds; ecological energetics would suggest that the area would be an important feeding ground for auks and several other species from the Caithness cliffs but definitive evidence of this is not available.

The potential information gaps relating to electromagnetic fields are also noted, and it is recommended that the research needs identified by Gill *et al*. (2009), and Bochert & Zettler (2006) are reviewed in the context of the DEFRA reviews of Round 1 and 2 wind farm monitoring. Recent research highlighting the potential sensitivity of seals to electrical fields and the risk that electrical fields from power cables could affect seal behaviour should also be more fully explored.

There is currently very little information on the interaction of birds, marine mammals and fish with surface and submerged wave and tidal devices. It is recommended that for proposed developments, regular, detailed and appropriately focused surveys of animal activity and behaviour should be undertaken at the site prior to installation and during subsequent operation. The SEA process may be an appropriate vehicle to summarise and circulate information from such monitoring.

Other potential effects relating to physical presence (e.g. fouling); and effects relating to receptors other than birds (e.g. fish and marine mammals), are considered unlikely to be significant at a strategic level, although further information on aspects such as collision risk and displacement will be required prior to the development of larger marine renewable arrays.

The potential fatal interactions between seals (and potentially other marine mammals such as harbour porpoises) and thrusters associated with dynamic positioning vessels has been highlighted recently (Thompson *et al.* 2010c). The SEA process may represent an appropriate mechanism to facilitate further research on this issue and promote appropriate mitigation measures. For example, Thompson *et al.* (2010c) indicate that the distributions of seal haulouts and foraging patterns, bathymetry and boat/industrial usage characteristics should be compared across sites to identify common features. Research examining the foraging patterns and usage of areas by seals has been funded through the SEA and this could be extended to examine the potential for interaction with boat/industrial usage (possibly through analysis of AIS tracking data). In general, the SEA recommends that a collaborative approach between the relevant offshore marine activities that utilise dynamic positioning vessels would be the most effective mechanism to fund research required to determine the extent of the problem and develop appropriate mitigation if required.

# 5.7 Physical presence and other users

## 5.7.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind Farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, “sanctuary effects”) | X | X | X | X | X | X | X | 5.7.2.2 |
| | Other interactions with shipping, military, potential other offshore renewables and other human uses of the offshore environment | X | X | X | X | X | X | X | 5.7.2.1<br>5.7.2.3<br>5.15.2 |

Interaction between offshore energy installations and other users of the marine environment is a prime concern for stakeholders, particularly for offshore wind, given the potentially large areas that developments will cover. Wave and tidal devices and installations used for carbon dioxide storage and gas importation and storage will also present potential obstacles to other users of the sea surface, water column and seabed. Previous SEAs (1-7 and OESEA) have considered the potential effects of the physical presence of hydrocarbon development on other users of the marine environment and concluded that effects were minor and that there were adequate existing assessment/mitigation measures. Appendix 3h Other users and material assets outlines the other users of the marine environment and this section provides a consideration of the potential for interactions between offshore energy infrastructure and these other users. Interactions between shipping and navigation, and fishing activities with offshore renewables probably represent the greatest potential for conflict and these are considered below. The interaction of multiple users of the marine environment, resulting spatial planning, potential buffer zones and implications for the siting of renewable energy devices are all discussed in Section 5.15.

## 5.7.2 Consideration of the evidence

### 5.7.2.1 Navigational risk assessment

Navigational risk factors associated with large-scale offshore wind farm developments are obvious and well-recognised, and both DECC and the MCA have issued guidelines on the assessment and consenting process. As with oil spill risk assessment for offshore oil and gas developments, the regulatory approach is risk-based, and therefore has elements in common with the regulation of health and safety in an industrial context; for example in the process of assessing risk through a quantitative process (here termed Formal Safety Assessment, FSA) and judging acceptable levels of risk against ALARP (As Low As Reasonably Practicable) criteria.

Offshore wave and tidal device deployment is not currently on the same scale as offshore wind and the likely spatial extent of development for the associated technologies over the lifetime of the current plan is expected to be at a demonstrator scale rather than full development arrays. Their impact on navigation is therefore currently less extensive than for offshore wind. For tidal stream devices mounted on the seabed, location within deeper waters should mitigate their impact on shipping (e.g. AECOM & Metoc 2009), however, both wave and tidal devices could form a potential hazard both during their construction and operational phases and are subject to the same offshore hazard regulations and assessments as for offshore wind (e.g. EMEC 2009, Halcrow 2006). Under the IALA O-139 recommendations for the marking of offshore manmade structures (IALA 2008) wave and tidal devices extending above the sea surface must be marked in accordance with the marking regulations for OWF. Appropriate navigation buoys (with lighting visible for 5nm) at the corners of arrays and above sub-surface devices which still pose a hazard to surface vessels is required, with active or passive radar reflectors, retro reflecting material, racons and/or AIS transponders expected to be fitted as the level of traffic and degree of risk requires. The Scottish marine renewables SEA (Faber Maunsell & Metoc 2007) assessed the impacts and mitigation measures associated with wet renewables recommending that a detailed review of shipping activities and consultation with local port, harbour and lighthouse authorities be undertaken as part of the site selection for any project development. Further, that a detailed survey and analysis should be undertaken in accordance with DTI (now DECC) guidance and the MCA's MGN 275 (now 371) guidance to determine risks and impacts.

A navigation risk assessment for the Wave Hub site off Hoyle, north Cornwall (Halcrow 2006) calculated, on the basis of existing shipping information, a risk of collision of a vessel with one of the devices (both in a powered and drifting scenario) as 1 collision per 169 years (a conservative estimate as it assumes a collision of every ship entering the site). The risk of ship to ship collision in the area was actually reduced from 1 in every 77 years to 1 in every 94 years with the installation of the devices due to vessels tending to navigate either side of the deployment area. The study also recommended a 500m safety zone around each device with a movement of the whole deployment zone 4km to the east reducing the impact on navigation and potential collision risk.

MCA Marine Guidance Note MGN 371 (M+F) Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues require that developers… *"In …..the preparation of Scoping Reports (SR), Environmental Impact Assessments (EIA) and resulting Environmental Statements (ES) should evaluate all navigational possibilities, which could be reasonably foreseeable, by which the siting, construction, establishment and de-commissioning of an OREI could cause or contribute to an obstruction of, or danger to, navigation or marine emergency response".* MGN 371 advises that a traffic survey of the area concerned should be undertaken within 12 months prior to submission of an OREI Environmental Statement. However, if deemed necessary, to cover seasonal variations or perceived future traffic trends, the survey period may be required to be extended to a maximum of 24 months.

The project-specific EIA should also assess potential navigational or communications impacts or difficulties caused to mariners or emergency response services, using the site area and its environs. Those difficulties which could contribute to a marine casualty leading to injury, death or loss of property, either at sea or amongst the population ashore, should be highlighted as well as those affecting emergency response. Consultation with local and national search and rescue authorities should be initiated and consideration given to the types of aircraft, vessels and equipment which might be used in emergencies. This should include the possible use of OREI structures as emergency refuges and any matters that might affect emergency response within or close to the OREI.

MGN 371 also indicates that an ES should consider whether any features of the OREI, including auxiliary platforms outside the main generator site, mooring and anchoring systems, inter-device and export cabling, could pose any type of difficulty or danger to vessels underway, performing normal operations, including fishing, or anchoring. Such dangers would include clearances of wind turbine blades above the sea surface[28], the burial depth of cabling, etc. The ES should also consider whether any feature of the installation could create problems for emergency rescue services, including the use of lifeboats, helicopters and emergency towing vessels (ETVs). All of the above will need to be addressed to the satisfaction of MCA prior to consenting of a development.

In late 2004, the Greater Wash wind farm developers group sought guidance from the MCA on the inter-relationship of wind farms to shipping routes so that they could take early account of the factors involved when planning turbine layout within their allocated water space (lease area). The resulting MCA *Template for assessing distances between wind farm boundaries and shipping routes* (Annex 3, MCA Marine Guidance Note MGN 371 (M+F)) integrates the radar results of the North Hoyle electromagnetic trials with published ship domain theory so as to better interpret the inter-relationship of marine wind farms and shipping routes.

Specific guidelines on navigation risk assessment for OWF developments have been produced by DECC (DTI 2005d), *Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms*. These set out a requirement for assessing risk by Formal Safety Assessment (FSA) using numerical modelling and/or other techniques and tools of assessment acceptable to government and capable of producing results that are also acceptable to government. The FSA is required to: estimate the “Base Case” level of risk based on existing densities and types of traffic and the existing marine environment; and predict the “Future Case” level of risk based on the predicted growth in future densities and types of traffic and reasonably foreseeable future changes in the marine environment. Both Base and Future Cases are to be assessed with and without the OWF development in place; and hazards identified which are caused or changed by the introduction of the wind farm, together with the risk associated with the hazard, the controls put in place and the tolerability of the residual risk. For consenting to proceed, risk must be assessed “Broadly Acceptable” or “Tolerable” on the basis of “As Low As Reasonably Practicable” (ALARP)”, based on criteria set out in the Methodology’s “*Mechanism for Assessing Tolerability of Marine Navigational Safety Risk*”. This considers both the tolerability of individual risks, and of societal concerns.

On the basis of risk assessment, offshore wind farm developers are required to indicate whether navigation in and/or near the site should be prohibited by specified vessel types, operations and/or sizes; in respect of specific activities; in all, or specified areas or directions; in specified tidal or weather conditions, or simply recommended to be avoided. Relevant information concerning applications for safety zones under SI 2007 No 1948 *The Electricity (Offshore Generating Stations) (Safety Zones) (Application Procedures and Control of Access) Regulations 2007* for a particular site during any point in its construction, operation or decommissioning, should be specified in the Environmental Statement accompanying the development application.

Developers are required to provide researched opinion of a generic and, where appropriate, site-specific nature concerning whether proposed structures could produce radar or radio interference such as reflections, blind spots, shadowing, or phase changes; with respect to any frequencies used for marine positioning, navigation or communications, including Automatic Identification Systems (AIS), whether ship-borne, ashore or fitted to any of the proposed structures.

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[28] Recommended minimum safe (air) clearances between sea level conditions at mean high water springs (MHWS) and wind turbine rotors are that they should be suitable for the vessel types identified in the traffic survey but generally not less than 22 metres, unless developers are able to offer proof that no risk exists to any vessel type with air drafts greater than the requested minimum.

It should also be determined how the overall site would be marked by day and by night taking into account that there may be an ongoing requirement for marking on completion of decommissioning, depending on individual circumstances; and how individual structures and fittings on the perimeter of and within the site, both above and below the sea surface, would be marked. If specific structures are not considered to be sufficiently radar conspicuous from all seaward directions (and for SAR and maritime surveillance aviation purposes), there will be a requirement for passive enhancers (i.e. reflectors) radar beacons (racons) and/or AIS transceivers. Appropriate sound signals may also be required.

All OREI generators and transmission systems should be equipped with control mechanisms that can be operated from the OREI Central Control Room or through a single contact point. Throughout the design process for an OREI, appropriate assessments and methods for safe shutdown should be established and agreed, through consultation with MCA's Navigation Safety Branch, Search and Rescue Branch and other emergency support services.

The DECC (DTI 2005d) *Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms* notes that levels of navigational risk associated with offshore wind farm developments, and their tolerability are likely to be dependent on a number of variables used in the assessment of a wind farm. These will include the size of the water space, its bathymetry and hence the sea room available for manoeuvring, and the variations in the marine operations taking place in the water space. Due to this site specificity, a strategic level FSA approach is not feasible. The spatial scale of Round 3 and future leases is relatively large, and any lease area is likely to include areas covering a wide range of shipping traffic densities. In addition, although there is an established methodology for FSA of individual developments, the output from this process does not facilitate an assessment of cumulative risk (i.e. there is no straightforward approach to sum the risk associated with individual developments).

However, in view of high correspondence between draft and unpublished MCA "OREI 1" primary navigation routes and the 2008 AIS data in the SEA analysis; generic indications of risk tolerability given in MCA and DECC guidance; and generic indications of the relative tolerability of wind farm distances from shipping lanes, it is recommended that offshore wind farm leases include a general prohibition on turbine location within a 1nm buffer of a primary navigation route (as mapped for the SEA using 2008 AIS data). This buffer width is based on the "high" to "medium" risk threshold of the shipping route template; and a larger buffer may be required where additional factors (such as traffic density and tidal set) increase the local risk (see Section 5.15 for relevant GIS analysis).

For small fishing vessels and most non-commercial vessels, including recreational craft, the navigational risk of offshore wind farm developments will be largely mitigated by a coastal buffer zone (Section 5.15.3), which is recommended to address several ecological and spatial conflict concerns. In addition, the recommended air gap of 22m between blade tip and sea surface should prevent any possibility of collision with the turbine rotors. Further guidance on navigation in the vicinity of OREIs is provided by MCA Marine Guidance Note MGN 372 (M+F) - Offshore Renewable Energy Installation (OREIs): Guidance to Mariners Operating in the Vicinity of UK OREIs.

It is noted that the identification of primary navigation routes is based primarily on AIS data, which currently has limited coverage beyond about 80km (line of sight from antenna height) of the coast; also that the IMO are working to fill data gaps beyond 80km in the near future. A system called SafeSeaNet has been set up in Lisbon by EU member states and the

European Maritime Safety Agency, to co-ordinate AIS data. With these factors in mind, and recognising that maritime traffic distribution can change, it is recommended that primary navigation routes are refined and reviewed periodically, with the results made available to developers.

Subject to the above recommendations, the SEA judgement is that sufficient regulatory control exists, at the consenting and operational stages, to manage navigational safety risk effectively. Outwith the primary navigation route network, there is no clear basis or requirement to spatially constrain offshore wind farm development on grounds of navigational safety. Although wave and tidal developments are at a relative infancy, regulations relating to navigational safety are also considered to be adequate.

### 5.7.2.2 Fishing interactions

The distribution of fishing effort around the UKCS was described previously in OESEA and updated in Appendix A3h.13 of the current Environmental Report, based on independent analyses of VMS, logbook and aerial surveillance data, consultation with fisheries stakeholders and various published reports. Important fishing grounds for consideration when siting offshore renewable energy installations are listed in Table 5.17. These areas exhibit high densities of fishing effort with high value of landings relative to all UK waters; emphasis is placed on sites with waters <60m depth. Deeper waters areas and those of great local importance (which are more difficult to identify) are described in the text below.

Table 5.17 - Important UK fishing grounds for consideration when siting OWFs

| Area | Primary gear type(s) |
|---|---|
| The south coast of the Moray Firth to approximately 12nm offshore, extending southeast to Peterhead (majority >60m water depth). | Primarily mobile gears, with most static effort closer to the coast. |
| Much of the Firths of Forth and Tay to approximately 12nm and particularly the areas of finer sediment off the coast of approximately Carnoustie to Montrose. | Mobile gears dominant in the Firth of Forth, primarily static gears to the north of Fife Ness. |
| Inshore waters off the coast of northeast England from approximately Hartlepool to Amble, extending northeast to the Farne Deeps (where water depth >60m). This area is fairly well defined by the extent of seabed sediments consisting of muddy sand. | Primarily mobile gears, with most static effort closer to the coast. |
| To a lesser extent, inshore waters between Hartlepool and the Humber extending up to approximately 20nm offshore, although greatest effort within 12nm. | Mixed throughout the area, with mobile gears dominant north of Flamborough Head, and static gears dominating to the south. |
| Nearshore waters of the Wash and the Thames area. | Mixed, with mobile gears notably dominating within The Wash. |
| Outer Silver Pit, approximately defined by the extent of seabed sediments consisting of muddy sand. | Mobile. |
| The southeast coast of England (primarily Sussex) from approximately Dungeness to Portsmouth. Effort is greatest within 12nm, although remains high to the UK/France median line. High densities of non-UK fishing vessels operate throughout the area although decreasingly so closer to the UK coast. | Mixed; static gears dominating close to the coast and limited further offshore, with mobile gears widespread throughout the area and dominant further offshore. |
| Inshore waters between Portland and the Lizard, with effort generally greatest closer to shore (ca. <6nm) although very high effort extending to approximately 12nm offshore between Sidmouth and Plymouth. Effort remains high beyond 12nm, with considerable densities of non-UK fishing vessels present. | Mixed throughout the area, although static gear effort focussed close to the coast. Static gears dominate between Start Bay and Salcombe. |
| The Bristol Channel. | Mobile gears offshore, with most |

| Area | Primary gear type(s) |
|---|---|
| | static gear effort inshore. |
| Between the west coast of the Isle of Man and the Northern Ireland coast, extending north to approximately Ballywalter and south into Republic of Ireland waters (considerable proportion >60m water depth). | Primarily mobile, with greatest static effort close to the Northern Ireland coast. |
| Waters off the east Cumbrian coast extending south and west from approximately to Whitehaven to 12nm offshore. | Mobile. |
| Inshore waters around the Isle of Arran, with high effort extending throughout much of the area between Kintyre and the Ayrshire coast (where water depth generally >60m). | Mobile. |
| The Minch, particularly inshore waters between mainland Scotland and the Isle of Skye, between Gairloch and Ullapool, and off the northeast coast of Lewis (considerable proportion >60m water depth). | Mixed throughout the area, although static gears dominating around Skye. |
| Nearshore waters of Orkney and Shetland, particularly to the northeast of the islands (where majority water depth >60m). | Static gear dominant around Orkney, mixed around Shetland. |

Outwith the areas of high effort and value from a UK context listed in Table 5.17, many less intensively fished areas exist which are of great local significance. Such areas are particularly sensitive to spatial conflicts; they are typically fished by small vessels operating within a limited range from port, and may serve communities with livelihoods dependent upon those fishing grounds. At a strategic level, it is not feasible to identify all such grounds; small, inshore vessels operate at almost all ports throughout the UK, although those in remote and rural areas are likely to be most sensitive. At region- and site-specific levels, early consultation with relevant Inshore Fisheries Conservation Authorities (IFCAs) (England and Wales) and fishermen, will facilitate the identification of these locally important areas. In addition to those areas mentioned above, there are many areas of very high fishing effort of considerable value in UK waters exceeding 60m water depth. These include the Fladen Ground, approximately defined by the extent of seabed sediments consisting of muddy sand. Additionally, moderate-high levels of effort are present throughout much of the deeper waters of the northern North Sea and waters north of Scotland, including numerous discrete areas of particularly high effort. Extending from approximately 25km southwest of Pembrokeshire, the Celtic Deep is an area of very high fishing effort, approximately defined by the extent of seabed sediments consisting of muddy sand and sandy mud; the area experiences considerable effort from non-UK vessels.

The distribution of non-UK vessels is mainly in offshore waters, apart from in southern areas, where many foreign fleets (in particular French, Belgian, German and Dutch) hold historical rights to fish within 6nm of the shore and fishing grounds are shared. The areas identified by the SEA spatial constraints analysis (Dogger Bank, scattered areas from Yorkshire to Norfolk, the outer Forth and Moray Firth, and eastern Irish Sea) were relatively lightly fished.

Experience in Round 2 development locations was discussed with representatives of the fishing industry and fisheries management organisations during the OESEA2 stakeholder dialogue. It was noted that extensive inshore fisheries take place throughout most UK waters to approximately 25nm offshore, and that through the activities of Sea Fisheries Committees (now IFCAs), the 0-6nm zone is generally quite well understood. The 6-12nm zone, however, is an area of typically high fishing effort but poorly understood - many foreign vessels operate in this area. Offshore wind farms may have cumulative effects on fisheries in these areas through their influence on the locations of other activities such as aggregate extraction, conservation sites etc. Inshore vessels are quite restricted in areas which they may fish by distance from home port, availability of sheltered waters and substrate type.

Stakeholder discussion also took place on fishing activities which may or may not be possible within wind farms. Risk was perceived to increase significantly if fishing within a wind farm; different fishermen have different perceptions of risk, with some willing to take more risks than others - it is was considered inappropriate to define one type of gear as compatible with offshore wind farms and another as incompatible. Mobile gears such as trawls or drift netting were generally not considered possible, although observations have shown vessels to be able to fish specific areas with good accuracy; there could be some scope for fishing mobile gears within offshore wind farms if the layout is suitable. Attention was drawn to observations of fishing activity within the Barrow offshore wind farm; trawling within the wind farm is widely considered hazardous and does not occur; however, potting activities are carried out safely. Catches from pots in the footprint of the wind farm are significant, with different boats now exploiting this area - not vessels which previously trawled the area. Regarding the issue of turbine spacing to minimise fisheries conflict, there was considered to be a trade-off between total wind farm footprint and potential fisheries compatibility. If this is to be achieved, communication between fishermen and developers at an early stage is essential.

The Scottish marine renewables SEA (Faber Maunsell & Metoc 2007) and the SEA of offshore wind and marine renewable energy in Northern Ireland (AECOM & Metoc 2009) also describe potential spatial impacts of construction, operation and decommissioning of offshore renewables on fishing. These include, for example, the displacement from fishing grounds during the construction and decommissioning phases with the implementation of temporary safety zones of 500m and potentially permanent safety zones of 50m around the array area during operation. Temporary or permanent Areas to Be Avoided (ATBAs) may also be required. As well as excluding fishing from the development area there may also be added pressure of other vessel traffic being diverted and impacting on fishing operations (Halcrow 2006). It is also noted that new subsea cables may make areas less attractive for mobile fishing methods (i.e. beam trawls, bottom otter trawls), displacing vessels operating such gear over a swathe of approximately 300m for each device array (assuming three export cables each separated by 100m) (AECOM & Metoc 2009).

Exclusion of fishing (or at least intensive trawling) effort would be likely to have a local beneficial effect on fish stocks, and also on reducing seabed disturbance and associated ecological effects. However, exclusion in some areas is likely to result in negative effects on other fishing grounds through displacement of effort. A “reef effect” has also been noted for offshore wind farms (for example at Barrow) and was the subject of a RAG commissioned study (Linley *et al.* 2008); although this is unlikely to be significant at a strategic level, in view of the limited spatial area affected by habitat alteration.

A report into the potential co-location of Marine Conservation Zones (MCZs) and OWFs identifies the negative and positive effects of this co-location on fishing activities (Blyth-Skyrme 2010b). Positive effects on excluding fishing from 1 combined area rather than 2 separate, potentially larger ones are identified as:

- May minimise social and economic impacts on the fishing industry;
- May support windfarm developers' efforts to engage with local fishing communities;
- Restrictions on fishing activities within windfarms may support MCZ conservation objectives;

The disadvantages for fishing activities of any potential co-location were identified as:

- May limit access to fishing grounds inside windfarms that would otherwise be targeted;

- Concern that fishermen will not receive compensation for lost fishing opportunities.

The effect of any co-location on fishing activities depends on the scale of fishing interests in the area, willingness to fish within the areas, the space available for displacement of fishing into other suitable areas and the management regime of fisheries in that area. Clarity would also be needed over the responsibilities of developers to both co-location with MCZs and additional compensation related costs to the fishing industry

At a strategic level, caution is required with regard to the siting of major expansion of offshore renewable energy infrastructure to ensure fishing activities and skills of local cultural importance in an area are not inadvertently lost, through the prevention or significant hindrance of fishing activity for a generation during the lifetime of the developments.

### 5.7.2.3 Other existing users

#### Ports and shipping

Whilst navigational risk analysis is discussed above, the physical presence of OWF, wave and tidal stream devices has additional potential significant impacts on other aspects of ports and shipping.

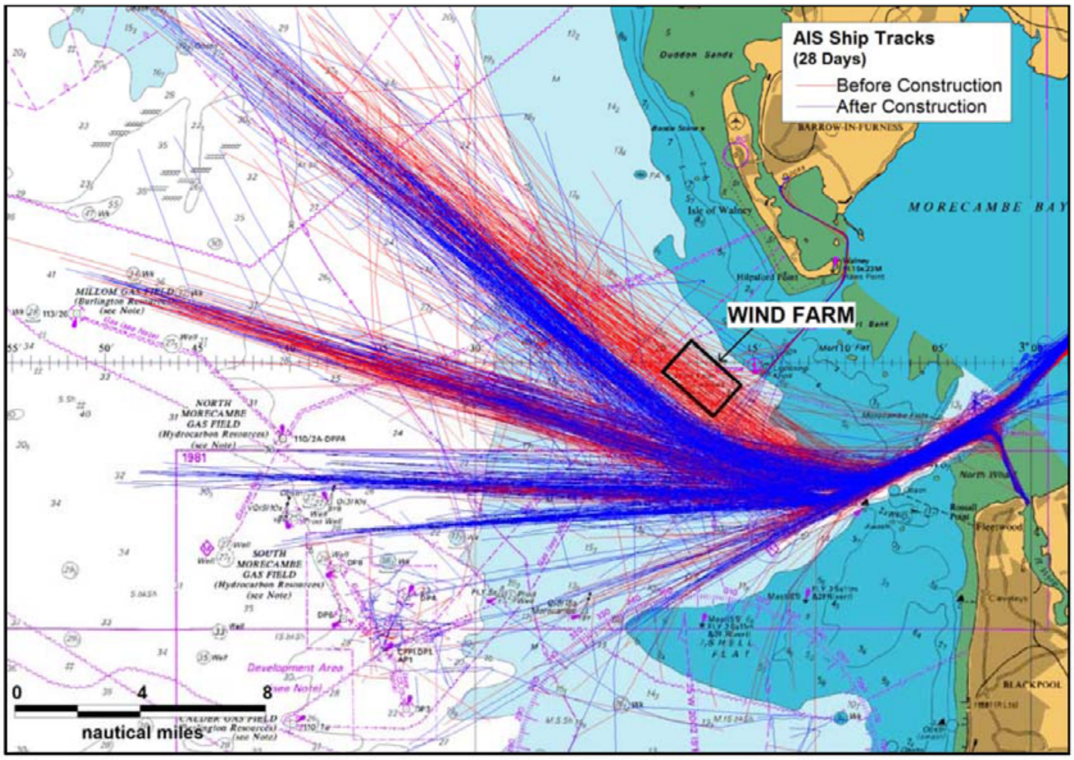
#### Displacement of shipping

A DECC report of AIS tracking data of ship navigation around OWF (DECC 2010p) presents information on the changes to vessel routes before and after the construction of the Barrow, Thanet and Greater Gabbard developments. The report shows that at the Barrow OWF, NW/SE shipping into Morecambe Bay that previously passed through the site had been displaced to the south (Figure 5.28), with the width of the navigation corridor reducing from 60% of the tracks within 1nm of the mean to 80% for the Stena Line ferries. The shipping in the vicinity of Barrow OWF is dominated by ferries which have adjusted their position to achieve a safe clearance of 0.5-2nm.

The results from other developments provide a similar, although slightly more complex picture with displacement of vessels at the Thanet site occurring to the north, east, south and west of the site (Figure 5.29). This displacement has the potential to cause constriction of vessels in areas and increase the collision risk both between vessels and between vessels and OWF infrastructure. This is increasingly likely in areas of multiple installations, high numbers of natural constrictions (e.g. sand banks) or high shipping densities (see Section 5.15 for further discussion) with Figure 5.30 illustrating the potential large scale constriction of vessel movements in the offshore Morecambe Bay region with the construction of several OWF and the Gateway gas storage project.

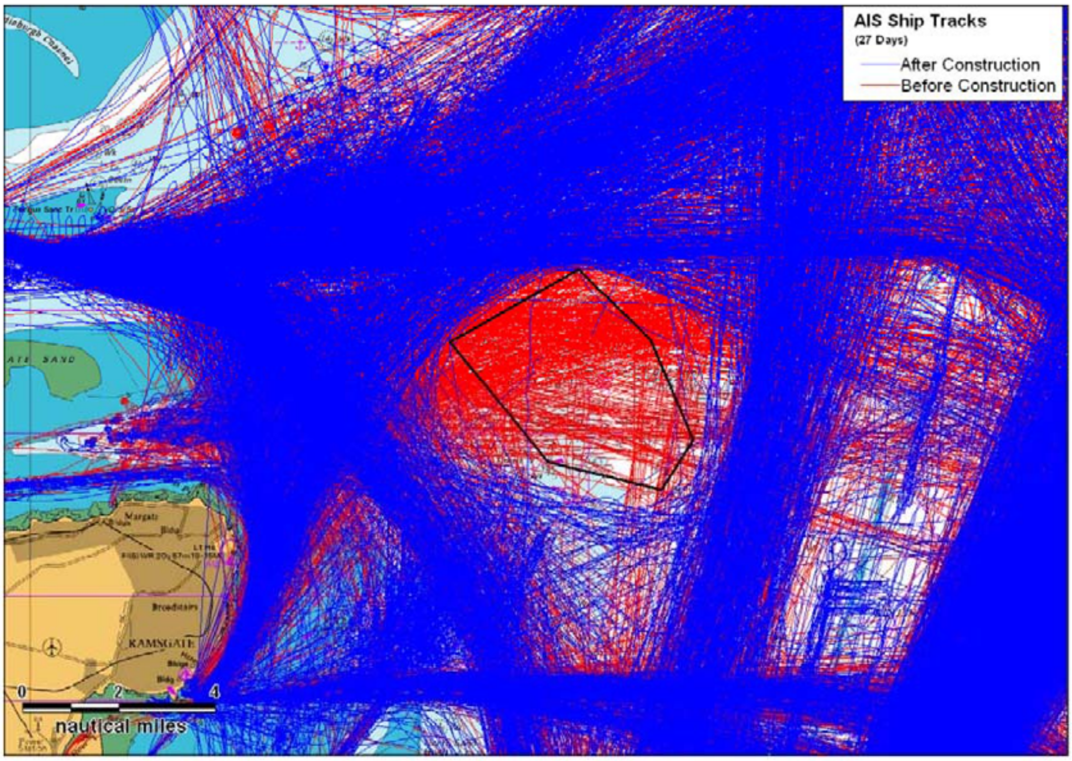
The number of vessels recorded as intersecting OWF developments (discussed in Appendix 3h.2) increases in areas with higher traffic densities and a variety of different types of shipping (DECC 2010p). At Greater Gabbard, Burbo Bank, Scroby Sands and Kentish Flats the vessels tracked inside the OWF were all fishing vessels, recreational craft, lifeboats, harbour pilot vessels or small passenger / inland waterways vessels. Only at Thanet was there any recording of the interaction of larger vessels with the OWF, with a small number of small cargo ships cutting the edge off the route around the development.

Figure 5.28 - AIS ship tracks before and after the construction of the Barrow wind farm



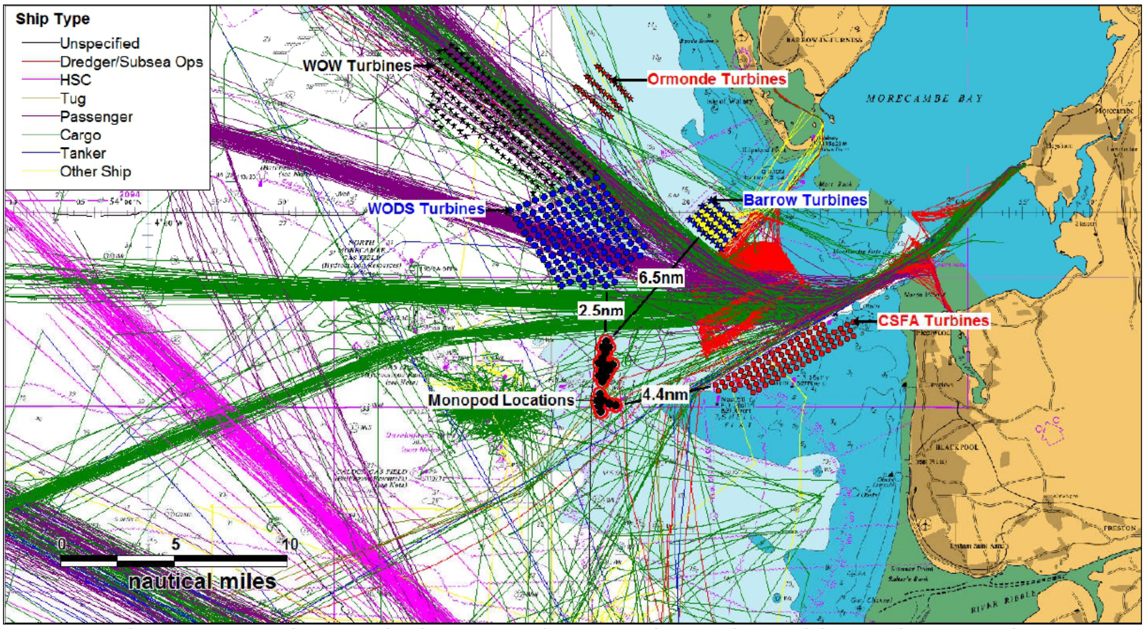

*Source: DECC (2010p).*

Figure 5.29 - AIS ship tracks before and after the construction of the Thanet wind farm




*Source: DECC (2010p).*

Figure 5.30 - One months shipping survey data for the region around Morecambe Bay with installed and proposed OWF and Gateway gas storage project locations




*Notes: WOW = Walney OWF; WODS = West of Duddon Sands OWF; CSFA = Shell Flat OWF; Monopod locations = Gateway gas storage project*
*Source: Gateway (2007).*

This interaction of cargo ships (and other vessels) with OWF developments and the displacement of vessels in all directions is partially addressed at several OWF sites with the introduction of traffic separation schemes (TSS). At Greater Gabbard (Figure 5.31 overleaf) the introduction of the TSS has helped manage routing in the vicinity of the wind farm, with the east traffic lanes located between north and south developments separating traffic by direction to minimise the risk of head-on encounters (DECC 2010p). An updated TSS scheme already exists at the planned Humber Gateway site, partially to assist port traffic management and safety and partially to move traffic away from the planned OWF site. This means that the subsequent impact of the OWF on traffic will be much reduced. Similarly the introduction of a TSS scheme at the planned Gwynt y Môr OWF site has resulted in tankers bound for Liverpool to line up early for the TSS and therefore avoid the planned OWF site.

There are a number of 'pinch points', which are either constrained locations within UK waters where there are currently high densities of shipping or areas of navigational importance such as turning areas. Often these constrained locations have strong tides and heavy seas and as such are likely candidate areas for tidal stream/wave development. Care needs to be taken that when siting these devices, areas of high vessel activity and limited manoeuvrability are not compromised. Similarly caution needs to be extended to siting devices in the entrance to estuaries / harbours where they may either restrict access or produce a hazard risk especially in areas prone to bad weather conditions.

Figure 5.31 - AIS ship tracks before and after the construction of the Greater Gabbard wind farm and traffic separation scheme


*Source: DECC (2010p).*

## Increased journey times and distances

The potential displacement of vessels around large arrays of devices, during installation, operation and decommissioning phases, may increase journey times and distances. The location and size of the development, size of safety exclusion zone and type of journey will all determine how much disruption occurs, with increased journey distances resulting in increased fuel consumption, associated increased greenhouse gas emissions and costs to the shipping operator. Cumulative impacts of multiple OWF developments on navigation and shipping are further discussed in Section 5.16 with issues associated with the mismatch of the siting of set navigation routes through different OWF arrays in adjacent areas resulting in complex navigational routes between developments and increased distances travelled also discussed.

## Reduced trade / supply opportunities

There is the potential issue that an increase in the number of obstacles in the vicinity of approach routes to ports will have indirect effects on the ports themselves, through higher insurance premiums for vessels manoeuvring in these areas and therefore potential displacement of vessels to easier access and cheaper ports. A number of the UK North Sea ports experience high numbers of days where fog is an issue for navigation. The construction of OWF and other obstacles in the vicinity of port approach routes and associated constriction of vessels into set channels and routes would increase the collision risk and may deter vessels from the ports. Long term reduced access to ports, potentially exacerbated during installation and decommissioning would have an effect on trade opportunities.

Tidal range developments have the potential to significantly impact access to ports and therefore trade opportunities. The presence of a barrage would affect the environmental conditions of an estuary and potentially alter the water levels and sediment deposition patterns affecting the available water depth for navigation. Changes to tidal velocities and vessel size restrictions posed by lock dimensions are also likely to affect access to specific ports. The Severn barrage feasibility study (DECC 2010e) outlined potential impacts on Bristol, Cardiff, Newport and Sharpness ports of the construction of the Cardiff to Western barrage, with for example a predicted reduction in employment of 2,100 people at Cardiff port alone and a reduction in GVA (gross value added) of £1.3bn over the 40 year evaluation period for all affected ports (DECC 2010f).

### Military activity

Potential disruption to military activities may occur during the installation, decommissioning and operation of a renewable energy site if both are in proximity. Current areas of military activity are considered further in Section 5.15, overall spatial considerations, as a hard constraint; one that definitely and consistently excludes subsequent renewable energy development in a shared area.

### Dredging and aggregates

Dredging and aggregate extraction have the potential to be significantly impacted by the exclusion of areas for renewable energy developments. Current technological limits of the water depth in which OWF turbines and wave and tidal stream devices can be deployed mean that the siting of these devices often concentrate on shallow areas and sand banks, which are also favoured for aggregate extraction and dredging. As a result the current areas under licence for these activities are considered further in Section 5.15, as a hard constraint, one that definitely and consistently excludes subsequent renewable energy development.

### Tourism and recreation

The likely conflict between recreational users of the marine environment and offshore energy installations, predominantly due to exclusion of areas and collision risks, is addressed as part of the discussion into a buffer zone in Section 5.15.

## 5.7.3 Cummulative impact considerations

The cumulative impacts of multiple users of the marine environment are considered as part of a discussion on marine spatial planning and overall spatial considerations in Section 5.15. The issue of navigation has significant cumulative impacts especially with regards to multiple installations in adjacent areas and constricted or high density shipping routes. The alignment of navigation zones through or around arrays should be considered as part of navigation within the wider region to avoid complex navigational manoeuvres to progress from one zone to another. Similarly cumulative displacement effects and the impact of multiple developments on the ease of navigation around the approaches to ports will have a significant effect on the ports themselves. The cumulative impacts of multiple arrays in important fishing areas are significant, with exclusion from large spatial areas potentially detrimental to local skills and income. Cumulative impacts of multiple renewable energy devices themselves within areas is discussed further in Section 5.16, with issues relating to the need for spatial planning so that subsequent energy schemes can be accommodated in regions discussed in Section 5.15.

## 5.7.4 Summary of findings and recomendations

The primary issues for other users of the marine environment relate to navigation risk and the interactions of fishing activities with marine devices. Despite R3 OWF zones being large there is no clear evidence that, other than excluding the primary navigation network areas, any spatial constraints on positioning of OWF need to be considered on the grounds of navigational safety. Monitoring data of existing OWF suggest that regular users of the area adapt to altered routes and in busy areas the introduction of a traffic separation scheme can significantly reduce any risk of accidental collision. As wave and tidal developments are currently at demonstrator scale the spatial extent of arrays of these developments and the implications for navigation are difficult to ascertain, although regulations on lighting and navigational aids mean that they are unlikely to be any more of an issue than OWF developments. The displacement of shipping and subsequent impact on the cost of shipping and port revenues is potentially significant, and should be taken into account when siting arrays of wet renewable devices.

The effect of renewable energy installations on fishing activities are more complex, with negative effects of the exclusion of large areas and potential displacement to other areas and therefore intensification countered by positive effects on fish stock numbers, seabed disturbance and reef effects. At a strategic level the siting of major renewable energy developments (especially ones covering large areas or multiple arrays in close proximity) need to consider fisheries implications and avoid any areas of significance.

## 5.8 Landscape/Seascape

### 5.8.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Potential visual impacts and seascape effects of development including change to character | X | X | X | X | X | X | X | 5.8.2.4<br>5.8.3 |

There are three principal considerations for an assessment of the likely impacts of offshore energy activity on the seascape/landscape of UK waters and coastlines:

- the limit of visual perception from the coast (i.e. are the devices or installations visible and what influences their visibility)
- the individual characteristics of the coast which affect its capacity to ‘absorb’ a development
- how people perceive and interact with the seascape

### 5.8.2 Consideration of the evidence

#### 5.8.2.1 Curvature of the earth and theoretical visibility

The curvature of the earth influences the visibility of offshore structures but is negligible except at very long distances – for instance an observer of height 1.7m would still see the top of a structure 160m in height, at 25-30km from the coast at sea-level, and would observe a similar scene (albeit at a reduced scale) at 45-50km from the coast at 100m above sea-level. The basic formula for calculating the distance over which an object is visible, taking account of the curvature of the earth and atmospheric refraction is (after Scott *et al*. 2005):

$$d = \sqrt{2rh1} + \sqrt{2rh2}$$

(Where: *d*=visible distance, *r*=radius of the earth (7,430km accounting for atmospheric refraction), *h*1=height of observer, *h*2= height to top of structure).

For instance, the sum of the height of an observer at 50m (+1.72m for average height of person) in addition to the height of a structure (160m) gives 217.2m. The resulting maximum theoretical viewable distance would be 57km. DTI (2005c) guidance in relation to wind farms considers that effects are likely to arise when the nacelle becomes visible at the horizon, as it is debatable as to whether blade tips can be distinguished by the human eye at such long distances. Table 5.18 indicates the ‘worst case scenario’ of visibility for wind and marine renewable devices from a range of viewer heights which are available at the coast, or within 10km of the coast, around the UK.

Table 5.18 – Theoretical maximum viewable distance due to curvature of the earth

| Viewer height (m) | Viewable Distance (km) | | |
|---|---|---|---|
| | **Wind turbine nacelle (115m ASL)** | **Tidal stream structure (10m ASL)** | **Surface wave device (3m ASL)** |
| 1.7 (sea level) | 46 | 17 | 12 |
| 9 | 54 | 25 | 19 |
| 22 | 60 | 31 | 25 |
| 100 | 80 | 51 | 46 |
| 150 | 89 | 60 | 54 |
| 250 | 102 | 73 | 66 |
| 500 | 128 | 99 | 93 |

*Note: based on a turbine of 160m to blade tip with a rotor diameter of 90m (i.e. central nacelle height of ~115m). Lower values of 9, 22 and 100m are based on typical viewing heights stated in White Consultants (2009).*

At a project specific scale, seascape studies consider the zone of theoretical visual influence (ZTVI) around a development, which is the extent of the potential visibility of a development. Digital terrain models and GIS tools are utilised to perform this calculation which takes into account, amongst others, aspect, height and intervisibility. Such visibility is theoretical in the sense that it assumes no surface cover (e.g. trees and other tall vegetation, buildings, sea defences etc. – though field survey can be used to inform the process) and so has a tendency to overestimate the potential area impacted – a result of this being that if it predicts no visibility then there is no effect (DTI 2005c).

### 5.8.2.2 Haze and meteorological factors affecting visual range

The above methods of determining viewable distance and visibility fail to take into account haze and meteorological conditions. Visibility affected by haze is the barrier to visual acuity brought about by atmospheric aerosols (Husar & Husar 1998). In this case, the viewable distance can be taken to mean, 'the maximum distance at which an observer can discern the outline of an object'. Husar and Husar (1998) present the following formula for calculating such distances (shown here as modified in Scott *et al.* 2005):

$$v=c/e$$

(Where: $v$=visual range, $c$=constant determined by the threshold sensitivity of the human eye and the assumed contrast of visible objects against their background, $e$=extinction coefficient – a measure of how much haze is in the air). Table 5.19 indicates the maximum likely viewable distance at which the outline of an object can be made out given a range of UK specific coefficients. Scott *et al.* (2005) point out that this visual range is not the same as visual significance, though it will influence significance. The acuity of an individual's eye and the number, form and lighting of viewable objects will vary this distance (Husar & Husar 1998).

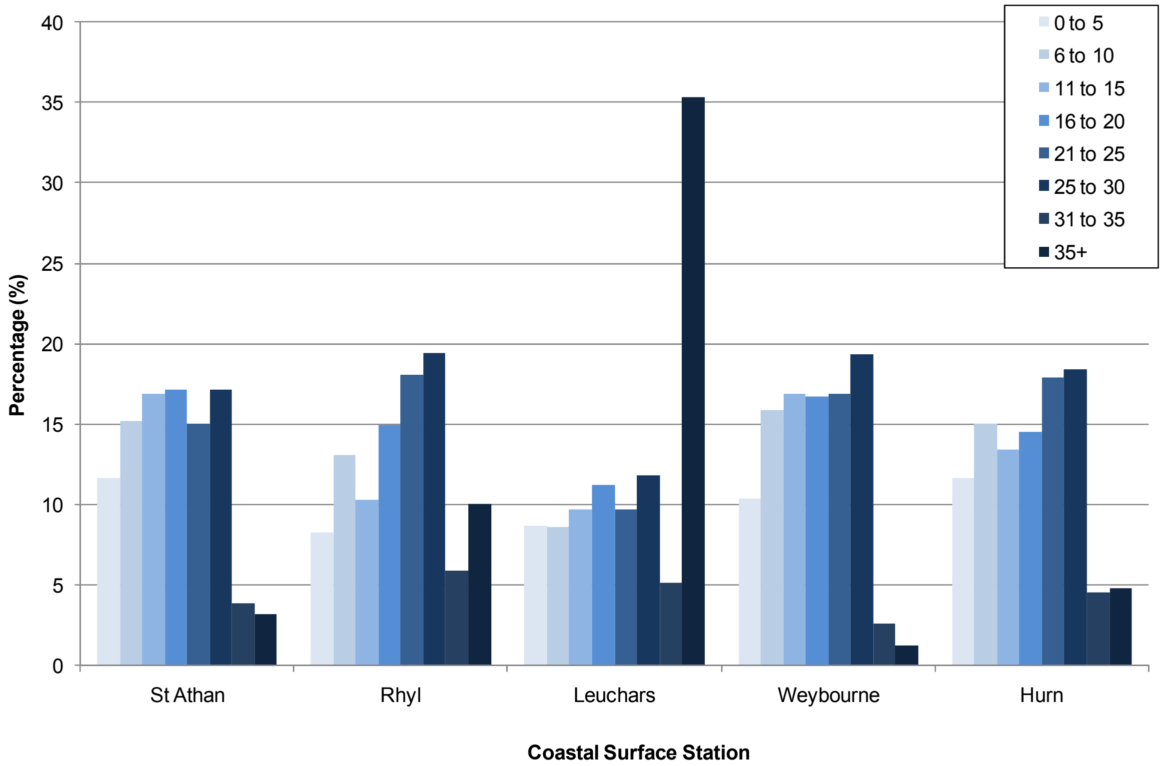
Table 5.19 – The influence of haze on viewable distance

| Applicable area and season | Haze coefficient (e) | Visual range (v) |
|---|---|---|
| Northern Scotland | 0.1 | 39km |
| Wales (spring and summer). Central and southern Scotland (summer to winter) | 0.15 | 26km |
| Central and southern England (spring). Central England, north and south Wales (winter). Parts of south- and north-east England (summer) | 0.2 | 19.5km |
| Southern England (winter) | 0.25 | 15.6km |

*Source: after Husar & Husar (1998). Assumes a 'c' value of 3.9 as recommended in Scott et al. (2005).*

The above calculation of haze filters out any meteorological phenomenon which might also affect visibility (e.g. rainfall, fog) and therefore represents clear visibility. Urban centres may be adversely affected more than rural areas due to greater amounts of particulate matter in the air (White Consultants 2009). DTI (2005c) recommend the use of Met Office visibility data to assess trends in conditions over a 10 year period for stations located landward of proposed wind farm sites. A review of Met Office visibility data for a number of coastal Met Office Stations by White Consultants (2009) for OESEA is summarised in Figure 5.32.

Figure 5.32 – Percentage incidence visibility (km) at coastal Met Office stations, 1999-2008




*Source: White Consultants (2009)*

### 5.8.2.3 Contrast, lighting and navigational markings

The atmosphere is thickest at the horizon and appears lighter there, darkening overhead. Structures which are white and light grey (typical of wind farms) will contrast least, though certain devices requiring high contrast navigational markings will contrast more. Tall structures may be silhouetted by sunset or sunrise (White Consultants 2009) and therefore certain viewing aspects are more greatly affected than others.

Lighting of renewables devices and other offshore installations must meet both Trinity House and CAA standards for marine navigation and aviation respectively. Navigation lights at the corners of wind farms must be visible for 9km, with intermediate ones at 3.6km, though it may be surmised that these lights could be viewable from a greater distance. Navigational aids for gas storage projects (e.g. Bains and Gateway gas storage) will utilise long-range lights, which Gateway Gas Storage (2007) state as having a range of 15nm (or approximately 28km). It is possible that marine navigation lighting may be viewable at the coast in clear night conditions particularly where other light pollution is absent and may therefore have greatest influence in rural areas. Those devices (typically tidal, though potentially also wave) which are completely submerged may still require identification buoys depending on their position in the water column, and these would have marine navigation lighting. With regard to wind farms, aviation lighting on the nacelle may appear to flash as turbine blades pass over them. CAP 393 Air Navigation: The Order and the Regulations Amendment 3/2008 issued by the CAA indicates lighting requirements are one medium intensity steady red light positioned as close as reasonably practicable to the top of the fixed structure, though some operators have opted for two lights. As the pace of rotational movement in each turbine may differ in any given farm, and the orientation of the blades for each turbine will be different, this may generate a sequence of irregular light flashes as the blades pass in front of the lights.

The MCA Marine Guidance Note 371 outlines considerations which need be taken with regard to operational safety and emergency response in areas used by offshore renewable energy infrastructure (OREI). The note contains a number of recommendations, including for design requirements. Issues outlined in this paper which may influence the appearance of devices from the shore and at sea include:

- Wind turbines should be individually marked with characters which can be identified at 150m from vessels or 500ft from aircraft overhead
- Identification characters should be illuminated but baffled to prevent excess light pollution
- High contrast markings at 10m intervals should be placed on both sides of wind turbine blades

### 5.8.2.4 Activity specific considerations

#### Offshore wind

DTI (2005c) guidance indicates that the limit of any significant effect on areas of moderate sensitivity can be considered at a distance of 30-35km offshore for offshore wind farms. If the results from Seascape and Landscape Visual Impact Assessments (SLVIAs) for Round 1 and 2 sites are considered, the average maximum distance at which low magnitude effects were assessed to occur was 32km (the maximum being 35.8km for Gwynt y Môr, North Wales). The exception to this is the Beatrice demonstrator in the Moray Firth, where low magnitude effects were calculated at a distance of 41km from the shore.

Table 5.20 indicates the likely maximum and average thresholds for low and medium magnitude effects based on previous project level seascape studies (e.g. SLVIA). Turbine size (MW) may be taken as a suitable proxy for site visibility, though the number of turbines will also have a significant effect.

Table 5.20 – Average and maximum distance at which low to medium magnitude effects may take place based on previous seascape studies

| | 2-3.6MW | 5-6MW |
|---|---|---|
| Average (Average) distance where medium magnitude of effect occurred | 11.2km | 17.5km |
| Average (Maximum) distance where medium magnitude of effect occurred | 12.8km | 17.5km |
| Average (Average) distance where low magnitude of effect occurred | 19.7km | 25.8km |
| Average (Maximum) distance where low magnitude of effect occurred | 24.4km | 34.4km |

*Note: These are based on a scenario with no other windfarms in visible view. Distances at closer proximity to the coast are provided for a scenario where other wind farms are considered.*
*Source: White Consultants (2009)*

The development scenario will vary for each individual wind farm; though the principal factors affecting visibility other than distance from the coast are lighting, turbine arrangement and individual turbine size. Initial results from a study of English seascape units draw the following preliminary conclusions about visibility based on three turbine sizes – these results must be viewed as indicative (Table 5.21).

Table 5.21 – Thresholds of significance for turbines of English seascape development scenario (at 22m asl)

| Turbine size | Height to blade tip | Height to nacelle | Threshold of significance for seascape units of high sensitivity | Threshold of significance for seascape units of medium sensitivity |
|---|---|---|---|---|
| 3.6MW | 137m | 83.5m | 18km | 13km |
| 5MW | 175m | 112.5m | 24km | 18km |
| 10MW | 190m | 115m | 24km | 18km |

*Note: Based on development scenarios of 50 (10MW), 98 (5MW) and 155 (3.6MW) turbines in a grid pattern separated by 550m.*
*Source: White Consultants (2009)*

## National and international experience in siting offshore wind farms

Windfarm siting in the UK has largely taken place at or within 8km of the coast, with a few farms (e.g. Dudgeon and Race Bank) being located over 20km from shore. Areas of the East Irish Sea off North Wales and Cumbria and the Greater Wash presently have the highest concentration of offshore windfarms in UK waters (see Figure 5.33 below). Turbine capacities of these farms generally range from 2-3.6MW, with a height to blade tip in the order of ~160m. The Round 3 leasing zones developed by The Crown Estate are generally outwith territorial waters (12nm or ~24km) and farms to be located in these are therefore likely to be less visible from the shore. The Round 2 SEA (BMT Cordah 2003) considered that seascape issues became significant within a distance of 8-13km, but that the distance from the coast at which development was acceptable varied due to differences in the quality of the seascapes being considered. Similarly, though made as part of a wider range of considerations relating to the possible impacts from offshore wind, it was recommended in OESEA (DECC 2009b) that developments should generally take place out with 12nm (~22km) from the coast (i.e. in offshore waters). Much like the recommendation made for Round 2, this was indicative and subject to a site specific consideration of seascape issues which may result in developments being more acceptable either closer to the coast, or further away. In addition to the Round 3 zones, a number of offshore wind demonstration zones (Aberdeen, Methil, Blyth and Gunfleet Sands extension) have been awarded by The Crown Estate most of which are located within 8km of the coast.

Siting offshore wind farms within 12.5km of the coast has been subject to local opposition in Belgium, which has led to the adoption of a wind farm zone beyond 12nm (some 22km) from the coast – a similar approach has been adopted by the Netherlands. Denmark has sited wind farms of limited size up to 20km from the coast, though more emphasis is given to public perception of turbine arrays rather than visibility, using public exhibitions held during the planning process. Some sizeable wind farms have been erected within viewable distance from the coast, for instance the Horns Rev 1 site which has 80 2MW turbines located just less than 20km from the Jutland coast. To the east, the Lillgrund wind farm lies between Denmark and Sweden and is highly intervisible between the coasts of both countries.

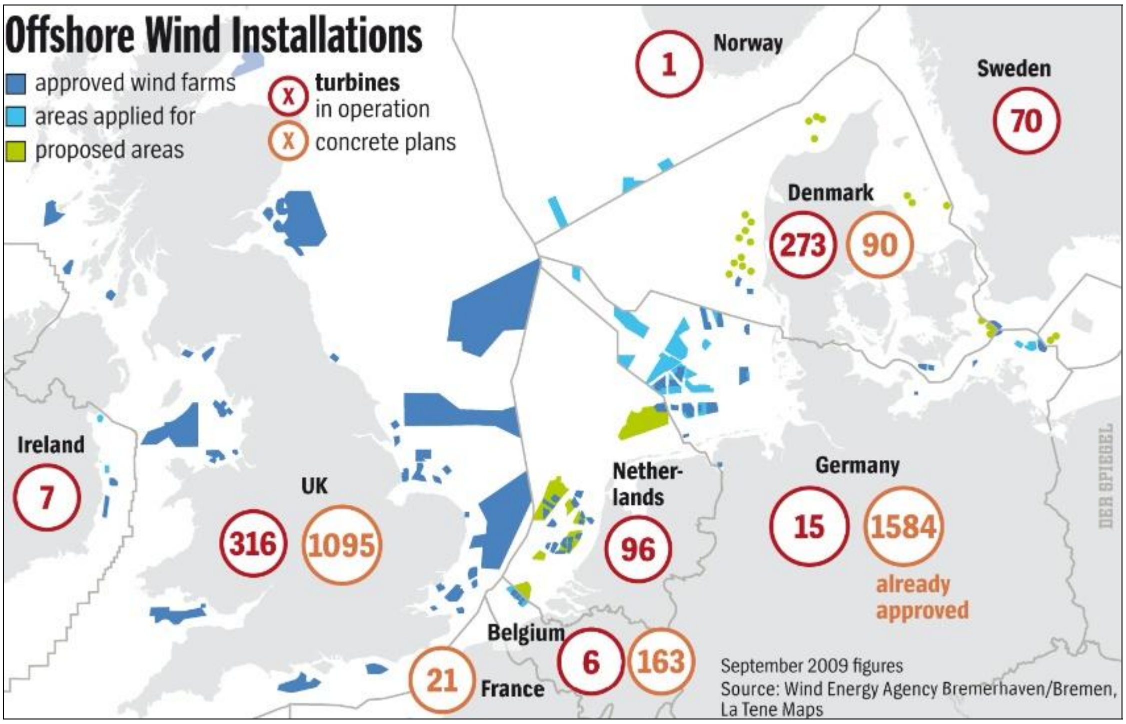
The deployment of offshore wind energy in Germany, in conjunction with other renewables, has increased considerably in recent years, towards a goal of achieving 15% of energy and 25% of electricity purely from offshore sources by 2025 (Portman *et al.* 2009). The first operational wind farm in German waters was the Alpha Ventus, a testing site 45km from Borkum Island. The site originally consisted of 6 5MW turbines, though has been upgraded to 12. There is in the order of 20 other sites for which approval has been granted and the first stages of construction are now commencing, and at least an equivalent number of sites are in the approval process. In Germany, seascape assessments are only required with developments within 50km of the coast. Of those projects mentioned above, almost all are at a distance of at least 35km from the coast, with the vast majority being further offshore than that, which should all but eliminate visual disamenities of turbines for shore based receptors, though will obviously change the character of the North Sea and Baltic Sea from passenger ferries, recreational craft and other commercial ships.

Figure 5.33 shows areas of European seas in which offshore wind farms/zones are presently operational, proposed or applied for. Considering all European countries, the average distance of offshore wind farms from the coast has been steadily increasing. Those farms installed in 2008 were on average 10.5km from the coast, rising to 12.8km in 2009, and if those under construction or approved are considered the average increases to 28.3km (Figure 5.34).

## Wave, tidal stream and tidal range

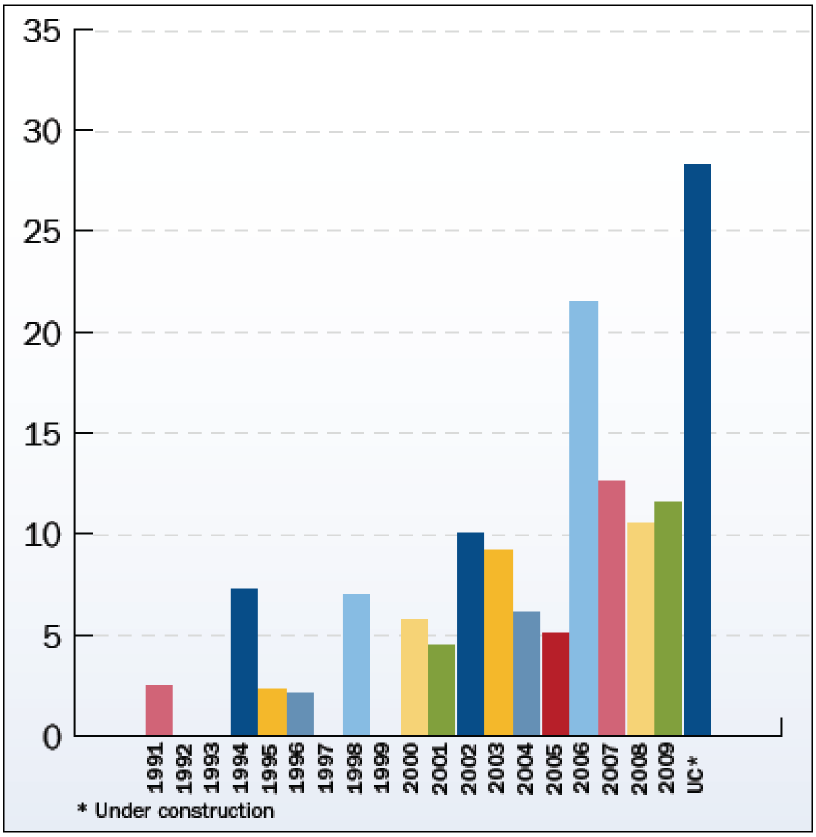
The draft plan/programme considered in this SEA would allow for the progression of leasing/licensing of areas of the seabed for wave, tidal stream and tidal range technologies that will introduce a number of new visual components into seascapes. Scotland has already completed a leasing round for commercial-scale wave and tidal devices in their territorial waters around Orkney and the Pentland Firth, with a further round proposed for locations around Shetland and the Inner and Outer Hebrides. Seascape studies currently available for such technologies include that for the Severn tidal barrage and lagoons and those contained within the SEAs for marine renewables in Scotland (Faber Maunsell & Metoc 2007) and Northern Ireland (AECOM & Metoc 2009).

Figure 5.33 – Offshore Wind in European waters




*Note: Though Round 3 zones are indicated as 'approved' wind farms, these are lease areas within which any number of developments may take place.*

Figure 5.34 – Average European wind farm distance to shore in km, 1991-2009




*Source: EWEA (2010)*

Very little work has yet been completed studying the impacts that wave and tidal devices may have on seascape. Indeed, the present demonstration phase of wave and tidal devices has led to a wide range of contrasting designs, the impacts of which will become more apparent as they progress towards commercial viability and are deployed in larger arrays. In an attempt to anticipate the level of impact a number of national scale studies for Wales, Scotland and Northern Ireland, have conducted assessments based on a few generic structure types (Table 5.22). The same assessment criteria for landscapes and seascapes as used previously for offshore wind will apply to these devices, and as such, site specific and device specific impacts will need to be considered at the individual development level. The smaller vertical component of open water wave and tidal devices will make them less obtrusive at a closer distance to the shore compared with offshore wind.

The Wales regional seascape study (CCW 2008b) considered the possible impacts from tidal current and wave devices of a scale and form thought probable in the next 10 years, with tidal stream represented by vertical columns projecting from the sea surface (10x3m), and wave by broad, flat objects (3x400m) – e.g. similar in form to the Seagen tidal and Pelamis wave devices. Seascapes generally displayed less sensitivity to the wave scenario than to the tidal one, though in both cases headlands and areas with restricted or focussed views (e.g. along estuaries) recorded high sensitivities. It should be noted that this exercise only looked at a single scenario for each technology (which were not well defined) and seascape unit, and the impacts of particular wave and tidal designs may differ significantly from these. Similar scenarios for wave and tidal devices were considered by the Scottish Government in its marine SEA (Faber Maunsell & Metoc 2007) and in the Northern Ireland offshore energy SEA (AECOM & Metoc 2009), though recognising that surface point structures may also be wave devices, (e.g. the Aquamarine clam).

## Table 5.22 – Generic wave and tidal structures and development scenarios for previous national level seascape assessments

| Generic device type | Wales | Scotland | Northern Ireland |
|---|---|---|---|
| Linear | Two rows of linear structures orientated either parallel or perpendicular to the coast, 400m in length and 3m high. | 2-3m in height above the water surface. Typical array of 4km$^2$. | 2-14m in height above the water surface. Arrays up to 6.5km$^2$ |
| Point | Single row of 10 structures angled to the coast consisting of towers 10m in height and 3m in diameter. | Typically protruding up to 10m above water surface. Up to 100 units occupying 3.2km$^2$. 30 unit tidal array may occupy 0.5km$^2$. | Height varies from marker buoys to 14m above sea surface. 50-100 devices occupying 1-2km$^2$. |

*Source: Faber Maunsell & Metoc (2007), CCW (2008b), AECOM & Metoc (2009)*

The Scottish study defined ten seascape ‘types’ which could be attributed to specific study areas, for which a sensitivity score was then attached for linear, point and shore connected structures. The study outlined that the least sensitive seascapes were those that offered open and expansive views, while those with a large vertical component were of moderate sensitivity. In keeping with CCW (2008b), Faber Maunsell & Metoc (2007) and AECOM & Metoc (2009) regarded linear wave devices to have less of an effect on broad, open seascapes compared with point structures, primarily as linear structures may follow the natural movement of the sea and be partially hidden by wave motion. The more enclosed and complex seascapes found in the sounds and fjords of Scotland’s west coast were regarded as having the highest sensitivity to wave and tidal devices. The reports further considered the potential significance of the effect at various distances from the coast (Table 5.23) based on visibility thresholds established through site visits to key areas.

Table 5.23 – Levels of visual significance derived for wave and tidal devices in Scottish and Northern Ireland waters

| Distance | Category | Magnitude of Change |
|---|---|---|
| 0-5km | High | Notable change in seascape characteristics over an extensive area |
| 5-10km | Medium | Moderate change in localised areas |
| 10-15km | Low | Small or imperceptible change in seascape components |
| 15km+ | Neutral | No discernible change in any seascape component |

*Source: Faber Maunsell & Metoc (2007), AECOM & Metoc (2009)*

Some devices such as the Openhydro open centre turbine are designed so that they have no surface component, and therefore visual impacts would be largely restricted to those occurring during deployment, monitoring and maintenance, and subsequent decommissioning, though any local substation would constitute surface infrastructure if it is required. Depending on the position of the device in the water column (i.e. whether it is at sufficient depth to be avoided by the draft of most vessels), these may be marked with buoys and navigational lighting (Faber Maunsell & Metoc 2007).

The Seagen tidal stream device in Strangford Lough, Northern Ireland, is an individual demonstrator project which is visible as a point surface structure, reaching 10m above sea-level. The Environmental Report for this development (Royal Haskoning 2005) indicated that the device would be visually obvious at all stages of development, which would affect views from land, particularly Portaferry, and the open seascape offered during ferry crossings. The requirements to use paints providing suitable contrast and lighting for navigation were highlighted as restrictions in making the device less visible, and that mitigation options were minimal. Visual impacts were considered most significant during maintenance as the turbine blades would be exposed above the water surface, though this is a temporary, but intermittent activity. Similar tidal stream devices are therefore likely to pose a transient visual impact proportional to the amount of time required for maintenance. Visual impacts present for the life of many submerged developments are therefore likely to be restricted to any local substation that may be required above water and associated landfall.

A seascape study was undertaken as part of the SEA for the Severn Tidal Feasibility Study (DECC 2008d, 2010r) in addition to that already completed for a hypothetical inner barrage between Lavernock Point and Brean Down by Land Use Consultants (2007a). Specific impacts (e.g. on individual AONBs, National Character Areas and viewing locations) for the Severn are presented in these reports, though only generic impacts are considered here as these may be more widely applicable to other estuaries considered for tidal range technologies in the UK. Barrages would alter the character of a given estuary due to land-use change associated with new infrastructure, for instance power cables and onshore development associated with the barrage (access roads and buildings), with significant effects predicted during construction and decommissioning (DECC 2010r). Any tidal barrage would be visible at all points in the tidal cycle and would block views in both directions on its landward sides. Secondary effects include the potential loss of intertidal habitat (and also associated fauna and flora), a reduction in the extent of intertidal areas at low tide, changes to water clarity and also shipping routes.

DECC (2010r) state that for the Severn tidal barrage, uncertainty surrounded what form intertidal areas would take following a change in sedimentation regime of the estuary, and how long it would take for such a new regime to become established. Therefore the consideration of landscape/seascape impacts of such structures is more complex than the more simplistic consideration given to other forms of offshore activity, and the Severn Tidal SEA recommended that local level, design stage visual assessment would be required to minimise impacts. Similar effects may be generated by lagoons, though some of these may be exacerbated at low tide as, depending on specifics of development design, more of the embankment structure would be exposed. Barrages may also be multi-use structures, incorporating a road crossing which could have its own street lighting that would be visible at night, in addition to the movement and lights of vehicles.

### Offshore oil & gas, gas storage and carbon dioxide storage

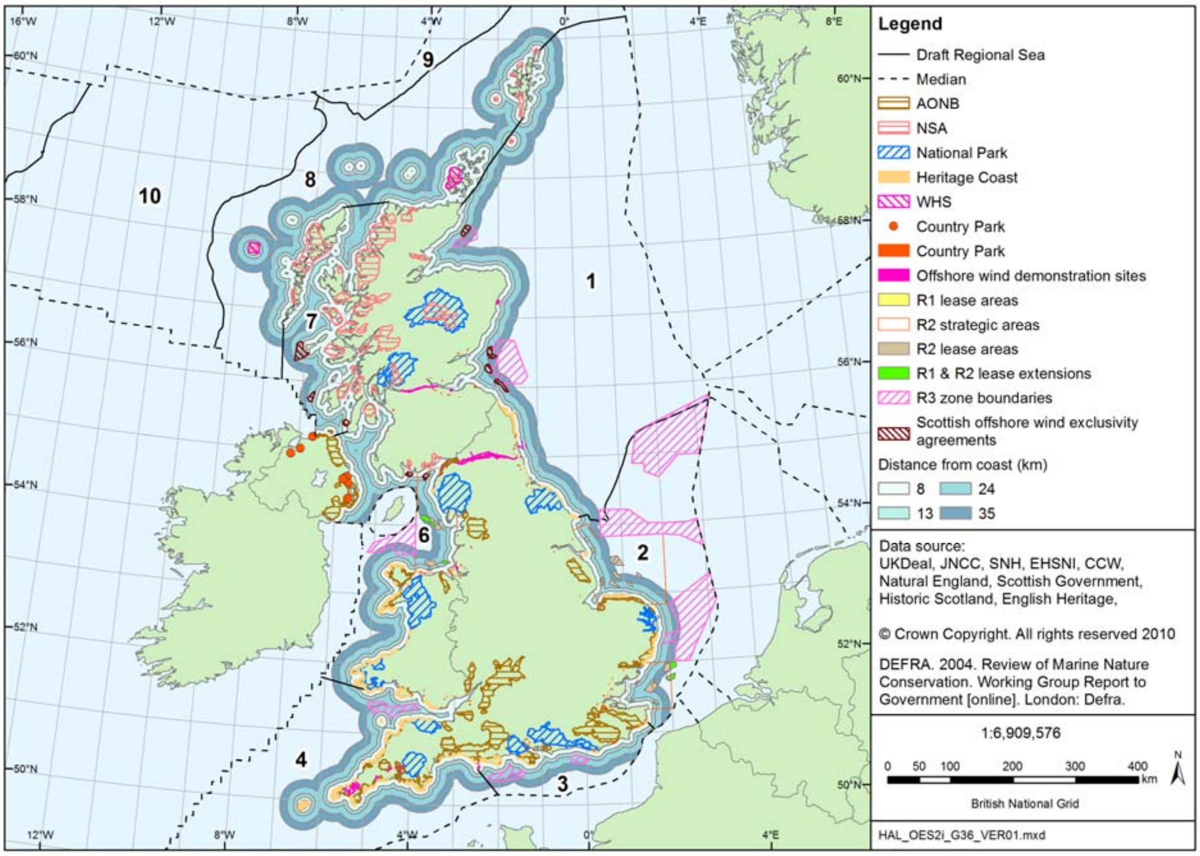
Carbon dioxide transport and storage facilities may have few visual components in the marine environment visible from coastal locations, and any associated structures may be restricted to the landfall of pipelines or increased, or new, port facilities at the coast and any associated tanker traffic. It is likely that 1 Government funded demonstration project will become operational towards 2020, though transportation infrastructure may be shared or clustered between other demonstration scale projects (DECC 2009e). Gas storage operations may have similar impacts, having both onshore and offshore facilities. A proposed facility in the east Irish Sea (Gateway Gas Storage) is the first development in the UK to use artificial salt cavern construction to provide gas storage capacity. The offshore facilities will lie 24km from the coast and comprise 20 wells, each with a monopod topside facility of dimensions 14x14m, reaching 50m above the seabed. It is uncertain whether this will be typical of the size, design and orientation of future developments of this type, and the results of the seascape study for this development (see Gateway Gas Storage 2007) may not generally be applicable to other locations, though provides an indication of how such facilities and offshore wind farms visually interact.

Though typically at some distance from the coast, a number of oil and gas facilities may be placed towards the coast in the near future. Many new oil and gas activities require only temporary surface infrastructure, as on completion many wells are tied-back to existing facilities. When this is not the case, longer term visual impacts may come in the form of jacket, semi-submersible or jack-up rig facilities, FPSOs, and transient support vessel and aviation traffic. At night, any flaring and lighting from support vessels and rigs may also be visible from shore.

### 5.8.2.5 Landscape or seascape ‘value’

Landscape value is assessed on the basis of the importance attached to a certain area because of natural or cultural qualities and these in turn are reflected in value ‘scores’ included in UK strategic level seascape studies (e.g. Scott *et al.* 2005). National landscape designations can be taken to represent a reasonably objective measure of such value. Figure 5.35 indicates the distribution of landscape designations around the UK in relation to shallow (<60m) waters and the indicative buffers and limit of visibility from the coast (as discussed above). There are a number of ways set out by the DTI (2005c) adopted from previous guidance, and utilised in the regional scale studies of Scott *et al.* (2005) and CCW (2008b) which attempt to identify through objective (and partly quantitative) means the sensitivity and ‘value’ of a particular coast or defined seascape unit.

Figure 5.35 – Designated landscapes in the UK in relation to wind leasing zones




## 5.8.2.6 Seascape sensitivity

Seascape sensitivity is defined as the inherent sensitivity of a landscape/seascape to any type of change, which is dependent on (Scott *et al.* 2005):

- Sense of scale
- Openness/scale
- Coastal and hinterland form
- Settlement pattern
- Seascape pattern and foci
- Movement
- Lighting
- Aspect
- Tranquillity/remoteness/wilderness
- Exposure
- How the seascape is experienced (Receptor sensitivity)

These factors are accounted for in each regional seascape study used in this section (Scott *et al.* 2005, CCW 2008a, b), and in a discussion of the English coast.

The ‘compatibility’ or degree to which an offshore development alters or harmonises with the character of a seascape in which it is observed, is largely determined by these sensitivity criteria, key considerations including how the form and scale of the development interacts with coastal morphology, and the level of development already experienced from coastal positions within viewable distance of the development. These characteristics are highly variable at the regional and local scale and are difficult to account for in a comprehensive manner at a strategic level.

The horizontal and vertical scale of the coast can influence the sensitivity of a seascape. Where the principal viewing platforms are across bays, inlets, sea lochs and inner firths, developments may take up more of the horizon and be framed by headlands, whereas more open, expansive views have the opposite effect (Scott *et al.* 2005). The apparent scale of intervisible aspects (e.g. coastal cliffs, mountains) may be diminished by turbines, as the scale of these is often not great but appears so due to the steepness of their slopes (Scott *et al.* 2005). Aspect influences structure visibility during sunset and sunrise, as they appear silhouetted against the sky.

Outside of scale, form, aspect and exposure, seascape sensitivity is greatly influenced by the level of coastal development, and this can be highly variable within regional scale seascape units. Urban and industrial settings, areas where other forms of mechanical movement are present (e.g. ships, cars), where artificial light is prominent, and where the observation points are from busy roads or beaches, may be considered more advantageous for development than rural areas. Where there is already considerable urban development however, cumulative impacts must also be considered (DTI 2005c).

Sensitivity is not just a measure of the compatibility of wind farms with coastal character, but also the users of that landscape. Examples of a range of sea and land based activities along a scale of sensitivity (for instance recreational boating to extractive oil and gas, and tourists/visitors to military and industrial users) are provided in DTI (2005c). The use of the coast for such activities may be relatively easy to define and measure, though the sensitivity of individuals is more complex.

Many of the factors influencing perceived aesthetic (landscape/seascape) quality are relative and subjective concepts which are bound by any given individual's attitude, perceptions, and *a priori* or *a posteriori* knowledge about offshore energy developments or indeed environmental/energy issues more generally. Prior knowledge or experience of offshore wind farms may take a variety of forms and Ladenburg (2009) found that (perhaps predictably) those people with experience of windfarms sited far from the shore were generally more positive about the visual impacts of future developments than those with experience of nearshore windfarms. Landscape preservation (and change), like many environmental issues, is an emotive topic. Attitudes range from romantic views of nature as unspoilt 'wilderness' to be preserved for its inherent landscape value, less anthropocentric 'deep ecology' ideas of humans as part of the natural ecosystem, or more recent 'wise use' ideas falling within the umbrella of sustainable development. In any case, the inherent quality or naturalness of some landscapes are valued more than others, as recognised in statutory designations and the landscape 'value' methodology employed in landscape/seascape studies.

Wilderness may often have more to do with perception than any ecological understanding, for instance GIS based research by Carver *et al*. (2002) attempted to identify and map wilderness based partly on perception as derived from public participation – the result is arguably a gradient of development. At a local level, perceptions may also be affected by prevailing or historical legislation and land ownership; for instance, access rights in England have always been restrictive, which helped to produce a public more constrained in their movements and range of permitted activities (Macnaghten & Urry 1998).

It is not just 'wild' places where visual intrusion is regarded as deleterious, for the countryside or cultural aesthetic may be regarded to be as important, for instance the recent attention given to 'Character Areas' which are assessed in the context of their natural (though more semi-natural) and cultural heritage qualities, and indeed for more recent urban qualities. Hedgerows are a key example of a largely relict countryside landscape component preserved for their cultural associations and ecological qualities, and the recognition of urban areas as distinct landscapes is highlighted in the European Landscape Convention, and by association with certain cultural World Heritage Sites (e.g. the Cornwall and West Devon Mining Landscape).

A Countryside Commission (1993) report indicated that over 60% of the UK public regarded the countryside as a vital component to their quality of life as opposed to the perceived 'stress and pollution' of cities (Macnaghten & Urry 1998), and given that over 80% of the UK population are urban dwellers (2001 census data, Pointer 2005) it may be presumed that for many people, experience of the countryside is an important occasional relief. Surveys of awareness and attitudes to renewable energy, specifically onshore wind (see DECC website), indicate that people are generally in favour of the use of renewables, including wind power, indicating that the general population perceives advances in renewables as necessary (possibly linked with perceptions, knowledge relating to climate change, depleting hydrocarbon reserves). Opinions on wind farm landscape issues can change during each stage of construction; for instance, a survey conducted for the Scottish Executive by MORI in 2003 found that 15% fewer people had concerns about landscape issues (27 vs. 12%) following turbine construction than in planning. Ladenburg (2009) notes a U-shaped change in attitude to offshore wind development, with attitudes being generally positive towards developments in the planning stage, with a general reduction in positive attitudes during construction, and a recovery following completion and operation.

## 5.8.3 Spatial consideration

### 5.8.3.1 Outline visibility assessment

Section 2.5 provides an indication of the prospectivity for each element of the draft plan/programme which gives an outline view of where activities are likely to take place on adoption of the plan/programme, and Section 2.5.4 outlines scenarios of the likely scale of activity that may be expected, on which the following discussion is based.

In the absence of any further assessment of landscape sensitivity to offshore development, it can be seen from Figure 5.35 that those areas least likely to generate significant visual intrusion are those to fall outside of the visible range of designated landscapes which may be surmised to have a high landscape/seascape 'value', and areas outwith 24km from the coast (i.e. a distance where devices are at the limit of visual acuity – particularly those devices with a low vertical component – and above which haze and meteorological conditions make it increasingly difficult to see significantly further). The 35km buffer represents an indicative maximum visibility threshold for most of the country based on the studies discussed above (notwithstanding those views from ferry and other sailing routes), though this is not necessarily as far as an individual may be able to see. In relation to wind, the Dogger Bank, parts of Hornsea and East Anglia Round 3 zones are well beyond the area of visual significance and development here would not be visible from any location on land.

The visibility of structures from the coast, or their intrusion on sites designated for their visual qualities, does not necessarily preclude development in planning (see: draft Energy National Policy Statement (EN-1) and draft Marine Policy Statement), and any consideration of coastal 'buffers' is too generalised an approach to take into consideration the many anthropogenic and natural variations along the coast and the variety of development scenarios which might take place (e.g. device type and design, array orientation). The application of indicative buffers is more useful at a strategic level, subject to development specific assessments being made.

Visibility of developments depends on the ability of people to access the coast. The *Marine and Coastal Access Act 2009* aims to create a coastal long distance route and open-air recreation areas around the English coast while balancing this need with environmental protection and coastal planning. A UK wide approach on access has been agreed with the devolved administrations of Wales, Scotland and Northern Ireland and therefore coastal access is likely to improve across the UK in the coming years. Currently in Scotland, the *Land Reform Act 2003* permits responsible access to coastal and inland areas, and anywhere where the coast is accessible to the public may be a viewing platform to the open sea. The *Countryside and Rights of Way Act 2000* enables public access on foot to the countryside in Wales. Improvements in access to the Welsh coast is expected in the coming years as a £1.5m grant was awarded in 2007 to coastal local authorities to improve coastal paths and access. In Northern Ireland, access to the countryside is controlled by the Access to the Countryside (NI) Order 1983, under which district councils may identify recreational routes and areas of open-air recreation.

## 5.8.3.2 Regional Sea 1

The English section of Regional Sea 1 has not currently been assessed for seascape sensitivity, though White Consultants (2009) have defined 11 seascape units for this area (see Appendix 3c). The results of the Scottish study by Scott *et al.* (2005) are summarised in Table 5.24 and these are used to generate a synthesis for the sensitivity of the Scottish coast below. The most likely renewables devices to be deployed in Regional Sea 1 are wind turbines. Though other wet renewables may be installed in Scottish territorial waters, these are not considered in this plan/programme. Oil & gas structures are typically located too far from shore to be perceptible, though a number of blocks were awarded in the last offshore oil and gas licensing round in close proximity to the North Yorkshire coast, and so activities associated with exploration and development may reasonably be expected to take place in this area in years to come should economic reserves be identified. Landfall associated with any gas storage, unloading or carbon dioxide transport and storage projects may locally affect certain areas. Teesside and Tyneside are centres of high $CO_2$ emissions, and may therefore be prime locations for CCS demonstration. Their proximity to the North Sea is also advantageous, as extensive existing oil and gas infrastructure exists which could be used for $CO_2$ transport and storage on depletion of hydrocarbon reserves (see Appendix 3b).

A high value score may be expected for the stretch of coast from Flamborough Head to the Scottish border due to the combination of Heritage Coasts (e.g. North Yorkshire and Cleveland, Flamborough Head, and North Northumberland), a National Park (North York Moors) and World Heritage Site (Hadrian's Wall). A number of National Trails traverse the area including the Cleveland Way and Yorkshire Wolds Way on which people would be primarily expecting wild and natural views across the land and sea. These paths are likely to be augmented with access (paths and recreation areas) to be created by Natural England under the *Marine and Coastal Access Act 2009*.

Cliffs along the coast between Flamborough Head and Saltburn-by-the-Sea reach between 100 and 150m, affording views over a wide open seascape, and though possibly viewed by few from these elevated locations, sunrises would silhouette turbine or other structures against the sky and make them more visible. On clear nights, navigation or aviation lights may be seen from the coast. The rugged coastal form, small coves, bays and coastal towns and fishing villages of the North York Moors area and the lightly settled area of the Yorkshire Wolds may not be compatible with the developed character of wind turbines or rig structures. In contrast, offshore infrastructure may be compatible with the Tees and Tyne, and Wear lowland areas which are highly developed low-lying coasts with extensive urban and industrial developments.

To the north of the Tees lowlands area, Magnesian Limestone has formed a varied line of bays and headlands – erosion has generated features such as caves and stacks, increasing the complexity of the coast. Highly visible offshore structures may detract from the complexity and the unique, incised gorge-like coastal denes, particularly where views are focussed down enclosed denes. Further north, the Northumberland coastal plain is sparsely populated and rural, and the coast affords wide open views to the east from both elevated hard-rocked cliffs in the north and soft low-lying coasts to the south.

The coast from the English border to the Firth of Forth affords wide open views to the sea from a generally linear coastline. Existing development and transport infrastructure already give a developed character in places and busy shipping lanes are present in the sea. The perception of exposure would connect to wind energy, but may conflict with the scale and character of traditional settlements and the dramatic coastal edge which exists in some sections of coastline. The scale of the outer Firths of Forth and Tay may be compatible with turbine structures, and would have only minor impacts on flatter land profiles, though may detract from the focus of the firths and views east out to the open sea. Distinctive islands/hills of the Forth form a focus which may be disrupted by turbines and careful siting would therefore be necessary. The firths have some industrial elements which may reduce their sensitivity to any proposed development. There is the potential for cumulative effects to occur with regard to offshore wind in the outer Firths of Forth and Tay, as a number of the Scottish exclusivity areas are located within territorial waters (i.e. within ~24km of the coast), and are adjacent to the Firth of Forth Round 3 leasing zone.

The east coast of Scotland attains low value scores (Scott *et al.* 2005) due to the paucity of statutory designations which amount to just two – the Dornoch Firth and Fair Isle National Scenic Areas. There are also Local Landscape Designations (Areas of Great Landscape Value or Special Landscape Areas) which stretch around Fraserburgh Head from Peterhead to Cullen, in the outer Dornoch Firth and parts of the Caithness and Rosshire coast though these are not regarded with the same weight as National Scenic Areas. A map recently produced by SNH (2010) showing the relative 'natural heritage' sensitivity of Scotland also depicts the North East of Scotland as being of low value compared to the west, and north of Inverness, though coastal areas around Fife achieve high values.

The coast north to Aberdeenshire has few large scale industrial features and the area has locally distinctive and natural coastal attributes. The simple landform, relatively linear coastline, general absence of focal features and expansive scale of the sea are key factors in limiting sensitivity to development. Turbines would need to be carefully sited to avoid intrusion on the setting of settlements. Similarly, the Moray coast has simple landform, general absence of focal features and wide open sea views which may limit sensitivity to development. Wind energy may affect the perception of this seascape unit where settlement is small scale and largely of a 'traditional' or 'historic' nature.

Any development in the Moray Firth is likely to have some visual impact on the coasts of the outer firth. The Beatrice demonstrator seascape study concluded that the average distance at which low magnitude effects occurred was 30.3km from the coast, extending to a maximum of 41km – the area where the water depth is shallowest (<60m) lies between 22 and 35km from the northern coast of the firth. Turbines may have less of an impact in the open expanse of the Outer Firth, though could detract from the focus of the Firth. The existing Beatrice wind demonstrator and oil platforms may reduce the sensitivity of this seascape to further offshore wind development, though care would need to be taken not to generate significant cumulative effects (e.g. between the Moray Firth Scottish exclusivity and Round 3 leasing areas). In the last ($26^{th}$) seaward licensing round for offshore oil and gas, a number of blocks were awarded in the Moray Firth in close proximity to the coast. Any activity in this area may contribute to the generation of cumulative effects with other offshore developments. With regard to carbon dioxide transport and storage, the Scottish Carbon Capture, Transport and Storage (CCTS) Development Study includes a work package to assess the capacity, technical feasibility and commercial viability of the Captain Sandstone in the Moray Firth for long term carbon storage. Though in the early stages of study, development in this area could generate incremental visual effects should new offshore infrastructure be required.

Appreciation of the East Caithness and Sutherland coast hinterland would likely not be adversely disrupted due to its simplicity of form and limitations of views inland. The expansiveness and exposure of the open sea may accommodate turbine structures, but would also introduce an additional industrial and illuminated feature into this seascape where the Beatrice and Jacky oilfield platforms can be seen from land by day and night, though are at some distance from any viewable location. This may further affect the perception of this area as being remote and 'undeveloped'. Turbines could also potentially visually conflict with the scale of small traditional settlements and the narrow coastal shelf if located too close to the coast.

The open and expansive seascapes viewable from Shetland's coast may be compatible with the scale of any wind farm development, though they may affect the intricate land/sea relationship and views of outlying islands including Fair Isle and the appreciation of the vertical scale of high cliffs where these are present. The nature of wave and tidal developments (e.g. surface piercing or fully submerged, requiring navigation lighting etc.) will determine their impact on seascape. The perception of remoteness and 'wildland' qualities of some coastal areas and the highly natural character of the outlying islands may also be affected by development.

## Forces of landscape change

For some areas such as the Firth of Forth and Firth of Tay, urban expansion is unlikely to significantly alter the sensitivity of the landscape. Onshore wind developments in the Grampian and Highland areas have the potential to generate cumulative effects with offshore developments, and a number of onshore, coastal wind farms are now operational (e.g. Boulfruich). There may be cumulative effects in relation to the Beatrice wind demonstrator and oil platforms if there is intervisibility between developments. Certain Round 3 zones are in close proximity to the Scottish exclusivity areas, for instance in the Moray Firth and Firth of Forth, and there is considerable potential for cumulative visual effects between developments at these locations both from coastal viewing points and at sea. Increased use of the seas around Shetland for aquaculture may visually conflict or generate in-combination effects with offshore energy developments.

Table 5.24 – Summary of landscape/seascape assessment for Regional Sea 1

| # | Area | Seascape character type | Sensitivity | Value |
|---|---|---|---|---|
| 1 | Berwick upon Tweed | Mainland Rocky Coastline with Open Sea Views although a small area of Remote High Cliffs encompasses St Abbs Head. | Low/Medium | 1 |
| 2 | Firth of Forth | Outer Firths, Developed Inner Firths | Medium | 1 |
| 3 | East Fife/Firth of Tay | Deposition Coastline with Open Views, Outer Firths, Less Developed Inner Firths. | Medium | 1 |
| 4 | North East Coast | Mainland Rocky Coastline with Open Sea Views/Deposition Coastline with Open Sea Views. | Low/Medium | 1 |
| 5 | North Aberdeenshire/ Morayshire coast | Mainland Rocky Coastline with Open Sea Views/Deposition Coastline with Open Views. | Low/Medium | 1 |
| 6 | Moray Firth | Outer Firths and Smaller and Less Developed Outer Firths. Less Developed Inner Firths and a small area of Developed Inner Firths. Deposition coastline with Open Sea Views occurs in Golspie. | Medium | 1 |
| 7 | East Caithness and Sutherland | Mainland Rocky Coastline with Open Sea Views and a short section Deposition Coastline with Open Views and Narrow Coastal Shelf. A small area of Remote High Cliffs occurs on the north eastern tip of Caithness. | Low/Medium | 1 |
| 8 | North Caithness/Pentland Firth | Remote High Cliffs with Mainland Rocky Coastline with Open Sea Views, occurring to the east. Small areas of Deposition Coastline with Open Sea Views are also present. | Medium | 1 |
| 33 | Shetland | Islands, Sounds and Voes with small areas of Remote High Cliffs. | Medium/High | 1 |

*Notes: **Wind**: development scenario of 100 turbines, 150m to blade tip, 8km from the shore in a grid covering 25km$^2$. Visibility based on 10km landward, 35km seaward buffer.*
*Value scores range from; 1=Low value, 5=High value*
*Source: Scott et al. (2005)*

### 5.8.3.3 Regional Sea 2

A number of Heritage Coasts recognise the value of this section of coastline, and include Flamborough Head, Spurn Head, and the Norfolk and Suffolk Coasts. In Norfolk and Suffolk these coincide with the Norfolk and Suffolk Coasts and Heaths AONBs and the Broads National Park.

Cliffs are only present along Holderness, North Norfolk, Flamborough Head and the Thanet coastline. Most of these cliffs are soft and eroding, but all provide wide, expansive views of the North Sea. The variation in local cliff height will alter the viewable distance of the observer, though if infrastructure is sited sufficiently offshore this should not significantly influence the impact of a development, though at night aviation lights may be more visible from higher ground. Water depths of <60m extend well offshore from the Holderness coast so wind farm development is possible where any visual impacts are likely to be only experienced by people on passenger ferries, recreational craft and commercial and fishing vessels. In the last (26th) seaward licensing round for oil and gas, a number of blocks were awarded in close proximity to the Holderness coast and so activities associated with oil and gas exploration and development may be reasonably expected within viewable distance of the coast in the coming years. Views from the coast here will be large scale and open, with the exception of the Humber, though the industrial nature of much of this area may be compatible with offshore structures. Open, eastern facing views may mean that there is a strong contrast between structures and the sky during sunrise.

Extensive areas of saltmarsh are present in the Humber and Wash Estuaries, and these provide low, open and simple landforms which may be incompatible with vertical turbine structures. Numerous smaller examples are located in estuaries draining the outer Thames in Suffolk, Essex and Kent (e.g. Medway, River Stour), and views may be focussed down some more enclosed estuaries. Any tidal range schemes which incorporate a barrage will alter such focussed views by generating a visual barrier to the open sea, having associated access roads, surface infrastructure, lighting, and the light and movement of vehicles. This may amount to a substantial change in the character of such areas. Individual tidal stream devices would be less of a visual intrusion, though may still require navigational marking and lighting.

The vast open views of the North Sea afforded from Norfolk, Suffolk, Essex and Kent coasts are likely to reduce the perceived visual intrusion of any wind farm or other offshore development. Cliffs tend not to be high, and their scale may be further diminished by large turbines. The coastline is made up of a combination of cliffs and low-lying shingle, sand and saltmarsh, and where these views are simple and horizontal; they may be undesirably interrupted by the vertical form of certain offshore structures. The development in this area is largely rural and existing developments (e.g. Sizewell and Bradwell nuclear power stations) are extremely visible in this very flat and open landscape. There are a number of industrial centres which may decrease the sensitivity of this part of the coast.

There are numerous coastal urban areas along the coast though many are small or holiday resorts (e.g. Great Yarmouth, Cromer, Skegness) rather than industrial towns. The low-lying Broads back onto the coast near Great Yarmouth and are a visually intricate landform which will increase the sensitivity of this section of coast to offshore structures. The largest and most developed areas are Hull and Greater London which include gas terminals, oil refineries, chemical engineering industries and various coal and nuclear power stations (e.g. Sizewell). Holiday resorts may have less capacity to absorb the visual intrusion of offshore structures than these more industrial areas. The Thames and Humberside are areas which have high $CO_2$ emissions, and as a result may be sites chosen early either in the demonstration of CCS, or its later commercial scale deployment assuming that it is proved to be economically and technically viable. Onshore developments may include those used for gas compression, or increased port activity and gas offloading – uses which are broadly comparable and compatible with activities already taking place here. The proximity of relevant geology for $CO_2$ storage also makes Regional Sea 2 a highly prospective area for CCS demonstration (see Appendix 3b), and any offshore infrastructure associated with this has the potential to generate cumulative or incremental effects in a region which is already extensively used for other marine activities (see Appendix 3h).

## Forces of landscape change

Pressures come in the form of further industrial and urban development around Hull and the Thames, and there is limited pressure from caravan, theme park, golf course and water sport development. There is a continuing spread of holiday resorts and homes (e.g. around

Cleethorpes, between Mablethorpe and Skegness). Beach nourishment and coastal defence and other engineering is altering the physical form at a number of locations along the coast which may continue in the future and the coastal squeeze of mudflat areas is likely to be exacerbated by any sea-level rise. In some other places, cliff erosion (e.g. Holderness, North Norfolk, Suffolk Coast) will continue to change the form of the coast. Some coastal areas have developed onshore wind energy sites (e.g. Out Newton, Humberside and Conisholme Fen). These, and any subsequent developments, could generate cumulative impacts if there is sufficient intervisibility of onshore and offshore structures.

#### 5.8.3.4 Regional Sea 3

The value of the Regional Sea 3 coast varies from east to west, with progressively more designated landscapes or features of natural and cultural importance to the west. Potential offshore wind farm development areas and tidal resources are primarily in the waters of the central and eastern English Channel but may be curtailed by the presence of major shipping lanes for vessels transiting the Channel.

Between Dover and Beachy Head, the coast includes elements of the Kent Downs, High Weald and Sussex Downs AONBs and the South Foreland, Dover-Folkstone and Sussex Heritage Coasts in addition to numerous country parks within 10km of the coast. These designations afford the landscape a high value where they meet the coast, and the North and South Downs Ways provide access to coastal cliffs at Beachy Head and between Dover and Folkstone, frequented by people seeking the views of the accompanying AONBs. Dover and Folkstone are urban areas which may be compatible with offshore structures, though the elevation of the landscape around the towns, which includes cliffs and high ground in excess of 150m, will increase the viewable distance and may diminish the scale of the cliffs if they are intervisible with developments. The potential impact of wind turbine lights and movement may be reduced due to the lights of the French coast and busy shipping traffic, though development here is probably not likely given that UK waters only extend to ~13km from the coast.

Further to the west, the Dungeness Foreland and Romney Marshes are low lying, with coasts affording expansive views across the English Channel. The coastal strip has numerous 20th century developments, and includes industrial elements such as the Dungeness nuclear power stations which may make the coast less sensitive to additional components with an industrial character. To the west of the Foreland, the Saxon Shore Way travels along a rugged, cliffed coast towards the town of Hastings which has low lying, open views out to sea. Hastings, Bexhill and Eastbourne are large urban centres, but are also tourist destinations and retain a largely non-industrial character which may be compromised by offshore structures.

The area off Hastings is likely to interact with two contrasting landscapes. There are a number of designated areas including the Sussex Downs AONB, the proposed South Downs National Park and the Sussex Heritage Coast. The coastal sections of these designations suggest low to moderate impacts from the developments with 5MW turbines between 13 and 24km offshore. Beachy Head has an extensive chalk cliffed area reaching heights in excess of 100m, and includes the distinctive Seven Sisters landform. The elevation of the cliffs will not only increase viewable distance, but may not be compatible with the scale of some developments. In addition, the relatively rural nature of the area around Beachy Head and the presence of the South Downs Way mean that people wishing to perceive a ‘wild’ part of the countryside may be impacted. This area contrasts markedly with lower and more developed urban areas along the coast including Brighton, Littlehampton and Bognor Regis.

Further west, designations include the Tennyson and Purbeck Heritage Coasts, the Isle of Wight and Dorset AONB sites, the New Forest National Park and the Dorset and East Devon World Heritage Site – these extend from the Isle of Portland to the Isle of Wight. People on the relatively rural stretch of coast from Weymouth to Bournemouth, which includes the South West Coastal Path, are likely to be impacted by offshore developments. Some of the coast along the same route reaches elevations of up to 150m, increasing the viewable distance. Larger developments may diminish the scale of these cliffs though they should be sufficiently offshore for this to be negligible in views from land to sea, but not sea to land or on certain cruising routes. This area of coast is quite complex, with enclosed views through The Solent and out from Weymouth Bay. The urban settlements of Weymouth, Bournemouth, and Portland Island and Harbour may be less sensitive to offshore infrastructure due to the level of development in these areas.

A number of other potential offshore developments may take place in the west of Regional Sea 3 in the coming years. A number of blocks were awarded in the last offshore oil and gas licensing round which adjoin the coast spanning an area from the Isle of Wight, almost to Portland. Tidal stream energy may be viable to the south of the Isle of Wight, and tidal power is also of moderate intensity to the south of Portland Bill. Submerged or partly submerged devices could be viable in these locations, with visibility determined by their design and requirements for navigational markings. Should such devices have a surface component, it will be relatively small (e.g. at the most 10m as suggested in Faber Maunsell & Metoc 2007) compared to offshore wind, though it is likely that these devices will be in close proximity to the shore. Should wind, tidal and oil and gas developments take place in the west of Regional Sea 3, there is the potential for cumulative visual impacts to develop.

#### 5.8.3.5 Regional Seas 4 & 5

The Regional Sea 4 coastline contains a dense array of landscape designations including the Dorset, East Devon, South Devon, Cornwall, Isles of Scilly, North Devon and Quantock Hills AONBs, Exmoor, Dartmoor and the Pembrokeshire Coast National Parks, part of the Dorset and East Devon Coast World Heritage Site and the Cornwall and West Devon Mining Landscape World Heritage Site. Numerous Heritage Coasts are also present in both England and Wales, and the South West Coast Path and Pembrokeshire Coast Path make the coast easily accessible to the general public. The combination of these elements provides an indication that the seascapes of this Regional Sea have a high landscape/seascape value.

Low and high cliffs continue to dominate the coastline all around the South West Peninsula to the inner Severn to around Burnham-on-Sea, where the elevation of the land near the coast diminishes. Much of this cliffed coastline is rural and sparsely populated, and the South West in general is considered to be one of the most tranquil areas in the country (Countryside Agency 2006). The high coastline affords wide and expansive views out to sea from the coast including Lyme Bay, between Falmouth and Bigbury bays, and out from Mount's Bay, and the scale of these views may decrease sensitivity to development. Any development between the Isles of Scilly and the South West Peninsula would interfere with views to and from the islands and would be incompatible with the rural and complex form of the isles.

Urban population centres include Plymouth and Falmouth, and though such areas are generally considered more compatible with offshore developments than rural coasts, the natural complexity of their setting may be disrupted by offshore structures. Indeed views may be focussed down The Sound, Plymouth, and Carrick Roads into Falmouth Bay. Other Urban areas include Cardiff and Bristol in the inner Severn. Towns such as Lyme Regis, Seaton, Beer and Bude are traditional and rural in nature which may not be compatible with the scale and form of large offshore structures. The northern Cornish coast also includes numerous dramatically sited ruins from 19th century mining buildings to Tintagel Castle, and the coast here in general has a visually complex geomorphology. Tourist centres such as Torbay and Torquay and Newquay have a distinctive character, and high surrounding cliffs and some small islets, the scale of which may be diminished by offshore developments. Views may be filtered down the Axe, Exe and Teign, and make turbines or other offshore structures a focus of attention on the horizon.

The Bristol Channel has surrounding coasts in England and Wales. Landscape value here is recognised in the Hartland, Lundy, North Devon, Exmoor, Glamorgan, Gower and South Pembrokeshire Heritage Coasts; North Devon and Gower AONBs and the Exmoor and Pembrokeshire coast National Parks. Unlike most other areas, the Bristol Channel is viewable from almost all sides from high cliffed coasts. Large developments may interfere with views across the Bristol Channel and down the Severn, where turbines would be silhouetted against sunsets. Views from Devon and Cornwall to Lundy Island may be compromised by developments in the offshore parts of this area (e.g. in the Bristol Channel Round 3 zone), and the rural undeveloped and often secluded nature of much of the coast in this region may clash with the industrial character of offshore structures. The Severn has already been subject to SEA for a feasibility study of tidal range options including two possible barrage structures and a number of tidal lagoons, and the visual impacts of these may be found in DECC (2010r). The Government concluded that it did not see a strategic case at present to bring forward a tidal energy scheme but wishes to keep the option open for future consideration. Therefore no cumulative effects with such structures are envisaged within the next 10 to 15 years.

The wave resource in the South West Approaches may lend itself to the deployment of wave based marine renewables. The WaveHub project developed in association with the SWRDA was installed in 2010, which consists of a seafloor interconnector for the demonstration of wave devices. These are likely to generate a short term and small scale visual intrusion as devices of various designs are tested. In the longer term, wider installation of devices which are deemed to be technically feasible may be a potential source of visual effect, though Welsh, Scottish and Irish studies found that such devices tended to have less of a visual impact than wind or tidal devices with sea surface components. Any impact would depend on the local characteristics of the coast and the distance from shore that any devices are placed. Floating devices are not so contingent on water depth as those requiring fixed foundations, and so may be placed further offshore where the wave resource is better, negating coastal visual impacts.

Table 5.25 indicates the relative sensitivity and value of seascape units identified by CCW (2008a) for the Welsh coast.

## Table 5.25 – Summary of landscape/seascape assessment for the Welsh coast relevant to Regional Sea 4

| # | Area | Seascape character type | Sensitivity | | | Value |
|---|---|---|---|---|---|---|
| | | | Wind | Wave | Tidal Stream | |
| 36 | Skomer Island to Linney Head | THMR, TSLD | Medium/High | Medium | Medium/High | 5 |
| 37 | Milford Haven | EHMR, EHMU, EHLR | High | High | Low/Medium | 4 |
| 38 | Linney Head to St Govan's Head | THMR | Medium/High | Medium | Medium/High | 5 |

| # | Area | Seascape character type | Sensitivity | | | Value |
|---|---|---|---|---|---|---|
| | | | Wind | Wave | Tidal Stream | |
| 39 | St Govan's Head to Old Castle Head | THMR | Medium/High | Medium | Medium/High | 4 |
| 40 | Old Castle Head to Giltar Point/Caldey Island | THMR | Medium/High | Medium/High | Medium/High | 3 |
| 41 | Giltar Point to Pembrey Burrows (Carmarthen Bay) | THMR, THMU, TSLD | Medium | Low/Medium | Low/Medium | 2 |
| 42 | Taf, Tywi and Gwendraeth estuaries | EHMR | High | High | Medium | 1 |
| 43 | Loughor Estuary | ESLR | High | High | Medium | 2 |
| 44 | Whiteford Point to Worms Head-Rhossili Bay | THMR | Medium/High | Medium | High | 5 |
| 45 | Worms Head to Mumbles Head-South Gower | THMR | Medium/High | Medium | High | 4 |
| 46 | Mumbles Head to Porthcawl Point (Swansea Bay) | THMR, TSLU, TSLD, THIU | Medium | Low/Medium | Low/Medium | 1 |
| 47 | Porthcawl to Nash Point | THMR, TSLD, THIU | Medium | Low/Medium | Medium/High | 1 |
| 48 | Nash Point to Lavernock Point | THIR, TSLU | High | Medium | Medium | 1 |
| 49 | Lavernock to Gold Cliff | TSLR, TSLU, THMU, THIR | High | Low/Medium | Low/Medium | 1 |
| 50 | Gold Cliff to Chepstow | TSLR | High | Medium | Medium | 1 |

*Key: T=Tidal, L=Tidal current – lateral, E=Enclosed estuary or ria, H=Hard rocked coastline, S=Soft coastline, I=High (>100mAOD 250m inland), M=Medium (25-100mAOD 250m inland), L=Low (<25m 250m inland), R=Rural, U=Urban, D=Dunes*
*Notes: **Wind**: wind farm development scenario of many parallel turbines (160m to blade tip) at 550m intervals, 13km from the shore. **Wave:** 2 rows of linear objects 500x3m at 500m intervals 5km from the shore. **Tidal Stream**: 1 row of surface point structures 10x3m, at 60m intervals 0.75km from the shore.*
*Visibility is based on a landward and seaward buffer of 24km.*
*Value scores range from; 1=Low value, 5=High value*
*Source: CCW (2008a, b)*

### Forces of landscape change

Tourist pressure continues to increase in the South West with more facilities, caravan parks, golf courses, marinas and holiday and retirement homes. In some cases, tourism has generated the sprawl of small coastal settlements. Defence works on the Isles of Scilly and elsewhere are likely to become a priority if sea-levels rise in coming years. There is continuing pressure for onshore wind farms and therefore any offshore structures should be considered in relation to these to avoid any cumulative visual effects.

## 5.8.3.6 Regional Sea 6

Designations relating to landscape value include NSAs in the Solway (Nith Estuary, East Stewartry Coast) and in the Firth of Clyde (Arran, Kyles of Bute). The Hadrian's Wall World Heritage Site, St Bees Heritage Coast and the Lake District National Park feature on

England's coast. Numerous Heritage Coasts are found in Wales (e.g. Ceredigion Coast, Great Orme) as well as two National Parks (Snowdonia, Pembrokeshire Coast).

Any offshore turbines located in the Firth of Clyde and the nearby sounds would significantly alter the seascape. Views to and from the Mull of Kintyre, Arran and Isle of Bute and the mainland would be compromised by turbines, and high offshore structures would diminish the scale of islands, hills and high coastline. Turbines would be the focus of any views down the sounds into the outer Firth which would not be easily accommodated by the largely undeveloped nature of the coast. To the south, the Ayrshire and Galloway coasts have larger more expansive views which may more easily accommodate turbine structures, though the coast is sparsely settled and largely rural here.

The coast of England in Regional Sea 6 varies from saltmarsh (e.g. Wyre Estuary) and shingle to localised sections of dunes (e.g. Walney Island), sandy beaches (e.g. Morecambe) and cliffs (e.g. St. Bees Head). The wide, open views of the sea will reduce the sensitivity of the area to offshore developments. To the south, the extensive intertidal sands and dunes of the Sefton coast are a distinctive landscape feature of the area and though views of offshore developments may be focussed from enclosed views through dune slacks, the wide, open views afforded at the coast may reduce the impact of the scale of developments.

Barrow-in-Furness, Whitehaven and Workington provide an industrial element to the landscape which will likely reduce the sensitivity of the seascape to turbine structures, as will the more developed areas of the Mersey and Dee Estuaries and the various nuclear and gas fired power stations along the coast. Light pollution from these and other urban areas (e.g. Blackpool) will make them less sensitive to navigation and aviation lighting.

Much of the Welsh coast consists of medium to low hard rocked cliffs, located around Anglesey, the Lleyn Peninsula, Cardigan Bay and the Pembrokeshire Coast. Cliffs of more than 80m in height are located around the Gower Peninsula, though most are lower than this at between 30-50m. These cliffs represent a substantial part of the UK's cliff resource and any turbine structures may change the perception of these, diminishing their apparent scale. Lower coastlines are located within Tremadog Bay, parts of Cardigan Bay and the northern coast of the Lleyn Peninsula, and shingle and sandy beaches and sand dunes are found in these areas. The wide, expansive views afforded across Cardigan Bay may accommodate turbine structures (although there are other constraints making potential wind farm development here challenging), though this effect would decrease approaching the cliffed coasts of Pembrokeshire and Lleyn. A number of estuaries support low-lying saltmarsh (e.g. Dyfi, Teifi estuaries), and the simplicity of these landforms may be compromised by vertical structures. This section of Wales is sparsely populated and largely rural, with few heavily urbanised and industrial areas and any development may therefore alter the perception of the coast as 'wild' or remote if improperly sited. The largely western facing aspect of Wales, and indeed most of the coast in Regional Sea 6, would mean that turbines would be highly visible at sunset.

Regional Sea 6 contains four of eight estuaries highlighted in a recent wave and tidal screening (AEA & Hartley Anderson 2010) as being potential sites for tidal range technologies, which are: Colwyn Bay, the Mersey, the Wyre and Solway Firth. Both lagoon (Colwyn Bay) and barrage (Wyre, Solway Firth) technologies were stated as possible types of development. A number of generic landscape/seascape implications of such devices have already been discussed above in Section 5.8.3.1, and these are likely to be applicable to these sites also. Cumulative effects with offshore wind (for which the East Irish Sea already has a number farms within visible range of the coast) may be possible, and further visual implications may arise from surface structures associated with offshore gas storage in the Irish Sea (discussed above). Tidal stream developments are most likely off the coast of Pembrokeshire, the Lleyn Peninsula and to the north of Anglesey where the resource is concentrated. Merseyside is also a site which would lend itself to CCS demonstration having high emissions of $CO_2$ in relatively close proximity to suitable storage formations, and existing oil and gas infrastructure which could be used for the purposes of carbon dioxide storage following decommissioning.

The relative sensitivity and value scores for relevant seascape units identified in studies of the Welsh and Scottish coastlines are stated in Tables 5.26-5.28.

Table 5.26 – Summary of landscape/seascape assessment for the Welsh coast relevant to Regional Sea 6

| # | Area | Seascape character type | Sensitivity | | | Value |
|---|---|---|---|---|---|---|
| | | | Wind | Wave | Tidal Stream | |
| 1 | Dee Estuary | ESLR | High | High | Low/Medium | 1 |
| 2 | Point of Ayr to Colwyn Bay | TSLR, TSLU, THLU | Low/Medium | Low | Low | 1 |
| 3 | Rhos Point to Great Ormes Head | THIR, THLU, THMR | Medium | Low/Medium | Medium | 2 |
| 4 | Conwy Estuary | EHMR, EHLR, EHLU | High | High | Medium/High | 3 |
| 5 | Great Ormes Head to Puffin Island | THIR, THIU, THLR, THMU, THMR | Medium | Low/Medium | Low/Medium | 3 |
| 6 | Puffin Island to Point Lynas | THMR, THLR | Medium | Low/Medium | Medium | 2 |
| 7 | Point Lynas to Carmel Head | THIR, THLU, THLR, THMR | Medium | Low/Medium | Low/Medium | 3 |
| 8 | Carmel Head to Holyhead Mountain North Stack | THIR, THMR | Medium | Low/Medium | Low/Medium | 2 |
| 9 | Holyhead Mountain North Stack to Penrhyn Mawr | THIR, THMR | Medium/High | Low/Medium | Medium/High | 4 |
| 10 | Penrhyn Mawr to Pen-y-Parc/Maltraeth Bay | THMR, THLR | High | High | High | 2 |
| 11 | Holy Island Straits | LHLR | Medium/High | Low/Medium | Medium | 2 |
| 12 | Menai Straits | LSLR, LHMR | High | High | Medium/High | 2 |
| 13 | Maltraeth Bay to Trefor | TSLR, THLR, THMR | Medium/High | Medium | Medium | 2 |
| 14 | Trefor to Porth Dinllaen | THIR, THMR | Medium/High | Medium | Medium/High | 4 |
| 15 | Trwyn Porth Dinllaen to Braich y Pwll/Mynydd Mawr | THMR, THIR | Medium | Low/Medium | Medium/High | 4 |

| # | Area | Seascape character type | Sensitivity | | | Value |
|---|---|---|---|---|---|---|
| | | | Wind | Wave | Tidal Stream | |
| 16 | Braich y Pwll and Bardsey Island | THIR, THMR | High | High | High | 5 |
| 17 | Bardsey Island to Trwyn Cilan | THMR, THLR | High | High | High | 5 |
| 18 | Trwyn Cilan to Penrhyn Du (Porth Ceiriad and St Tudwal's Island) | THMR | Medium/High | Medium | High | 4 |
| 19 | Penrhyn Du to Pen-ychain (Abersoch and Pwllheli) | THLR, TSLR | Medium/High | Medium | Low/Medium | 3 |
| 20 | Pen-ychain to Morfa Dyffryn (Tremadog Bay) | THLR, TSLR | Medium/High | Medium/High | Medium | 4 |
| 21 | Porthmadog Estuary | ESMR, ESLR | High | High | Medium/High | 5 |
| 22 | Morfa Dyffryn to Pen Bwch Point (Barmouth Bay) | TSLR, THMR, THIR, TSMR | Medium | Medium | Medium | 5 |
| 23 | Mawddach Estuary | ESLR, EHMR | High | High | High | 5 |
| 24 | Pen Bwch Point to Upper Borth | TSLR, THMR | Medium | Low/Medium | Medium | 3 |
| 25 | Dyfi Estuary | ESMR, ESLR | High | High | Medium/High | 3 |
| 26 | Upper Borth to Newquay (central Cardigan Bay) | THMR, THIU | Medium | Low/Medium | Medium | 1 |
| 27 | Newquay to Cardigan Island | THMR, THIR | Medium/High | Medium | Medium/High | 1 |
| 28 | Teifi Estuary | EHMR, ESLR | High | High | Medium/High | 2 |
| 29 | Cemaes Head to Trwyn y Bwa | THIR, THMR | Medium/High | Medium/High | High | 4 |
| 30 | Trwyn y Bwa to Dinas Head (Newport Bay) | THMR | Medium/High | Medium | Medium/High | 5 |
| 31 | Dinas Head to Crincoed Point (Fishguard Bay) | THMR, THMU | Medium | Medium | Medium | 3 |
| 32 | Crincoed Point to Strumble Head | THMR | Medium/High | Medium | Medium/High | 3 |
| 33 | Strumble Head to St David's Head | THMR | High | Medium/High | High | 3 |
| 34 | St David's Head to Ramsey Island | LHMR, THMR | High | High | High | 5 |
| 35 | Ramsey Island to Skomer Island (St Brides Bay) | THMR, TSLR | High | Medium/High | High | 4 |

*Source: CCW (2008a, b)*
*Key: T=Tidal, L=Tidal current – lateral, E=Enclosed estuary or ria, H=Hard rocked coastline, S=Soft coastline, I=High (>100mAOD 250m inland), M=Medium (25-100mAOD 250m inland), L=Low (<25m 250m inland), R=Rural, U=Urban, D=Dunes*
*Notes: **Wind**: wind farm development scenario of many parallel turbines (160m to blade tip) at 550m intervals, 13km from the shore. **Wave:** 2 rows of linear objects 500x3m at 500m intervals 5km from the shore. **Tidal Stream**: 1 row of surface point structures 10x3m, at 60m intervals 0.75km from the shore. Visibility is based on a landward and seaward buffer of 24km. Value scores range from; 1=Low value, 5=High value*

Table 5.27 – Summary of wind landscape/seascape assessment for the Scottish coast relevant to Regional Sea 6

| # | Area | Seascape character type | Sensitivity | Value |
|---|---|---|---|---|
| 26 | Firth of Clyde | Outer Firth with Islands | Medium/High | 3 |
| 27 | South Arran/South Ayrshire/South Easy Kintyre | Narrow Coastal Shelf, Remote High Cliffs, Sounds, Narrows and Islands | Medium | 1 |
| 28 | Corsewall Point-Mull of Galloway | Remote High Cliffs | Medium | 1 |
| 29 | Outer Solway | Remote High Cliffs, Mainland Disposition Coastline/Open Views, Outer Firths | Medium/High | 1 |
| 30 | Inner Solway | Less Developed Inner Firths | High | 3 |

*Source: Scott et al. (2005)*
*Notes: **Wind**: development scenario of 100 turbines, 150m to blade tip, 8km from the shore in a grid covering 25km$^2$*
*Visibility based on 10km landward, 35km seaward buffer Value scores range from; 1=Low value, 5=High value*

Table 5.28 – Summary of wave and tidal stream landscape/seascape assessment for the Scottish coast relevant to Regional Sea 6

| Area | Seascape character type | Sensitivity | |
|---|---|---|---|
| | | Wave | Tidal Stream |
| Bute and Cumbrae | Inner Island and Coastal Areas associated with inner firths, low lying agricultural coastal fringe | Low/Medium | Medium/High |
| Ayrshire coast | Rugged coastal shelf and headlands with open views to sea | Medium | High |
| Argyll and Firth of Clyde | Low coastal sand and flats, High Cliffs, Rugged coastal shelf and headlands with open views to sea | Low-High | Medium/High |
| Ayrshire Basin | Low coastal sand and flats, low lying agricultural coastal fringe | Low | High |
| Dumfries and Galloway | Low coastal sand and flats, High Cliffs, Sounds and Narrows, Rugged coastal shelf and headlands with open views to sea | Medium/High | High |
| Argyll and Bute | Sounds and Narrows | High | High |
| Arran | Inner Island and Coastal Areas associated with inner firths, Rugged coastal shelf and headlands with open views to sea | Medium | Medium/High |

*Source: after Faber Maunsell & Metoc (2007)*

*Notes: **Wave**: linear devices 2-3m in height above water, or point structures up to 10m above water. Typical linear array of 1x4km, or 4 rows of 25 point structures. **Tidal Stream**: 30 unit tidal array expected to occupy ~0.5km$^2$.*

## Forces of landscape change

Parts of the Welsh section of Regional Sea 6 are under considerable development pressure, particularly North Wales around principal urban areas (e.g. Bangor). Recreational pressure including access to coastal paths (generating trampling of cliff top vegetation in some places), caravan, campsites, tourist infrastructure, golf courses and increased use of coastal waters for watersports, are all generating pressure on the landscape of England and Wales. Coastal erosion is a problem for much of the coast in Wales and England, and in the future coastal defence may become more of an issue. At Goodwick, there is increased port development and ferry services are to develop in the Fishguard Bay area. Oil and gas activity in the Irish Sea (primarily in the north-eastern part) is likely to continue to provide an industrial offshore element to the seascape in years to come. The Welsh Renewable Energy Route Map indicates the intention to diversify offshore energy production to include wave and tidal energies while increasing offshore wind developments. The combination of these various technologies may generate cumulative impacts and reduce the sensitivity of the seascape to further developments. A number of sizeable onshore wind farms (e.g. Llyn Alaw, Trysglwyn on Anglesey) are already operational and pressure for such developments is likely to continue. Cumulative effects of these with new offshore structures must be considered carefully.

## 5.8.3.7 Regional Sea 7

Table 5.29 summarises the relative sensitivity and value of seascape character units identified by Scott *et al.* (2005) and the following is a synthesis of the sensitivity analysis of this report, augmented with information presented in Faber Maunsell & Metoc (2007).

The coast in Regional Sea 7 from Cape Wrath to the Mull of Kintyre is calculated to have the highest value scores for Scotland (Scott *et al.* 2005) due to a high density of NSAs, which cover the west coast, Inner and Outer Hebrides.

Development would conflict with the coast from Cape Wrath to Loch Torridon where the coast is complex and of high naturalness and remoteness. To the south, turbines would dominate seascapes of contained areas such as the Inner Sound, which is also a highly natural area with qualities of remoteness in places – development would have an incompatible form and character and would detract from distinctive natural forms like those on Trotternish Peninsula.

West Coll, Tiree, Canna and Rum have predominantly large scale, flattish and open seascapes which may reduce their sensitivity to turbine structures, however there are also numerous smaller scale seascapes and limited views of the sea from smaller bays and inlets. Turbines would conflict with key views of Rum which has a dramatic and vertical profile. Wind energy would relate to the feeling of windiness and exposure of these seascapes but may detract from their ‘wild’ aesthetic. Turbines would conflict with the natural qualities of the area and the traditional small scale character of the settlements. Night lighting and interference with sunsets would also create significant impacts and change of character.

From the Sound of Sleat to the Point of Ardnamurchan, the seascape pattern of interlocking mountains, islands and sea is a key characteristic which would be disrupted by development. Turbines would introduce a large scale modification into a highly natural area with some extremely remote hinterland creating a significant change in character. Landmarks views of high peaks and views of Small Isles, Skye and Morar would be compromised.

To the south in the Sound of Mull, Firth of Lorn and Sound of Jura, the enclosed nature of the narrow sounds is incompatible with wind farm development, and can be considered to have a high sensitivity to both wave and tidal devices. The strong containment and scale of the islands would be diminished by development. Further west, there are larger scale horizontal seascapes, though development would conflict with the apparent vertical scale of steep mountains rising from the sea around Mull. Development would not relate well to the highly natural and predominantly indented and fragmented coastline particularly around Mull, as well as scale and character of settlement. Large scale and open views around Islay and Jura could accommodate development though it would substantially alter the character of the area, parts of which are only accessible by boat or foot, and are therefore extremely remote. Turbines may detract from the Paps of Jura which are a large scale feature in the landscape. A number of blocks were awarded in the last oil and gas offshore licensing round between Islay and the northern coast of Northern Ireland in the North Channel. Additionally, the area to the south and west of Islay has a potentially viable tidal stream resource. It may be reasonably expected that activities associated with such developments may take place in the coming years.

## Forces of landscape change

Much of the west coast is under increasing pressure from tourism and tourist related developments including holiday/retirement homes and improved access and infrastructure. Such developments may influence the perception of remoteness. Pressure for onshore wind developments is increasing all along the coast, particularly on the Isle of Lewis and Kintyre, and any development that takes place will alter the landscape substantially and may change the perception of some areas as ‘wild’ and potentially generate cumulative impacts with any offshore development. Other marine renewables including wave may also generate cumulative impacts as an increasing number of built, industrial structures are imposed on this largely rural coast. Aquaculture is likely to increase in years to come.

Table 5.29 – Summary of wind landscape/seascape assessment for the Scottish coast relevant to Regional Sea 7

| # | Area | Seascape character type | Sensitivity | Value |
|---|---|---|---|---|
| 10 | Cape Wrath to Loch Torridon | Enclosed Bays, Islands and Headlands cover most of this area with Remote High Cliffs at the northern tip. | High | 4 |
| 11 | Inner Sound/Sound of Raasay | Sounds, Narrows and Islands. Low Rocky Island Coast represents two small sections at the edges of this area. | High | 5 |
| 12 | North East Lewis | Low Rocky Island Coasts | Medium/High | 1 |
| 14 | The Little Minch | Low Rocky Island Coasts, and Sounds, Narrows and Islands. | High | 2 |
| 17 | Barra | Sounds, Narrows and Islands, Deposition Coasts of Islands and Low Rocky Island Coasts | High | 2 |
| 18 | West Coll and Tiree, Canna and Rum | Deposition Coasts of Islands, Low Rocky Island Coasts and Sounds, Narrow and Islands. | Medium/High | 1 |

| # | Area | Seascape character type | Sensitivity | Value |
|---|---|---|---|---|
| 19 | Sound of Sleat to Ardnamurchan | Sounds, Narrows and Islands. | High | 5 |
| 20 | Sound of Mull/Firth of Lorn/Sound of Jura | Sounds, Narrows and Islands | High | 2 |
| 21 | West Mull/East Tiree and Coll | Low Rocky Island Coasts with small areas of Deposition Coasts of Islands | High | 2 |
| 22 | West Islay | Low Rocky Island Coasts with areas of Deposition Coasts of Islands. | Medium/High | 1 |
| 23 | South Mull/Colonsay/West Jura/Sound of Islay | Low Rocky Island Coasts, Sounds, Narrows and Islands. | High | 2 |
| 24 | West Kintyre/South East Jura and South East Islay | Sounds, Narrows and Islands with a small area of Remote High Cliffs | High | 1 |

*Notes: Based on a wind farm development scenario of 100 turbines, 150m to blade tip, 8km from the shore in a grid covering 25km$^2$*
*Visibility based on 10km landward, 35km seaward buffer.*
*Value scores range from; 1=Low value, 5=High value*
*Source: Scott et al. (2005)*

Table 5.30 – Summary of wave and tidal stream landscape/seascape assessment for the Scottish coast relevant to Regional Sea 7

| Area | Seascape character type | Sensitivity | |
|---|---|---|---|
| | | Wave | Tidal Stream |
| West Sutherland | Sounds and Narrows | High | High |
| Wester Ross | Sounds and Narrows, | High | High |
| Wester Ross and Lochaber | Complex indented coastline with offshore islands | High | High |
| Skye and Lochalsh | Sounds and Narrows, Complex indented coastline with offshore islands | High | High |
| Lochaber | Rugged coastal shelf and headlands with open views to sea | Medium | High |

*Notes: **Wave**: linear devices 2-3m in height above water, or point structures up to 10m above water. Typical linear array of 1x4km, or 4 rows of 25 point structures. **Tidal Stream**: 30 unit tidal array expected to occupy ~0.5km$^2$.*
*Source: after Faber Maunsell & Metoc (2007)*

### 5.8.3.8 Regional Sea 8

Regional Sea 8 includes the high cliffs of Scotland's northern coast, affording wide open views which would accommodate offshore turbines, though their presence may diminish the appreciation of the scale of the cliffs. Views to Hoy and Orkney would be compromised by developments in the Pentland Firth, though development here is unlikely due to practical considerations. Views from Orkney would likewise be compromised, as turbine height would most conflict with the scale and complexity of the cliffs and stacks on Orkney's west coast. The wide, open views afforded from many locations of the coast of Orkney (and Shetland) may help to prevent the coastal scale and complexity being diminished with developments at distance from the shore. The remote, small-scale and rural character of the west coast of the Outer Hebrides would not easily accommodate the industrial character of wind turbines, and large, visible developments would compete for focus over distant mountain views. The perception of 'wildness' provided by the remote, undeveloped and natural form of most of Regional Sea 8 would be degraded should offshore developments be visible from the coast at day or night. The seas to the west of the Western Isles contain some of the best wave resource on the UKCS and may therefore be subject to the installation of such devices once they are technically proven. The Scottish SEA of wave and tidal devices in territorial waters recorded a Medium/High and High sensitivity to wave and tidal stream devices respectively in the waters around the Western Isles. Any activities arising from adoption of the draft plan/programme for this SEA would be in offshore waters and it is unlikely they would be visible from the shore.

Table 5.31 summarises the sensitivity and value analysis for Scottish seascape units identified in Scott *et al.* (2005).

Table 5.31 – Summary of wind landscape/seascape assessment for the Scottish coast relevant to Regional Sea 8

| # | Area | Seascape character type | Sensitivity | Value |
|---|---|---|---|---|
| 32 | East Orkney | Deposition Coasts and Islands | Medium/High | 1 |
| 8 | North Caithness & Pentland Firth | Remote High Cliffs and Mainland Rocky Coastline with Open Sea Views to the west, and Deposition Coastline with Open Sea Views to the east | Medium | 1 |
| 10 | Cape Wrath | Kyles and Sea Lochs and Remote High Cliffs | Medium/High | 4 |
| 13 | Butt of Lewis to Carloway | Low rocky Islands and Coasts | Medium | 1 |
| 15 | Carloway to Griminish Point | Low Rocky Island Coasts, Deposition Coasts of Islands, Sounds, Narrows and Islands. | High | 4 |
| 16 | West Uists | Deposition Coasts of Islands | Medium | 1 |
| 17 | Barra | Sounds, Narrows and Islands, Coasts of Islands and Low Rocky Island Coasts | High | 2 |
| 33 | Shetland | Islands, Sounds and Voes with small areas of Remote High Cliffs. | Medium/High | 1 |

*Source: Scott et al. (2005)*
*Notes: Based on a wind farm development scenario of 100 turbines, 150m to blade tip, 8km from the shore in a grid covering 25km$^2$*
*Visibility based on 10km landward, 35km seaward buffer.*
*Value scores range from; 1=Low value, 5=High value*

Table 5.32 – Summary of wave and tidal stream landscape/seascape assessment for the Scottish coast relevant to Regional Sea 8

| Area | Seascape character type | Sensitivity | |
|---|---|---|---|
| | | Wave | Tidal Stream |
| Orkney | Low coastal sand and flats High Cliffs, Inter island associated with outer island areas, low lying agricultural coastal fringe | Low/Medium | High |
| Western Isles | Low coastal sand and flats, Sounds and Narrows, Inter island associated with outer island areas, Complex indented coastline with offshore islands, low lying agricultural coastal fringe, Rugged coastal shelf and headlands with open views to sea | Medium/High | High |
| Caithness and Sutherland | Low coastal sand and flats, High Cliffs, Complex indented coastline with offshore islands, Rugged coastal shelf and headlands with open views to sea | Medium/High | High |
| Shetland Islands | High Cliffs, islands, sounds and voes | Medium | High |
| St Kilda | St Kilda | High | High |

*Notes: **Wave**: linear devices 2-3m in height above water, or point structures up to 10m above water. Typical linear array of 1x4km, or 4 rows of 25 point structures. **Tidal Stream**: 30 unit tidal array expected to occupy ~0.5km$^2$.*
*Source: after Faber Maunsell & Metoc (2007)*

### Forces of landscape change

The north coast of Scotland is under increasing pressure for onshore wind developments and cumulative effects may arise should offshore structures be intervisible with these, which would in turn increase the sensitivity of this area. Increasing use of the seas around Orkney and Shetland for aquaculture and the Orkney EMEC marine energy testing sites may conflict with other offshore energy developments. On Lewis and the Uists there is increasing pressure for improved roads and onshore wind developments. The erosion of machair sites on the west of the Outer Hebrides is expected to increase as a result of climate change.

## 5.8.4 Controls and mitigation

The form of offshore structures is largely functional, and therefore mitigation opportunities are limited to siting and certain elements of development aesthetics, though the former will be restricted by spatial and technical constraints, or due to the location of particular energy resources. DTI (2005c) highlights a number of considerations which may help to reduce the impact of a given development, in this case offshore wind, though these may be reasonably extrapolated to any offshore structure. These mitigation measures have been modified for the purposes of this assessment below.

**Siting**:

- Try to locate in low sensitivity or high capacity seascapes
- Place development as far offshore as possible

- Try to locate developments away from coastal landscape designations
- Try to use development siting to minimise visibility (e.g. behind headlands)
- Consider siting relationships with other offshore infrastructure (cumulative effects)

**Layout and Design**:
- Consider different viewpoints, try to attain the best possible arrangement of structures
- Through the SVIA process, try to design out aspects of the development that are the source of most significant impacts
- Make the SVIA process iterative in order to try a variety of locations, patterns and number of structures
- Where possible, while taking account of all navigational standards and recommendations, the use of colour most appropriate for prevailing/average meteorological conditions may reduce the actual visibility of structures, particularly at increasing distances
- Where possible minimise the height of structures above sea-level, with fully submerged structures being preferable, particularly those at sufficient depth in the water column to avoid the use of surface lighting

## 5.8.5 Cumulative impact considerations

In coming years offshore wind is likely to be placed further offshore partly due to the location of the Round 3 leasing zones and as turbine foundations develop so that deeper waters can be exploited. A significant number of offshore wind farms and development zones are now in place in UK territorial and offshore waters. It is difficult to resolve the local implications on seascape from such developments at a strategic level, though in the areas of the East Irish Sea, Thames and Wash, the concentration of farms and their proximity to the coast may lead to the seascapes of these areas being dominated by this use of the sea. This is already being reflected in a number of offshore wind Environmental Statements (e.g. Walney, Sheringham Shoal) for developments in these areas, which outline that other offshore wind developments are a potential source of at least moderate cumulative impacts. Resources for wave, tidal and wind technologies tend not to overlap and therefore it is unlikely that different renewable technologies will compete for space, or generate a scenario where there are cumulative effects from different types of renewable technologies. Where this might occur is in views down certain estuaries should tidal stream or range devices interrupt open sea views which are then overlain with, for instance, offshore wind turbines.

Other activities which may result from the draft plan/programme which could lead to cumulative visual impacts include gas storage and carbon dioxide storage, and any ancillary development of any element of the plan, though this would need to be assessed at the local level. It is unlikely that any significant new oil and gas infrastructure will be commissioned within the currency of OESEA2, and in the foreseeable future as UKCS reserves decline.

## 5.8.6 Summary of findings and recommendations

The following summarises the consideration of the evidence and spatial consideration above:

- Viewable distance is restricted by the curvature of the earth, atmospheric haze and prevailing meteorological conditions.
- The height, form, lighting, motion and aspect of an offshore object affects how well it can be seen and its relative impact on the coast.

- Landscape designations provide a relatively objective general assessment of the 'value' attached to certain areas of the coast, though in keeping with the European Landscape Convention, all landscapes should be considered in seascape assessment.
- A range of physical attributes which are locally variable, in combination with the design of a development, define the sensitivity and capacity of a particular location to change.
- Wind farms are starting to move further offshore, and will continue to do so as Round 3 sites develop, reducing shore based visual disamenity, though there remains potential for cumulative effects between leasing areas in territorial and offshore waters, and at sea.
- The scope for cumulative impacts between different renewables aspects of the draft plan/programme is minimised by little overlap in the geographical range of energy resources.
- Cumulative impacts are most likely to occur between offshore oil and gas, $CO_2$ storage, gas storage and wind farm development in the East Irish Sea, Moray Firth, west English Channel and areas of the Southern North Sea off Holderness and Thames Estuary.
- A development specific seascape assessment incorporating cumulative impact assessment is necessary in order to minimise visual impacts from the variety of activities covered in the draft plan/programme, and existing and likely future uses of the sea.
- England's seascape presently lacks a comprehensive characterisation or high level analysis with regards to the sensitivity or capacity of particular seascapes to offshore development.

# 5.9 Marine discharges

## 5.9.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Potential for non-native species introductions in ballast water discharges or spread through "stepping stone" effect | X | X | X | X | X | X | X | 5.6.2.4<br>5.9.2 |
| | Potential for effects on flora and fauna of produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | X | X | X | X | X | ? | X | 5.9.2 |
| | The nature and use of antifouling materials | | | | ? | X | ? | X | 5.9.2 |
| | Sediment modification and contamination by particulate discharges from drilling etc or re-suspension of contaminated sediment | X | X | X | X | X | X | X | 5.9.2 |
| | Effects of reinjection of produced water and/or cuttings and injection of $CO_2$ | X | X | X | | | | | 5.9.2 |
| | Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | X | X | X | X | X | ? | X | 5.9.2 |
| | Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment | | X | X | | | X | | 5.5.2<br>5.9.2 |
| | Potential for effects on human health associated with effects of discharges of naturally occurring radioactive material in produced water | X | X | ? | | | | | 5.9.1 |

As described in previous SEAs, marine discharges from exploration and production activities include produced water, sewage, cooling water, drainage, drilling wastes and surplus WBM, which in turn may contain a range of hydrocarbons in dissolved and suspended droplet from, various production and utility chemicals, metal ions or salts (including Low Specific Activity (LSA) radionuclides). In addition to these mainly platform-derived discharges, a range of discharges are associated with operation of subsea infrastructure (hydraulic fluids), pipeline testing and commissioning (treated seawater), and support vessels (sewage, cooling and drainage waters). The effects of the majority of these are judged to be negligible and are not considered further here (note, they would be considered in detail in Environmental Statements and chemical risk assessments under existing permitting procedures). The list above equally applies to gas storage (e.g. the proposed Baird gas storage project) or CCS activities in depleted reservoirs, although produced water and scale volumes will be minor.

In addition to discharges associated with drilling and support activities, construction of salt caverns involves the discharge of relatively large volumes of high salinity brine, which in addition to dissolved halites may potentially contain trace quantities of other components.

OWF and other renewable energy developments have essentially no planned discharges, although there is a potential incidental release of copper and carbon dust from abrasion of the slip-rings of wind turbines; this is considered to have negligible environmental effect (Danish Hydraulic Institute 2000). Some wave energy devices have significant inventories of hydraulic fluids, although there is no planned discharge.

Discharges from offshore oil and gas facilities have been subject to increasingly stringent regulatory controls over recent decades, and oil concentrations in the major streams (drilling wastes and produced water) have been substantially reduced. However, due mainly to increasing water cut from mature oil reservoirs, and the use of water injection to maintain reservoir pressure, the total volume of produced water discharges on the UKCS has increased and is expected to continue to increase into the near future.

Produced water is derived from reservoir (“fossil”) water, through condensation and injection water. The majority of produced water discharge volume to the North Sea and elsewhere is associated with oil production and produced water volumes from gas fields are extremely small in comparison. OSPAR Recommendation 2001/1 for the Management of Produced Water from Offshore Installations includes a presumption against the discharge to sea of produced water from new developments. The assumption that reinjection will be the normal method of produced water disposal (at least 95% by volume) is fundamental to the consideration of potential effects of produced water in the SEA process, although it is also noted that under certain circumstances (e.g. injection pump maintenance) the effluent may be routed to sea. Any produced water discharged will be treated since it is still required to meet legal quality standards in terms of oil in water concentration.

Drilling wastes are a major component of the total waste streams from offshore exploration and production, with typically around 1,000 tonnes of cuttings resulting from an exploration or development well. Water-based mud cuttings are discharged at, or relatively close to sea surface during “closed drilling” (i.e. when steel casing and a riser is in place), whereas surface hole cuttings will be discharged at seabed during “open-hole” drilling. Use of oil-based mud systems, for example in highly deviated sections or in water reactive shale sections, would require the onshore disposal or reinjection of a proportion of waste material.

The contaminant composition of drilling wastes has changed significantly over the last few decades, in response to technical and regulatory developments. Previous widespread and substantial discharges of oil-based muds, and later synthetic muds, have been superseded by alternative disposal methods (either containment and onshore treatment, or reinjection) or by use of water-based muds.

### 5.9.2 Consideration of the evidence base

#### 5.9.2.1 Produced water

Potential effects of produced water discharges are described in previous SEAs. *It should be noted that a general presumption is in place that produced water from future developments on the UKCS will be reinjected and not discharged.*

Most studies of produced water toxicity and dispersion, in the UK and elsewhere (see E&P Forum 1994, OLF 1998, Riddle *et al*. 2001, Berry & Wells 2004) have concluded that the necessary dilution to achieve a No Effect Concentration (NEC) would be reached at <10 to

100m and usually less than 500m from the discharge point. The SEA 6 commissioned study (Kenny *et al*. 2005) reviewed recent studies and data (including analyses of produced water composition from Irish Sea facilities), and reached a similar conclusion. However, under some circumstances (e.g. strong stratification: Washburn *et al*. 1999), a plume concentration sufficient to result in sub-lethal effects may persist for >1000m (Burns *et al*. 1999).

The ICES Biological Effects Monitoring in Pelagic Ecosystems workshop (BECPELAG) analysed samples from caged organisms and passive samplers using a wide range of biomarkers and bioassays for chemical, molecular, cellular and physiological changes. e.g. toxicity bioassays, enzymatic induction (EROD), lysosomal damage, Scope for Growth (SFG), genotoxicity, endocrine disruption effects, metallothionein induction, PAH metabolites, acetylcholinesterase inhibition, bacterial diversity. Although a variety of detectable responses (in caged organisms) around an oil platform were observed and attributed to produced water effects, there was not a gradient of effect and the ecological significance of these responses is unclear.

The QSR 2010 noted that water column monitoring to determine possible effects from polycyclic aromatic hydrocarbons (PAHs) and other chemicals such as alkyl phenols discharged with produced water has been carried out to a limited extent in the OSPAR area.

Monitoring with caged mussels in the Netherlands and Norwegian sectors of the North Sea has shown that mussels exposed to produced water discharges may accumulate PAH and show biological responses up to 1000m from the discharge. Concentrations of PAHs and alkyl phenols and measured biological responses in wild fish such as cod and haddock caught in the vicinity of offshore installations from Norwegian waters in 2002 and 2005 showed a mixed pattern mostly with no increased concentrations, but some elevated biological responses suggesting past exposure. Exposure of cod sperm cells to environmentally relevant concentrations (100, 200, 500 ppm) of produced water from the Hibernia platform, Newfoundland, did not result in a strong toxicity to the cells (only subtle changes were observed) or a significant change in fertilisation rate (Hamoutene *et al*. 2010).

The QSR further noted that results from water column monitoring are complex to interpret, particularly for wild fish for which it is not possible to link observed biological responses to a specific exposure source. Monitoring data are limited and do not yet allow conclusions to be drawn on the significance of observed responses for marine life and ecosystems.

### 5.9.2.2 Drilling discharges

Mud systems used in surface hole drilling for exploration wells are usually simple (seawater with occasional viscous gel sweeps) and would not result in significant contamination of sediments. However, the composition of closed drilling discharges likely to result from exploration, appraisal and development drilling (and to a lesser extent from well maintenance activities) is more complex, and will include cuttings (i.e. formation solids, in varying degrees of consolidation and in a range of particle sizes), barite, salts (sodium and potassium chloride), bentonite and a range of mud additives in much smaller quantities. Water-based mud additives perform a number of functions, but are predominantly polymeric organic substances and inorganic salts with low toxicity and bioaccumulation potential. In addition to mud on cuttings, surplus water-based mud may be discharged at the sea surface during or following drilling operations. Due to its density, a proportion of the particulate component of the mud (including barite) may settle in the immediate vicinity of the discharge.

A major insoluble component of water-based mud discharges, which will accumulate in sediments, is barite (barium sulphate). Barite has been widely shown to accumulate in sediments following drilling (reviewed by Hartley 1996). Barium sulphate is of low bioavailability and toxicity to benthic organisms. Other metals, present mainly as salts, in drilling wastes may originate from formation cuttings, from impurities in barite and other mud components or from other sources such as pipe dopes. Although a variety of metals (especially chromium) are widely recorded to accumulate in the vicinity of drilling operations, the toxicity of settled drill cuttings appears to be related primarily to hydrocarbon content, even in WBM discharges; probably because in the past hydrocarbon spotting fluids had been used as a contingency measure (UKOOA 2002, Hartley Anderson 2003).

Dispersion of mud and cuttings is influenced by various factors, including particle size distribution and density, vertical and horizontal turbulence, current flows, and water depth. In deep water, the range of cuttings particle size results in a significant variation in settling velocity, and a consequent gradient in the size distribution of settled cuttings, with coarser material close to the discharge location and finer material very widely dispersed away from the location, generally at undetectable loading.

The past discharge to sea of drill cuttings contaminated with oil based drill mud (OBM) resulted in well documented acute and chronic effects at the seabed (e.g. Davies *et al*. 1989, Olsgard & Gray 1995, Daan & Mulder 1996). These effects resulted from the interplay of a variety of factors of which direct toxicity (when diesel based muds were used) or secondary toxicity as a consequence of organic enrichment (from hydrogen sulphide produced by bacteria under anaerobic conditions) were probably the most important. Through OSPAR and other actions, the discharge of oil based and other organic phase fluid contaminated material is now effectively banned. The “legacy” effects of contaminated sediments on the UKCS resulting from OBM discharges have been the subject of joint industry work (UKOOA 2002) and reporting to OSPAR (BERR 2008a).

In response to the progressive tightening of OSPAR and UK discharge and other standards for cuttings drilled with OBM and organic phase fluids, and for the oil content of produced water and production, drilling and cementing chemicals, the UK Government/Industry Environmental Monitoring Committee has reviewed UK offshore oil and gas monitoring requirements. The committee has developed a monitoring strategy which aims to ensure that adequate data is available on the environmental quality status in areas of operations for permitting assurance and to meet the UK’s international commitments to report on UK oil industry effects. This strategy has been implemented since 2004 and has included regional studies in various parts of the North Sea, and surveys around specific single and multiwell sites.

Overall indications are of recovery of sediments and communities in both the Fladen Ground and East Shetland Basin from the historic effects of oil-based mud discharges; Forties crude oil equivalent, diesel oil equivalent, total PAH and total n-alkane concentrations in Fladen Ground sediments were all lower in 2001 than in 1989 and are now at levels which are considered below ‘background’. In the East Shetland Basin, comparison of 2002 and 2007 survey data with historic surveys showed that there has been a significant decrease in Forties crude and diesel oil equivalent concentrations. There was also a significant decrease in the concentrations of PAHs. Time series studies of hydrocarbon contamination at selected field developments throughout the North Sea suggest that long-term changes in nearfield concentrations are limited, with recovery periods likely to be multi-decadal.

The timescale of recovery at exploration well sites has also been investigated by UK Government/Industry Environmental Monitoring Committee surveys. THC and metals concentrations in surface sediments at the single exploration wellsite (21/12-2B) drilled with diesel based OBM had declined substantially between 1987 and 2004 although the process of biodegradation and recovery was not yet complete. A similar situation was evident at another single exploration wellsite (16/27-4z drilled with low toxicity OBM) where only low concentrations of OBM derived hydrocarbons were present in surface sediments and concentrations in depth sectioned cores from the 50mS station were substantially less than those found in 1987.

In contrast to historic oil based mud discharges, effects on seabed fauna of the discharge of cuttings drilled with WBM and of the excess and spent mud itself are usually subtle or undetectable, although the presence of drilling material at the seabed close to the drilling location (<500m) is often detectable chemically (e.g. Cranmer 1988, Neff *et al*. 1989, Hyland *et al*. 1994, Daan & Mulder 1996). Considerable data has been gathered from the North Sea and other production areas, indicating that localised physical effects are the dominant mechanism of ecological disturbance where water-based mud and cuttings are discharged.

However, Cranford & Gordon (1992) reported low tolerance of dilute bentonite clay suspensions in sea scallops (*Placopecten magellanicus*). Cranford *et al*. (1999) found that used water based mud and its major constituents, bentonite and barite caused effects on the growth, reproductive success and survival of scallops, which were attributed to chronic toxicity and physical disturbance. It may be that *Placopecten* is especially sensitive to drill muds (or fine sediments in general) or that in the field, water based drilling discharges very rapidly disperse to below effective concentrations. Barlow and Kingston (2001) report damage to the gills of two species of coastal bivalves where barite was added to experimental system although no controls with other sediment added were tested and the concentrations of material added were very high so it is unclear how or if the results apply to the field situation. Experimental additions of WBM cuttings to benthic mesocosms showed a variety of effects on fauna and geochemical fluxes (Schaanning *et al*. 2008; Trannum *et al*. 2010) but again the results cannot be readily extrapolated to field effects since discharge of WBM drilling waste is intermittent and near surface, allowing differential settlement of particulates and dispersion of water soluble components.

A comprehensive synthesis and annotated bibliography of the composition, environmental fates and biological effect of WBM and cuttings was prepared on behalf of the Petroleum Environmental Research Forum (PERF) and American Petroleum Institute by Neff (2005). The review, covering more than 200 publications and reports, concludes that effects of WBM cuttings piles on bottom living biological communities are caused mainly by burial and low sediment oxygen concentrations caused by organic enrichment. Toxic effects, when they occur, probably are caused by sulphide and ammonia byproducts of organic enrichment.

A recent PhD study (Strachan 2010) was carried out to observe effects of standard grade and fine grade barite on the filtration rates of four suspension feeding bivalves, *Modiolus modiolus*, *Dosinia exoleta*, *Venerupis senegalensis* and *Chlamys varia*. The species were exposed to 0.5mm, 1.0mm and 2.0mm daily depth equivalent doses of standard grade barite, which were maintained in permanent suspension. Standard grade barite, the most commonly used weighting agent in water-based drilling mud, was found to alter the filtration rates of the four bivalve species and to damage the gill structure. All three barite treatments altered the filtration rates leading to 100% mortality. The horse mussel, *Modiolus modiolus* was the most tolerant to standard barite with the scallop, *Chlamys varia* the least tolerant. Fine barite, at a 2mm daily depth equivalent, also altered the filtration rates of all species, but only affected the mortality of *Venerupis senegalensis*, with 60% survival at 28 days. In-vivo studies showed damage to the gills, ranging from displaced inter-lamellar junctions to the deletion of large parts of the demibranch. Post-mortem microscopy studies showed damage to individual filaments with a marked reduction in the active surface area of the gill. Field studies undertaken by Strachan (2010) showed that the presence of standard grade barite was not acutely toxic to seabed fauna but did alter benthic community structure when persistent.

Strachan (2010) concluded that it may be less detrimental to the marine environment if fine barite was used in preference to the coarser standard barite. Although suspensions of finer particles may be dispersed over greater distances than those of coarser particles, they will also be more dilute and therefore can be expected to have less impact on the marine environment. Although chemically inert, suspended barite has been shown under laboratory conditions to potentially have a detrimental effect on suspension feeding bivalves causing demonstrable damage to the gill filtration system and, after prolonged exposure, mortality. When the suspended barite levels used in laboratory studies are translated to field conditions (i.e. distances from the point of discharge) it is clear that any effects will be very local to a particular installation (in the case of oil and gas facilities, well within the 500m statutory exclusion zone). Research initiated under the DECC SEA programme is underway to examine growth records in the shells of a large and long lived bivalve (*Glycymeris*) collected at various distances between 50m and 15km from an exploration well drilled with WBM; these results will help link laboratory and field observations of the effects of drilling discharges.

Most studies of ecological effects of drilling wastes have involved soft-sediment species and habitats. Studies of the effects of water based mud discharges from 3 production platforms in 130-210m water depth off California found significant reductions at some stations in the mean abundance of 4 of 22 hard bottom taxa investigated using photographic quadrats (Hyland *et al*. 1994). These effects were attributed to the physical effects of particulate loading, namely disruption of feeding or respiration, or the burial of settled larvae.

The introduction of non-native species through vessel ballast water discharges has also been considered in previous SEA Environmental Reports. The majority of rigs and vessels likely to be used will already be operating in NW Europe and hence not a potential source of exotic species introductions (although they could facilitate the spread of species). The International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in February 2004, but has still to enter into force. Pending ratification, the Helsinki and OSPAR Commissions together with the European Community have issued General Guidance on the Voluntary Interim application of the D1 Ballast Water Exchange Standard as of April 2008 which requests that vessels entering the waters concerned, exchange all their ballast tanks at least 200 nautical miles from the nearest land in water at least 200m deep. In view of these mitigation measures and the limited scale of activity predicted significance effects are not anticipated.

#### 5.9.2.3 Saline aquifer and halite cavern construction discharges

Displacement of saline formation fluids from aquifers and construction of caverns in salt formations will potentially result in discharge of significant quantities of brine. For example, proposed construction of the Gateway gas storage facility in the eastern Irish Sea will involve solution mining of 20 salt caverns (total gas capacity 1.136 billion cubic metres) over a four year period. The leaching process at each cavern will involve cycling large amounts of seawater through the well; thereby dissolving some of the salt in the deposit and discharging the resultant brine mixture into the sea at a maximum discharged rate of 386 $m^3$/hour. The maximum anticipated discharge salinity, which will occur during the cavern commissioning will be in the order of 7 times that of seawater (ca. 250 parts per thousand (ppt)), although it is anticipated to be much less than this during most of the leaching process. The maximum temperature of the discharge will also occur during the cavern commissioning period and is estimated to be 8.68ºC.

Modelling studies of dispersion of the brine plume around each of the discharges indicated that the brine effluent would be best discharged through two 0.15m diameter horizontal ports located at right angles to the main current direction at about 10m above the seabed. This configuration would be expected to give at least a 33 times dilution at the point of seabed impact and a maximum salinity rise at the seabed of less than 7ppt. Further 3D hydrodynamic modelling of the saline discharges showed that the dilution and dispersion of the discharge by the tidal currents would result in a number of separate plumes from each monopod. It was predicted that there would be some merging of the plumes, but only at low salinities (less than about 1ppt above ambient). The saline plumes are expected to be confined to the bottom 0.5 to 1.0 m of the water column. Central concentrations are about 7ppt, consistent with the initial dilution (i.e. there is no significant build-up that would reduce the dilution efficiency). The average impact at more than 1ppt above ambient is expected to be confined to an area within some 100m of each monopod during spring tides and within about 300m of each offshore structure during neap tides.

With respect to discharge temperature, it is anticipated that the temperature will reduce to about 2ºC above ambient or less within 1m of the point of discharge. There will also be an insoluble fraction to the discharge, mainly comprising fine mudstone particles. Modelling of this fraction found that in all cases the suspended sediment concentration that results from the discharge was very low, less than 0.5ppm. This is negligible compared with natural levels of suspended sediment and would not be expected to result in visible discolouration of the water.

Very little data is available on the composition of trace minerals in aquifer formation water, which may potentially include toxic species; however, the limited available information suggests a high proportion of sodium chloride (and much smaller proportions of calcium, magnesium, sulphate, carbonate and bicarbonate, all of which are present in seawater).

Halite deposits, being generally formed by evaporation of seawater over geological timescales, have a composition which is comparable to dissolved salt in sea water (i.e. predominantly sodium chloride). There is little data on the composition of brines from solution mining of halite caverns on the UKCS. Geochemical analyses of the Preesall halite formation which will be solution mined to form the Gateway Gas Storage Project caverns was provided in Supplementary Information to the Offshore Environmental Statement. Core samples from onshore and offshore locations of the formation were very similar, and showed only trace quantities of the metals mercury, cadmium arsenic, chromium, copper, lead, nickel, vanadium and zinc. The halite formation will also contain insoluble components, and the Gateway Project ES considered it a reasonable assumption that the insoluble:soluble ratio identified from the onshore cores will be very similar to the offshore cores. A possible reason for any difference might be a result of later mineralisation associated with hydrothermal activity along faults. However, there are no faults identified in the area of the Gateway 1-e borehole, and the lower zinc content recorded is a good indication that post-depositional mineralisation has not occurred. Also Gateway 1-e core descriptions show little evidence of diagenetic alteration within the salt. The Gateway Project ES concluded that available data provided sufficient confidence that the discharges would meet the requirements of EC Directive 76/464/EEC on Water pollution by discharges of certain dangerous substances (List 1 and 2).

Potential ecological effects from both saline aquifer and halite solution mining discharges are therefore likely to be associated with osmotic effects of hypersalinity rather than toxicity, and will be mitigated by effective dispersion of brine plumes.

Although there have been no previous developments of offshore salt caverns in the UK, the environmental effects of brine discharges have been well studied in other countries, notably in relation to discharges from desalination plants but also in relation to solution mining. Construction of salt caverns on the coast of the Gulf of Mexico as part of the US Strategic Petroleum Reserve Program in the 1970s was accompanied by a major environmental monitoring study of the discharge from the Bryan Mound (Texas) site, coordinated by Texas A&M University (Randall & Hann 1981). This included extensive measurement of the brine plume and baseline and postdisposal evaluation of water and sediment quality, nekton (free-swimming fauna), benthos, phytoplankton and zooplankton. Biological and water and sediment quality data indicated no substantial effects of the brine plume, which extended over a maximum recorded area of 7.4km$^2$ and vertical height above the seabed of 7.6m. A complementary study of the West Hackberry (Louisiana) site found no demonstrable effects on sediments or phytoplankton, and limited long-term effects on zooplankton, benthos and nekton (Giammona & Darnell 1990). Seasonal variability in species abundances was a predominate feature as dramatic population fluctuations occurred in all groups studied. Differences among stations of relatively small magnitude were observed for many species and biomass estimates studied. Some of these differences were consistent when specific comparisons were made between control and diffuser area stations. They include: statistically significant differences in population densities of certain numerically dominant macrobenthic species, and significantly lower values for coefficient of condition (weight at length) of certain nekton target species collected in the vicinity of the brine diffuser. None of the observed changes in biotic communities were catastrophic in nature and all other measured parameters were either within expected ranges of or could not be attributed to diffuser activities (DeRouen *et al*. 1983).

## 5.9.3 Controls and mitigation

### Hydrocarbon related activities

OSPAR Recommendation 2001/1 for the Management of Produced Water from Offshore Installations provides for a reduction in the discharge of oil in produced water by 15% over a five year period and a lowering of the discharge concentration from each installation to 30mg/l over the same period. The recommendation also includes a presumption against the discharge to sea of produced water from new developments. The *Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005* updated and largely superseded the *Prevention of Oil Pollution Act, 1971* (POPA). A system of permits for oil discharges has been introduced to replace the POPA exemptions and more wide-ranging powers have been given to inspectors. Operators are required to regularly make reports of actual oil discharge. The regulations are a mechanism to continue implementation on the UKCS of OSPAR Recommendation 2001/1 and make provision for the introduction of the dispersed oil in produced water trading scheme.

A permit is required in advance for the use of chemicals offshore including drilling, well workover, production and pipeline chemicals (*Offshore Chemicals Regulations 2002*). Permit application includes mandatory risk assessment. Any variation in use from permit must have prior approval. Chemical use and discharge must be reported at the end of the activity. Chemicals are ranked by hazard, based on a PEC:PNEC (Predicted Effect Concentration : Predicted No Effect Concentration) approach.

The management of produced water and chemical discharges will continue to be a key issue addressed through the environmental assessment process for planned developments (under *The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999*).

Solid and aqueous waste discharges from exploration and production operations are also regulated under the *Prevention of Oil Pollution Act 1971*, and are exempted (at the point of production) from the *Food and Environment Protection Act 1985*. Discharges associated with specific exploration drilling or development projects in the licensed areas require to be assessed under the *Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999*.

Alternative disposal methods for cuttings, including onshore treatment and reinjection as currently implemented for oil and synthetic-based muds, are also feasible for drilling with water-based mud (for example, if particular benthic biotope sensitivities were identified).

### Wind farm related activities

Although the depth of boreholes potentially drilled as part of OWF development is significantly shallower than those drilled in connection with hydrocarbon E&P or gas storage, drilling muds may also be used. The use and discharge of these muds and associated cuttings are presently controlled under the FEPA permitting system. All chemicals utilised in the drilling operation must be selected from the List of Notified Chemicals assessed for use by the offshore oil and gas industry under the *Offshore Chemicals Regulations 2002* (this list is derived from the OSPAR list and is available at www.cefas.co.uk). Should any system other than a water-based mud be considered for use in the drilling operation written approval and guidance of disposal of any arisings will be required from the Licensing Authority.

The general FEPA licence conditions are currently under review, including consideration of. whether a separate FEPA licence is necessary when drilling (e.g. during installation of turbine foundations) is proposed.

No additional mitigation measures are currently regarded as necessary for any components of the draft plan/programme.

## 5.9.4 Cumulative impact considerations

The contamination background of the UK marine environment was reviewed in Appendix 3b. In general, the industrial history of the UK has resulted in a widespread legacy of contamination of sediments, particularly in major estuaries and coastal waters. Ongoing sources of contamination are dominated by terrestrial inputs, with a significant contribution of hydrocarbons from offshore produced water discharges; a significant proportion of the total input of persistent substances occurs through atmospheric deposition.

In their assessment of direct, physical anthropogenic pressure on the seabed offshore of the UK, Eastwood *et al*. (2007) considered that field studies have shown that, for the majority of North Sea installations, biological communities are largely unaffected beyond a 500m radius (Kingston *et al*. 1987) and therefore applied buffers of 500m radius to all platforms and wells to provide an estimate of the spatial area affected. The estimated total of 923.6 $km^2$ physical loss by smothering, in English and Welsh waters, represents 0.4% of the total seabed area. However, this estimate is questionable, since a) the 500m radius of effect is applicable to OBM discharges primarily in the central and northern North Sea (Scottish waters not included in this study); predominantly WBM discharges in English and Welsh waters generally have little or no radius of effect; and b) this estimate excludes the major developed areas of the central North Sea and east Shetland basin. Nevertheless, it is evident that the total UKCS seabed area directly affected by drilling waste discharges is a small (probably <1%) proportion of the total.

Given the presumption in favour of reinjection of produced water from oil and gas production, the limited contamination and ecological effects of WBM mud and cuttings discharges, and the scale of discharges to the marine environment associated with the other activities under consideration, significant cumulative effects are not considered likely.

### 5.9.5 Summary of findings and recommendations

#### Offshore wind leasing

With the potential exception of drill muds and cuttings, no significant discharges to the marine environment are predicted to result from the proposed leasing for future OWF developments.

#### Oil & gas including gas storage and $CO_2$ storage in depleted reservoirs

The environmental effects of the major discharges from oil and gas activities have been extensively studied, and are considered to be relatively well understood. The environmental effects of produced water discharges not reinjected are limited primarily by dispersion. Discharges of WBM cuttings in the North Sea and other dispersive environments have been shown to have minimal ecological effects.

#### Gas storage in saline aquifers and halite cavern construction

Carbon dioxide storage in saline aquifers may result in the production and discharge of aquifer water. The *Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005* apply to discharges containing reservoir hydrocarbons and although they have been amended to apply to carbon storage, it is not yet clear whether they will apply to aquifer discharges. The quality of aquifer water is variable and the concentrations of elements and compounds of potential environmental concern are poorly characterised: a permitting mechanism is needed to ensure that such discharges can be controlled.

On the basis of dispersion modelling and experience from the Gulf of Mexico and elsewhere, effects of saline brine discharges resulting from solution mining of halite caverns are predicted to be localised, and not to result in significant ecological effects.

# 5.10 Waste

## 5.10.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Onshore disposal of returned drilling wastes – requirement for landfill | X | X | X | | | | | 5.10.2 |

The transfer of offshore wastes to shore for treatment and disposal can result in a variety of effects including nuisance, changes in air quality, onshore land use and cumulative effects, with the scale of effect dependent on quantity, effective waste management and eventual disposal method. Large-scale offshore oil and gas production can generate significant quantities of waste (comparable to an equivalent onshore industrial/residential development); however, OWF developments are generally not manned and waste generation will be minimal.

As with onshore industrial waste streams, waste from offshore can be characterised (for management and regulatory purposes) as special waste (e.g. chemicals/paints, oils and sludges), general waste (e.g. scrap metal and segregated recyclables) and other (e.g. radioactive materials).

## 5.10.2 Evidence base

In 2007, UKCS offshore oil and gas operations produced around 121,046 tonnes (2006 amount 121,260 tonnes) of waste of which 4,229 tonnes was reused, 21,192 tonnes recycled, 2,082 tonnes used in waste to energy and 71,468 tonnes were landfilled (EEMS 2007).

The return of drill muds and cuttings to shore for treatment and disposal is the major change in offshore waste disposals in recent years. In 2007, 44,313 tonnes of treated cuttings were disposed of to landfill. It is unlikely that major changes to these volumes would result from the proposed licensing and likely scale of drilling. In view of the volumes of material (drilling wastes and general oilfield waste) likely from drilling or operations together with the stringent control of waste disposal activities under IPPC and the Landfill Directive it is considered that any effects on land will be negligible.

Used drill muds and cuttings may be ground and reinjected to rock formations rather than discharged to sea or returned to land. A permit is required for UK interfield transfer of oily cuttings for reinjection. The reinjection of wastes to source is generally regarded as resulting in positive benefits, such as reduced requirement for landfill space. However, the process of reinjection can be energy intensive and thus result in increased atmospheric emissions from an installation.

The target formation(s) for reinjection of such materials is selected on the basis of geological understanding from previous drilling in the area, with performance monitored over time. Any release to sea or to other unintended rock strata is regarded as an accident and considered later in this section. Cuttings cleaning technologies which are capable of reducing oil on cuttings to levels below 1% may have a future positive impact on quantities of cuttings disposed of to land.

Substantial waste generation would be expected at decommissioning of offshore infrastructure (both oil & gas and OWF), although at end of life a high proportion of materials (especially structural steel, copper cabling and other metals) would be expected to be reused or recycled. Regulatory controls over decommissioning are in place and will require a detailed assessment of re-use, recycle and waste disposal prior to end of life.

### 5.10.3 Cumulative impact considerations

Onshore, during 2006/07, some 22.58 million tonnes of controlled waste (household, commercial and industrial, construction and demolition and agricultural, fisheries and waste) arose in Scotland, with each household in Scotland producing an estimated 1,228kg of waste. An estimated 159 million tonnes of waste was managed in England and Wales. Of this, 65 million tonnes were landfilled, 50 million tonnes were transferred, before final disposal or recovery, 28 million tonnes were treated, 11 million tonnes were handled through metal recycling facilities and 5 million tonnes were incinerated.

At around 0.01% of national waste generation, the contribution from offshore energy production is, and is expected to remain, negligible.

### 5.10.4 Summary of findings

At a national scale, waste generation from offshore energy activities is negligible. Effective regulatory controls are established which have minimised the generation of hazardous waste materials, and provided waste management procedures comparable with those onshore.

## 5.11 Air Quality

### 5.11.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Local air quality effects resulting from exhaust emissions, flaring and venting | X | X | X | X | X | X | X | 5.11.2 |
| | Air quality effects of a major gas release or volatile oil spill | X | X | X | | | | | 5.13.2.3 |
| | Potential for effects on human health associated with effects on local air quality resulting from atmospheric emissions | X | X | ? | | | | | 5.11.2.3<br>5.11.2.4<br>5.11.2.5 |

Atmospheric acid gases include sulphur dioxide ($SO_2$) and oxides of nitrogen ($NO_X$). These gases can react with water vapour forming acids to increase the acidity of clouds and rain which can result in vegetation damage, acidification of surface waters and land, and damage to buildings and infrastructure. In addition, these gases can transfer directly to surfaces through dry deposition (close to the source) causing similar damage to acid rain (UKTERG 1988). Shipping contributes up to 15% of the deposition of acid gases in some coastal areas; though in the North Sea, the declaration of a $SO_x$ control area requires the use of fuel with a sulphur content of not greater than 1%, reducing to 0.1% from 2015. Similar reductions in $NO_x$ are also in planning. Deposition is higher around major shipping routes such as the Southwest Approaches and English Channel (see Appendix 3e). The potential effects of emissions of acid gases are considered to be most important at a regional to local scale.

Reduction in local air quality through inputs of contaminants such as oxides of nitrogen ($NO_X$), volatile organic compounds (VOCs) and particulates, may contribute to the formation of local tropospheric ozone and photochemical smogs, which in turn can result in human health effects. Ozone is known to impair lung function and $NO_X$ causes irritation of the airways and can be particularly problematic for asthma sufferers (EPAQS 1996).

The absorption of anthropogenic $CO_2$ in sea water appears to be causing the gradual acidification of sea water. Potential effects of this acidification include the dissolution of the shells of plankton and coral skeletons (Feely *et al.* 2004, see Appendix 3d Water environment).

### 5.11.2 Consideration of the evidence

#### 5.11.2.1 Offshore wind farms

The operational stage of OWF development has minimal energy requirements (principally maintenance activities), OWF development will result in atmospheric emissions during the construction, commissioning and decommissioning phases of the project, principally through gaseous emissions from power generation of vessels.

The installation sequence of a turbine will vary depending on the type of foundation structure: gravity base will require initial preparation of the seabed, then placement and infill, however the structure can be constructed onshore, thereby reducing offshore operations. Other foundation types (monopile, multipile and bucket) only require placement and pile drive/suction installation (see Section 5.4.2.1 for explanation of different foundation types). Therefore time in the field of installation/support vessels may vary depending on foundation structure design, discussed further in the climatic factors section (Section 5.12.2.5).

Turbines are most likely to be taken to site on a barge, and installed from either a jack-up barge or a floating (semi-submersible) vessel/crane, depending on water depth, vessel/crane capability/availability. Positioning of barges/crane vessels will likely be by tugs and other vessels used could include survey vessels, guard vessels and support vessels for equipment/supply transfer and air support for crew changes (Table 5.33). During the operational phase of the wind farm, there may also be the requirement for maintenance trips, which will require supply vessels and support.

Table 5.33 – Possible vessels for turbine installation and their fuel consumption

| Vessel | Fuel type | Approx. fuel consumption rate (tonnes/day) |
|---|---|---|
| Jack-up barge | Diesel | 8 |
| Crane barge | Diesel | 8[1] |
| Anchor handlers (can be more than 1 used) | Diesel | 18 |
| Standby vessel | Diesel | 3 |
| Supply vessel | Diesel | 18 |
| Guard boat | Diesel | 3 |
| Crew transfer vessel (no. of trips will depend on operation) | Diesel | 18[2] |
| Helicopter (if air support used for crew change) | Helifuel | 0.3 |
| Diving barge | Diesel | 21[3] |
| Survey vessel | Diesel | 15 |
| Marine mammal mitigation vessel | Diesel | 13[4] |

*Notes: [1] have used fuel usage for jack-up, [2] have used fuel usage for supply vessel, [3] have used fuel usage for diving support vessel, [4] have used fuel usage for inspection vessel*

Emissions to atmosphere from individual projects will vary depending on the number of vessels required and the time these vessels are in the field. These assessments will be undertaken at a project specific level.

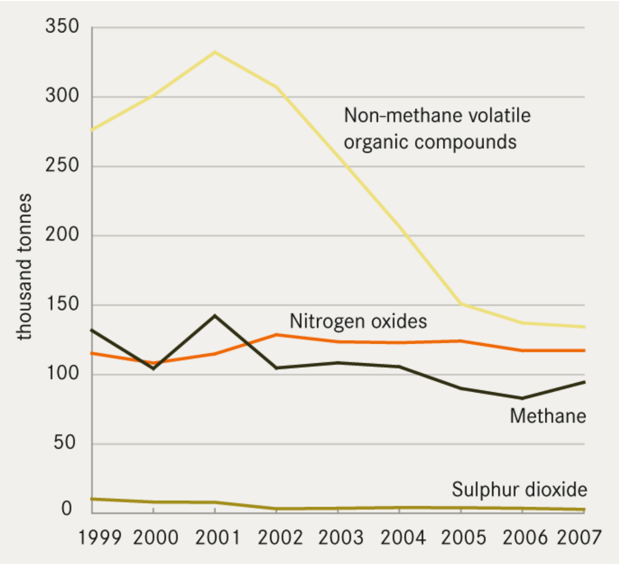
### 5.11.2.2 Wave and tidal developments

The effects on air quality identified in the OWF section also apply to wave and tidal stream technologies and predominantly relate to atmospheric emissions from the vessels used for installation, decommissioning and maintenance of installations. Atmospheric emissions and therefore air quality associated with tidal range schemes are skewed heavily by the long construction times (e.g. 7 years for La Rance), with high cumulative levels of emissions from construction and dredging vessels and vehicles (see Section 5.12.2.5 Climatic factors).

### 5.11.2.3 Oil and gas

The major sources of emissions to atmosphere from offshore oil and gas exploration and production are internal combustion for power generation by installations, terminals, vessels and aircraft, flaring for pressure relief and gas disposal, flaring from well clean-up and testing, cold venting from storage and loading operations and fugitive emissions. Further information, including quantitative estimates for previous licensing rounds, are given in SEAs 1-7.

Figure 5.36 – Emissions to air from the offshore industry, 1999–2007




*Source: OSPAR (2010a)*

Carbon dioxide accounts for the greatest proportion of emissions to air from offshore installations with around 32 million tonnes emitted in the OSPAR area in 2007. Emissions of carbon dioxide and nitrogen oxides have been relatively stable since 1999, while sulphur dioxide and methane emissions have been substantially reduced. Emissions of non-methane volatile organic compounds have halved. Measures taken by operators to reduce fugitive emissions (gas escapes, for example, from leaks or processes) and the use of vapour recovery systems at off-loading facilities have helped reduce emissions of methane and other volatile organic compounds (Figure 5.36, OSPAR 2010a).

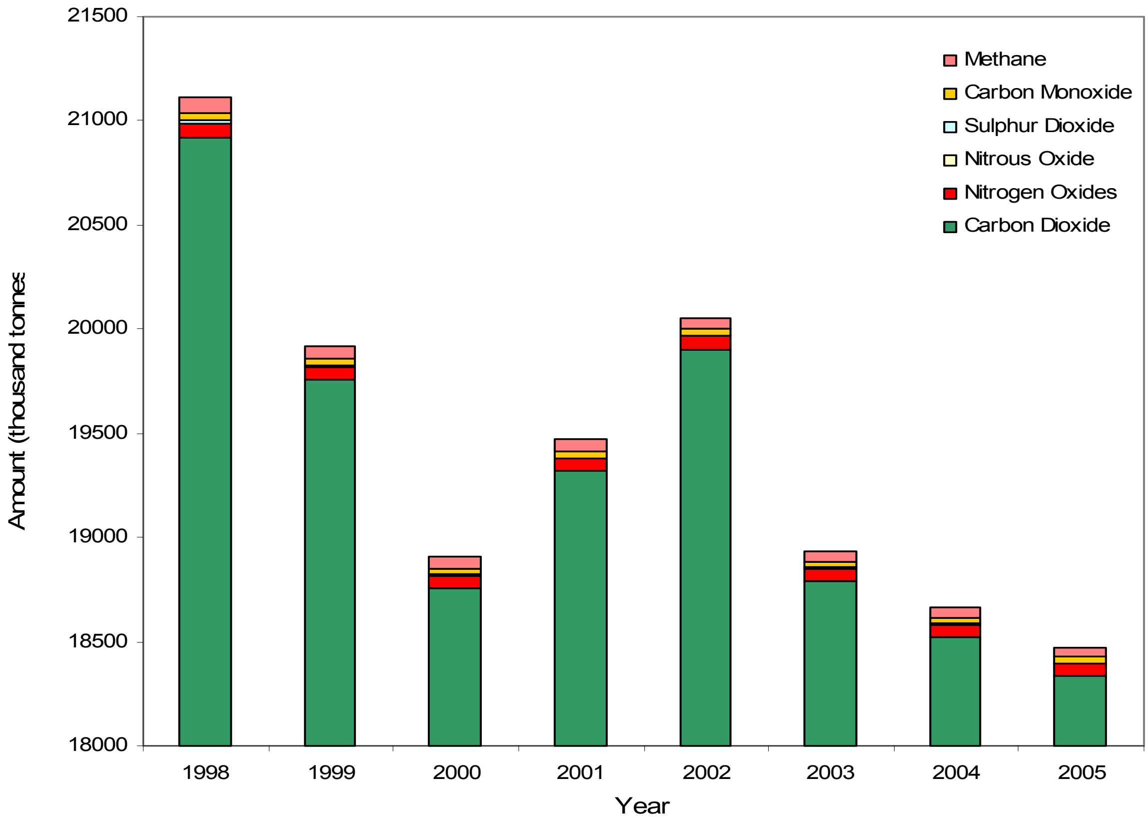
Emissions on the UKCS declined between 2003 and 2005 (Figure 5.37) and may be attributed to a decline in exploration activity (partly offset in subsequent years) and falling production. However it would be expected that emissions would increase due to greater power demands associated with operating mature fields, the use of injection as a method of disposal of produced water and drill cuttings and the potential use of reservoirs for gas storage.

Flaring from existing UKCS installations has been substantially reduced relative to past levels, largely through continuing development of export infrastructure and markets, together with gas cycling and reinjection technologies. Total flaring (excluding terminals) on the UKCS was 1,559,817 tonnes in 2005 (an increase of approximately 12% above 2004 figures (1,372,893)), compared to 1,699,978 tonnes in 1999. Generally though, gas flaring has reduced by 30% in the last 10 years (Defra 2010e). New developments will generally flare in substantial quantities only for well testing, start-up and emergency pressure relief, with “zero routine flaring” now considered a realistic design target for planned developments. Other than start-up flaring, subsea tie-back developments, which are predicted to account for the majority of production from proposed licence areas, will generally have little effect on host platform flaring.

Power requirements for the UK offshore industry are dominated by oil production installations (typically >50MW per platform), with smaller contributions from gas platforms and mobile drilling units (typically 10MW per unit) and support vessels. The major energy requirement for production is compression for injection and export, with power generated by gas or dual-fuel turbine (see below).

The Environmental Emissions Monitoring System (EEMS) database was established by UKOOA in 1992 to provide a more efficient way of collecting data on behalf of the UK oil and gas industry. Atmospheric data from the EEMS system is produced on an annual basis and can be used to show trends in UK offshore oil and gas activity greenhouse gas emissions. Emissions for the period 1998 to 2005 are summarised in Figure 5.37 (due to the roll out of the new EEMS reporting system, detailed industry reports with complete data sets are not yet available for years 2006 or 2007).

Figure 5.37 – Atmospheric emissions from combined UKCS production and exploration activities, 1998-2005




*Note: Due to the roll out of the new EEMS reporting system, detailed industry reports, with complete data sets, are not yet available for years 2006 or 2007, therefore data up to 2005 only have been used here.*
*Source: EEMS*

### 5.11.2.4 Gas storage

Atmospheric emissions associated with gas storage include those resulting from power requirements from compression. Types of compression machinery used in gas storage applications will depend on the operating conditions, but can include centrifugal compressor units (usually used for medium and high volumetric rates), driven by gas turbines or electric motors, or reciprocating compressors (usually used for lower flow rates) driven by electric motors or gas engines.

There are a small number of onshore gas storage facilities (e.g. Hole House and Hatfield Moor) and one offshore facility currently in operation: the Rough 47/8 Alpha facility (hereafter referred to as Rough). Rough is located approximately 26 miles off the Humber Estuary and is the largest gas storage facility in the UK, capable of supplying in excess of 7.5% of peak day demand. Gas is injected via 30 wells which have been drilled into the reservoir and withdrawn the same way using the internal pressure of the reservoir. Extracted gas undergoes several separation processes offshore before onward subsea transport to the Easington terminal, and after further processing, enters the National Transmission System. Rough has a total storage capacity equivalent to 30TWh at pressures of over 200bar and gas can be injected into the reservoir at an average of 160GWh a day, depending on the reservoir pressure. The Bacton Gas Storage project environmental assessment modelled predicted hourly and annual mean $NO_2$ concentrations from the onshore plant, with annual concentrations of 16-19μgm$^{-3}$ well below the 40μgm$^{-3}$, annual mean Air Quality objective (Bacton Storage Company Ltd 2009). As well as emissions from fuel use, emissions can be generated from a blowdown of the compression system, either planned for maintenance purposes or under emergency conditions.

#### 5.11.2.5 Carbon dioxide storage

Significant atmospheric emissions associated with carbon dioxide storage could result from potential accidental releases from shipping, pipelines or the storage areas themselves. Monitoring evidence from the North Sea Sleipner project suggests that all the gas injected into the formation has remained *in situ*, spreading throughout the formation (currently covering about 3km$^2$ of the 26,000km$^2$ available), with no leakage to the surface (Statoil website). Any failure would result in a large release of $CO_2$ in gaseous form either into the water or atmosphere. Low concentrations would have minimal effect beyond associated climate impacts and possibly small localised acidification of adjacent waters, but high concentrations could affect human life, ecology and other organisms. $CO_2$ is denser than air and therefore can displace it causing a suffocating effect, for instance a very large natural release of $CO_2$ from the Lake Nyos volcanic crater in Cameroon caused 1,700 human deaths and loss of livestock up to 25km from the crater (Clark 2001). Concentrations of $CO_2$ in air would need to be sufficient to reduce the oxygen content to 15-16%, at which time signs of asphyxiation would be noticed (IPCC 2005a).

Catastrophic releases are not the only concern, for instance IPCC (2005a) reports that chronic effects of $CO_2$ exposure at atmospheric concentrations of between 0.5 and 1% can result in metabolic acidosis (an increase in blood acidity) and increased calcium deposits in soft skin and is toxic to the cardiovascular system at concentrations exceeding 3% - note that $CO_2$ is naturally present in the atmosphere at a concentration of ~0.037%. Significant survey work would need to be undertaken to avoid formations and storage areas with faults or other features that could cause loss of containment and long term monitoring would need to be carried out on any storage site to make sure that leakages do not occur during operation and once the site is full to capacity. The Health and Safety Executive is assessing whether to regulate $CO_2$ as a hazardous substance under the *Pipelines Safety Regulations 1996* which would further help ensure that health and environmental effects of releases of $CO_2$ to the atmosphere are considered. A wider range of considerations with regard to carbon dioxide transport and storage and accidental release is provided in Section 5.13 Accidental events.

### 5.11.3 Spatial considerations

Section 2.5 outlines the likely scale and geographical distribution of plan activities. There are currently a small number of possible new offshore gas storage developments including the Gateway gas storage project, consisting of offshore underground salt cavern construction in the East Irish Sea, approximately 24km off the coast at Fylde, north west England. The onshore and offshore infrastructure associated with this project is expected to be completed by 2014. A second is the possible conversion of the Bains gas field in the East Irish Sea into a dedicated seasonal gas storage facility (estimated to be approximately one fifth the size of Rough described above), although a requirement for additional funding for this project is currently ongoing. The facility is expected to have a storage capacity of up to 20 billion cubic feet and could be available for production and injection in 2013. This development would also require a new unmanned platform and additional compression facilities, with resulting emissions associated with installation (gaseous emissions from installation and support vessels) and operation (fuel use for gas compressors). Permission has been granted by North Norfolk County Council for the construction of the onshore infrastructure for ENI's Baird gas storage project in the southern North Sea and proposals for the offshore elements of the project were submitted to DECC (Baird gas storage project website) with a storage licence issued in October 2010. Engineering and construction is likely to start in 2011 with an expectation of being operational by 2013. Due to the distribution of suitable geology (Southern North Sea, East Irish Sea), future projects are likely to occur in these areas.

In March 2010 the UK government announced funding for E.ON and Scottish Power to develop carbon capture and storage demonstrator scale projects potentially with 1,200-1,600MW of storage capacity at Kingsnorth, Kent and Longannet, Firth of Forth. E.ON has subsequently withdrawn from the programme but the Longannet scheme is still due to go ahead, with atmospheric emissions reductions associated with fitting CCS technology over an existing power station expected by 2014.

Currently tidal range developments are only likely in south western or western areas of England and Wales. The Severn Tidal Power feasibility study determined that a tidal range scheme was not currently feasible but may be open to future consideration. A feasibility study of options for a Mersey tidal energy scheme is currently underway. Given that there are currently no tidal range projects proposed it is not possible at this time to estimate the potential atmospheric emissions associated with their construction.

The increase in shipping that will be required for installation, maintenance and decommissioning of all new marine energy projects will result in a localised increase in emissions at port facilities. A DECC (2009d) study into the port facilities required to meet Rounds 1-3 OWF demands detailed the current UK facilities available and concluded that at least 6 ports spread around the UK would be required to be developed by 2014 (see Appendix 3h). There would be both associated atmospheric emissions from the construction of facilities as well as the increased shipping activity in these areas.

### 5.11.4 Cumulative impact considerations

Atmospheric emissions from offshore oil and gas exploration and production activities may contribute to reduction of local air quality, though the recent trend of declining emissions from activities are likely to continue and, for instance, incremental flaring associated with new developments is not expected to be significant. Flaring from existing UKCS facilities has been substantially reduced relative to past levels, largely through continuing development of export infrastructure and markets, together with gas cycling and reinjection technologies. In addition, offshore oil industry emissions are subject to an Emissions Trading Scheme. New developments will generally flare in substantial quantities only for emergency pressure relief, with "zero routine flaring" now considered a realistic design target for new developments. Other than start-up flaring, subsea tie-back developments will generally have little effect on host installation flaring.

Greenhouse and acid gas emissions effectively contribute to a mixed regional or global "pool" and can therefore be considered cumulative. The implications of the ultimate use of oil and gas production from UKCS for greenhouse gas emissions and on UK commitments under the Kyoto Protocol were not considered here since these are subjects for different high level policies, fora and initiatives including UK energy policy, security of supply considerations, emissions trading etc.

Atmospheric emissions associated with offshore renewables are largely from their manufacture and deployment, with maintenance involving less intensive boat-based visits. Cumulative effects from an increase in port capacity or the increased utilisation of ports with existing capacity could lead to local air quality effects. The increased deployment of offshore renewables towards 2020 and beyond, in association with CCS and other energy efficiency measures, could cumulatively make a positive contribution to both greenhouse gas abatement and air quality improvement.

Operational air quality effects of carbon dioxide transport and storage are unlikely to be significant and should not pose any cumulative effects, for instance the offset of emissions of both $CO_2$ and $SO_x$ provide positive contributions to climate and local air quality targets respectively. The emission of gases which could lead to acidification or eutrophication (e.g. $NH_3$) would continue to pose a possible source of cumulative effect in combination with other industrial sites/operations (not considered in this plan/programme) in areas of the UK where high emissions tend to be concentrated.

Previous SEAs have forecast the atmospheric emissions likely to result from exploration drilling following the last three licensing rounds (Table 5.34), and as a proportion of total UKCS emissions from exploration drilling (Table 5.35). It is clear that successive rounds each make a relatively small incremental contribution to total emissions from this sector, and therefore negligible contribution to overall UK emissions.

Table 5.34 – Indicative atmospheric emissions resulting from SEA forecasts for exploration drilling resulting from previous licence rounds

| | $CO_2$ (tonnes) | $NO_x$ (tonnes) | $N_2O$ (tonnes) | $SO_2$ (tonnes) | CO (tonnes) | $CH_4$ (tonnes) | VOC (tonnes) |
|---|---|---|---|---|---|---|---|
| SEA 7 | 20,480 | 86 | 1 | 26 | 6 | <1 | 2 |
| SEA 6 | 8,192 | 34.5 | 0.5 | 10.3 | 2.4 | <0.1 | 0.8 |
| SEA 5 | 40,960 | 172.8 | 2.81 | 51.2 | 11.77 | 0.4 | 3.77 |

Table 5.35 – Incremental contribution of atmospheric emissions resulting from SEA forecasts for exploration drilling resulting from previous licence rounds, relative to existing emissions from exploration drilling

| | $CO_2$ (%) | $NO_x$ (%) | $N_2O$ (%) | $SO_2$ (%) | CO (%) | $CH_4$ (%) | VOC (%) |
|---|---|---|---|---|---|---|---|
| SEA 7 | 0.06 | 0.07 | 0.08 | 0.44 | 0.01 | <0.01 | <0.01 |
| SEA 6 | 0.10 | 0.13 | 0.10 | 0.78 | 0.02 | <0.01 | <0.01 |
| SEA 5 | 2.98 | 1.0 | 3.7 | 8.1 | 0.21 | 0.01 | 0.16 |

## 5.11.5 Summary of findings and recommendations

OWF, wave and tidal stream development will result in atmospheric emissions during the construction, commissioning and decommissioning phases of the project, principally through gaseous emissions from power generation of vessels. Emissions will also be associated with the construction of the devices to be deployed and the choice of construction materials, and it is possible that some of these may take place outside of the UK. The potential expansion of ports to facilitate R3 OWF development (see Appendix 3h) may have implications for local air quality in these areas. Operational effects of offshore renewables are expected to be negligible, and effects at the strategic level are not considered to be significant.

Major sources of emissions to atmosphere from offshore oil and gas exploration and production, and gas storage and carbon dioxide storage, are internal combustion for power generation by installations (e.g. for compression and injection), terminals, vessels and aircraft. Significant combustion emissions from flaring are not expected from potential development in the proposed licence areas, given the availability of existing gas process and export infrastructure. Though the use of carbon dioxide storage may alter the emissions portfolio of a given coal or gas power plant (e.g. see an increase in the emissions of $NH_3$), it is not a consideration of this SEA and would need to be considered at the project specific level. The lack of a recent detailed industry report for which EEMS data is available represents a gap in publicly available and collated information on emissions from the offshore oil and gas sector.

Potential environmental effects of acid gas and greenhouse emissions are, respectively, regional and global in nature. Given the distance of most prospective areas for oil and gas from the coastline, local air quality effects from atmospheric emissions are not expected. Few new effects are expected in terms of the siting of gas storage and carbon dioxide storage facilities in existing hydrocarbon reservoirs. However, the use of vessels for construction and maintenance and the potential transportation of liquid $CO_2$ by ship to some carbon dioxide storage reservoirs make shipping the greatest potential source of atmospheric emissions from these technologies.

In view of regulatory controls and commercial considerations, combustion emissions from power generation are unlikely to represent a major contribution to industry or national totals.

# 5.12 Climatic factors

## 5.12.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Contributions to net greenhouse gas emissions | X | X | | | | | | 5.12.2.5 |
| | Reduction in net greenhouse gas emissions | | | X | X | X | X | X | 5.12.2.5 |
| | Positive socio-economic effects of reducing climate change[2] | | | X | X | X | X | X | 5.12.2.2 |

*Note: [2]Outline assessment only*

There is a high level of scientific understanding with regards to the effect of anthropogenically enhanced levels of greenhouse gases (GHGs) and ozone on global radiative forcing (IPCC 2007), with less known about other potentially important factors including aerosols and solar irradiance (i.e. the influence of cyclic solar activity on the Earth's climate, see Blaauw *et al*. 2004). The following section considers the aspects of the current draft plan/programme (see Section 2.1) with regards to climate change and the policy context which has developed in recent years in order to try and avert its worst effects. The plan/programme is complementary to current policy, e.g. renewable generation targets and $CO_2$ reduction commitments, and enhanced security of supply through a maximisation of domestic fossil fuel production. Though this latter aspect of the plan may be regarded as deleterious to climate change mitigation efforts, projections of the likely energy mix suggest a dependence on fossil fuels for the foreseeable future, and certainly within the currency of OESEA2.

A combination of a commitment to reduce carbon equivalent emissions and increase the proportion of our energy generated from renewable sources is a positive move towards trying to reduce any anthropogenic influence on climate change. Moreover, such commitments will help to reduce other negative externalities (e.g. ocean acidification) of acidifying emissions (see Section 5.11 and Appendix 3d Water environment) while reducing the present dependence on finite stocks of hydrocarbons and enhancing the security of energy supplies.

## 5.12.2 Consideration of the evidence

### 5.12.2.1 Climate change

Anthropogenic sources of greenhouses gases are implicated in amplifying the natural greenhouse effect resulting in global warming and potential climate change (IPCC 2007). Carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$) are termed "direct" greenhouse gases as they have a direct effect on radiative forcing within the atmosphere. Other gases including carbon monoxide (CO), volatile organic compounds (VOC), oxides of nitrogen (NO and $NO_2$) and sulphur dioxide ($SO_2$) although not significant direct greenhouse gases, are reactive and impact upon the abundance of the direct greenhouse gases through atmospheric chemistry.

### 5.12.2.2 Energy and climate change policy context

Much of the policy context relating to climate and climate change is discussed in Appendix 3f and Appendix 4. The following provides a short description of the policy and legislation which is relevant to the draft plan/programme considered in this SEA.

The residence time of $CO_2$ in the atmosphere is in the range 5-200 years (see Appendix 3f for a greater range of estimates), and it is therefore apparent that current policy decisions with regard to climate change, and those which may occur in the near future, have far reaching effects for the trajectory of changes in the coming decades and to at least the end of the century. The economic costs of not attempting to avoid the worst effects of climate change at the earliest opportunity outweigh any subsequent cost of climate change mitigation (The Stern Review 2006). In the absence of the high-level mitigation suggested in recent UK Government policy, and partly its realisation through the decarbonisation of the energy sector impacts (e.g. sea-level rise, coastal flooding and coastal squeeze) would occur at a faster rate than if efforts to reduce emissions were realised. Access to water, food and also the health effects of climate change will all have a socio-economic impact in the UK and elsewhere.

In December 2008 the European Parliament and Council of Ministers reached political agreement on legislation to require that by 2020, 20% of the EU's energy consumption must come from renewable sources, with requirements set out in the Renewable Energy Directive. The UK's contribution will require its share of renewable energy consumption to increase from around 1.5% in 2006 to 15% by 2020. The UK Government Renewable Energy Strategy (2009) outlines scenarios for achieving this goal. In July 2009, the UK Government published the Low Carbon Transition Plan, which outlined how the challenges of reducing greenhouse gas emissions for each sector will be met while ensuring clean, affordable and secure energy supplies. These broad principles are in line with those of the 2007 Energy White Paper, 'Meeting the Energy Challenge'. This document outlined targets and plans relating to $CO_2$ emissions and energy production to 2050. The legislative aspects of this paper passed into law in the *Energy Act 2008*, which makes provisions for a number of areas relevant to the current draft plan/programme:

- Gas importation and storage (including Carbon Capture and Storage)
- Electricity from Renewable Sources (strengthens the existing renewables obligation in order to generate enhanced speed of delivery and diversity of supply technologies)
- Decommissioning of Energy Installations
- Improvements to offshore oil and gas licensing
- Miscellaneous energy issues (e.g. provision of smart meters, renewables heat incentives, transmission access powers and costs relating to network connections, gives effect in legislation to earlier administrative transfer of responsibilities for certain aspects of energy regulation, and contains provisions relating to nuclear security)

The *Energy Act 2008* seeks to not only help to maintain energy supply reliability, promote competitive markets and ensure affordable heating, but also contribute to the reduction in $CO_2$ emissions which may be linked to climate change. The *Climate Change Act 2008* makes provisions for the reduction of carbon equivalent emissions through a number of legislative measures, which includes the setting of a carbon budget. The Act aims to meet this target through a range of measures, but principally the establishment of the Committee on Climate Change (CCC), to provide a system of carbon budgeting and trading, to encourage activities that reduce or remove greenhouse gases from the atmosphere and to promote through financial incentive the production of less waste and more recycling. The carbon budget currently sets a target for the reduction of greenhouse gas emissions by 80%

on 1990 levels by 2050 and a specific reduction in $CO_2$ emissions of 34% by 2020 (as implemented through a 2009 Order brought about through a recommendation by the CCC). Net $CO_2$ emissions in 2009 were provisionally 19% below 1990 levels – the UK has a domestic goal of reducing these emissions to 20% below 1990 levels in 2010.

The later *Energy Act 2010* provides additional support to the low carbon transition through the introduction of a CCS incentive for commercial-scale CCS demonstration projects, the retrofit of additional CCS capacity to these projects should they need it, and the requirement for government to report on the progress being made to decarbonise the electricity market and the development and use of CCS.

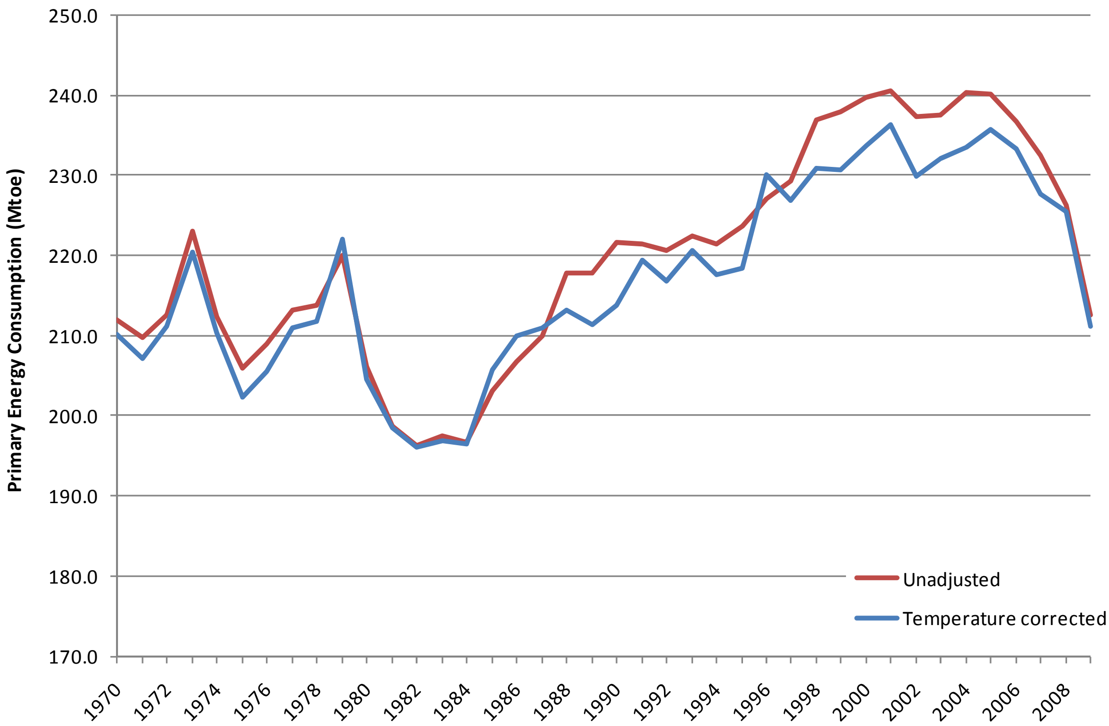
The proportion of renewables covered by the Renewables Obligation (i.e. biofuels, wave, solar photovoltaic, onshore/offshore wind and small scale and re-furbished hydro) in energy supply has grown from just under 1% in the early 1990s to 11% in 2010/11 and is set to grow towards 15.4% by 2015 (as set out in the *Renewables Obligation Order 2009*). The reform of the Renewables Obligation under the *Energy Act 2008* introduces the banding of technologies, whereby the number of Renewables Obligation Certificates (ROCs) earned by suppliers per KWh varies depending on the energy supply technology, which provides incentives to develop and diversify renewables energy production. Currently, fossil fuel energy is the primary source of energy supply in the UK followed by nuclear power, the remainder coming from hydro and wind power.

The UK is presently the EU's largest producer of oil and second largest producer of gas due to energy production and exports from the North Sea (IEA website). In the 1990s, the UK changed from an energy net importer to a net exporter, with government policy designed to maximise production from domestic reserves for as long as possible. To achieve this end, the licensing system was reformed with the introduction of two new licences: i) the 'promote' licence and ii) the 'frontier' licence (IEA website, DECC Oil and Gas website). However, with oil & gas production having peaked during 1999, UK oil & gas production is falling. In the second quarter of 2010, the UK was a net importer of oil and oil products by 2.6 million tonnes, compared to the situation for the same quarter in 2009 where the UK was a net exporter by 0.4 million tonnes. The UK became a net importer of natural gas in 2004, and in quarter 3 of 2010 importation was 54.2% higher than at the same time in 2009, with a corresponding increase in gas demand of 9.6% (DECC 2010m). The issue of maximising the economic production from the UK's oil and gas reserves was reiterated in the UK Government's Low Carbon Transition Plan, and also features in the draft Marine Policy Statement which will form the basis for marine planning by, principally, the MMO until Marine Plans are in place.

## 5.12.2.3 Energy consumption

Since 1970 the consumption of primary energy has fluctuated, peaking in 2001 at 263.3 Mtoe (Million tonnes of oil equivalent), falling by 11% to 211.2 Mtoe in 2009. Energy consumption is partly a function of weather conditions, though when these are factored into the calculation of energy consumption the broad trend remains the same (Figure 5.38). Since 1980, consumption of natural gas and primary electricity has risen considerably, whilst consumption of oil has remained around the same and coal has fallen (DECC 2010k). The increase in the total consumption figures through the 1980s and 1990s can be linked to the growing output of goods and services associated with economic growth, increasing travel, rising numbers of households and the gradual increase in population, with the recent decline attributed to a reduced use of gas and petroleum, though economic recession would also have been a factor (DECC 2010k).

Figure 5.38 – Total Primary Energy Consumption (Mtoe), 1970-2009




*Source: DECC (2010k)*

Annual primary energy consumption in the UK averages about 234Mtoe (2000-2009), with the share of fossil fuel used in energy consumption standing at an average of ~90% over the same period (DECC 2010j). The final consumers of energy in the UK can be divided into four groups: industry, domestic sector, transport and services. Table 5.36 shows final energy consumption for the main sectors, indicating that overall energy consumption for every sector has declined in the last six years, though in the context of long-term trends for energy consumption, this does not represent a significant reduction.

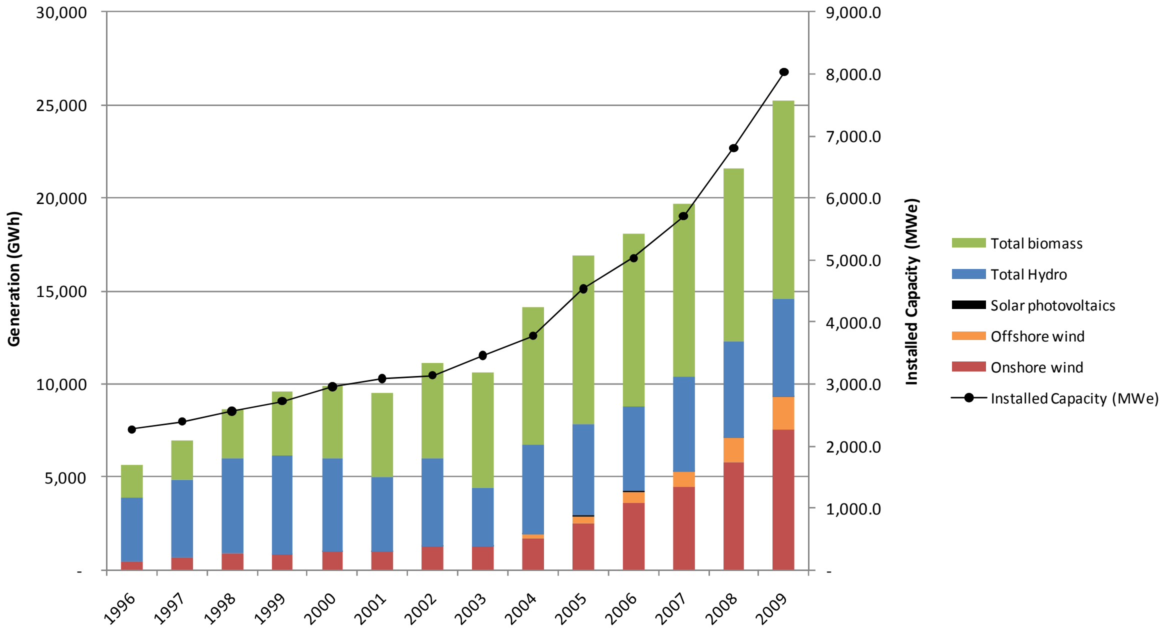
Table 5.36 – Final energy consumption by end user (Mtoe)

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| Industry | 33.2 | 32.6 | 31.8 | 31.0 | 30.8 | 26.7 |
| Domestic sector | 48.6 | 47.8 | 46.5 | 44.9 | 46.0 | 43.6 |
| Transport | 57.8 | 59.2 | 59.9 | 60.2 | 58.9 | 56.5 |
| Other final users | 20.3 | 20.3 | 19.2 | 18.6 | 18.7 | 17.1 |
| **Total final energy consumption** | **159.8** | **159.9** | **157.5** | **154.8** | **154.3** | **143.9** |

*Note: Excludes non-energy use of fuels*
*Source: DECC (2010k)*

The supply of renewable energy has substantially increased in recent years from a total of 1.02 Mtoe in 1990 to 5.17 Mtoe in 2007. The largest growth in renewable energy production has been in biomass, though there has been a net increase in all renewables components, particularly onshore and offshore wind. Wind energy has increased substantially up to 2010, accounting for nearly 10% of electricity generation from renewable sources, and this is likely to increase as new onshore and offshore wind farms develop. Figure 5.39 shows the change in energy generation for a range of renewable sources of energy, and the total installed capacity for all renewable technologies up to 2009.

Figure 5.39 – Renewable energy generation (GWh) and installed capacity (MWe), 1996-2009



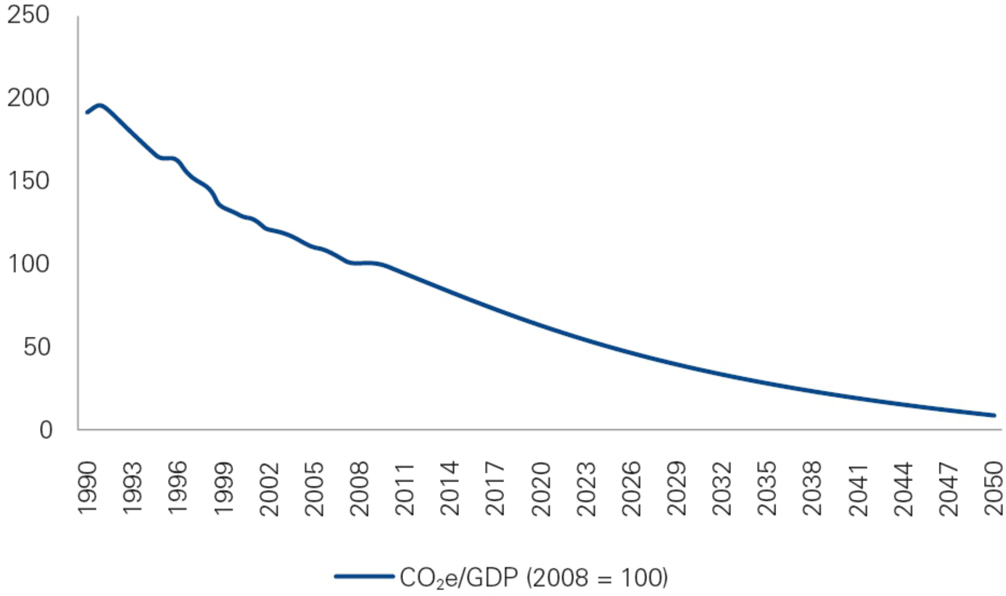

*Source: DECC (2010j)*

## 5.12.2.4 Carbon intensity and the energy mix

Carbon intensity (the ratio of greenhouse gas emission to economic output (i.e. GDP)) reflects both a country's level of energy efficiency and its overall economic structure. During 1995 and 2000 carbon intensity of primary energy consumption fell significantly due to the 'dash for gas' within the electricity generating sector (and to a lesser extent within industry as a whole), increased use of more efficient generation technology such as combined cycle gas turbines and combined heat and power plants (CHP) as well as better performance by nuclear power stations (House of Commons 1999, Baumert *et al.* 2005, Bishop & Watson 2005). DECC (2009c) have estimated the potential future trajectory of UK carbon intensity (Figure 5.40). The projection assumes that the 2050 carbon budget is met (80% reduction on 1990 levels) and that GDP grows by 2.25-2.5% per year. By 2050 the UK GHG intensity would have to decrease to less than one tenth of its 2009 level. Sectoral emissions over this period have been estimated by the CCC using the MARKAL model (see DECC 2009c). Actual performance to date against domestic and international (i.e. Kyoto) targets are provided in DECC (2010n).

Overall, energy consumption has risen more slowly than economic activity (as measured by gross domestic product), reflecting the tendency of organisations and individuals to find ways of using energy more efficiently (RCEP 2000). This trend is likely to continue due to the Climate Change Levy (CCL) that came into effect in 2001, encouraging industries to examine more energy efficient production methods. The Government is now also offering Climate Change Agreements (CCAs) to some sectors which allow for up to an 80% reduction in CCL contributions provided that additional $CO_2$ emissions targets are met. The Carbon Reduction Commitment (CRC) also seeks to reduce emissions principally from large, but low-energy use private and public sector organisations. It is thought that alongside the EU Energy Performance of Buildings Directive, measures set out in the CRC should deliver reductions equivalent to 0.5MtC per year to 2015, and 1.2MtC per year to 2020 (Defra 2007).

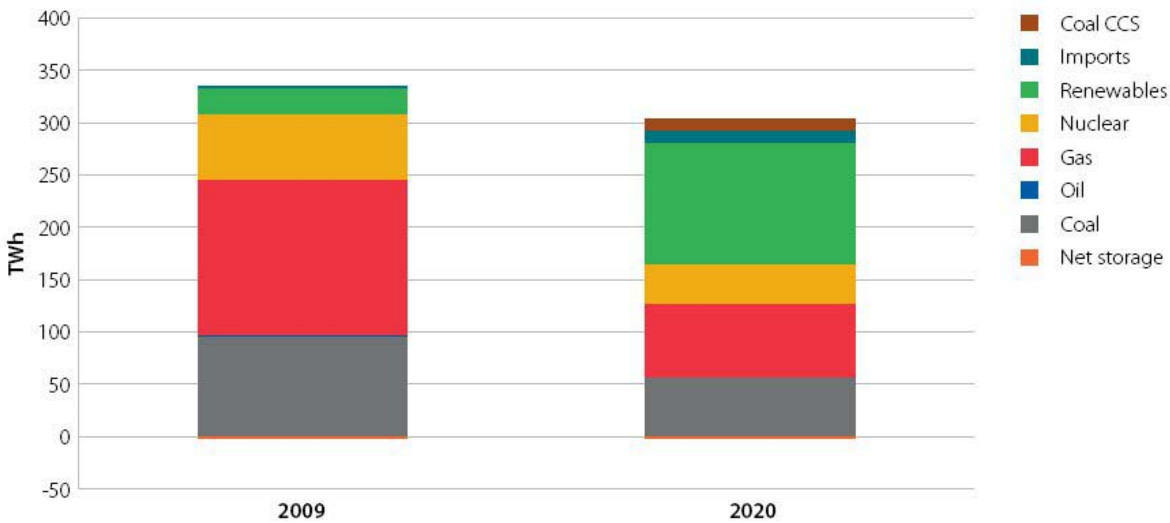
Figure 5.40 – Historic and illustrative future trajectory for UK GHG emission intensity, 1990-2050




*Source: DECC (2009c)*

Figure 5.41 reflects the output of calculations by the Committee on Climate Change (2010), showing the electricity generation mix in 2009, and an indicative scenario of the mix in 2020, based on the level of decarbonisation (i.e. falling levels of conventional coal-fired generation, new investment in renewables, nuclear and CCS generation) and energy efficiency in the energy sector required to meet climate change commitments.

Figure 5.41 – Indicative CCC scenario for mix of supply in 2020 compared to actual 2009 figures



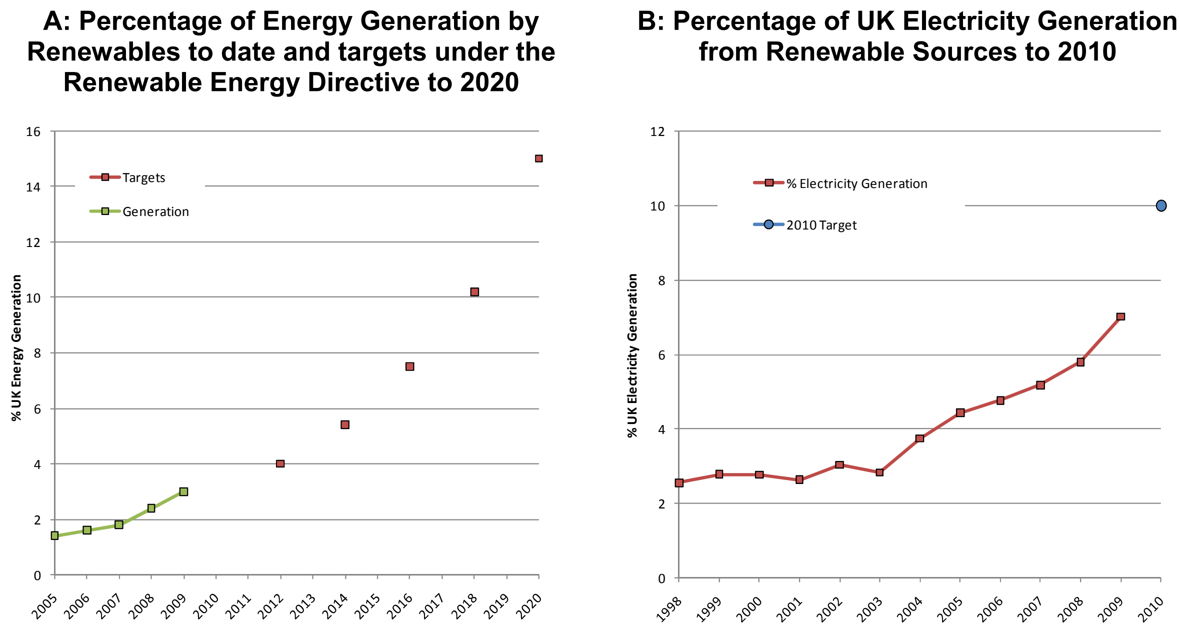

*Note: based on CCC calculations on figures from the 2010 DECC Energy Trends (March). Based on gross supply of electricity from all major power producers and all renewable generators. Assumes: 23GW of new wind generation to 2020, up to three new nuclear plants by 2022, four CCS demonstrators by 2020.*
*Source: CCC (2010)*

## 5.12.2.5 Technology specific considerations

### Offshore renewables

In the coming years, renewable energy will contribute to achieving a more desirable carbon intensity through a net reduction in greenhouse gas emissions. The Renewable Energy Strategy states that with the relevant policies in place, and the achievement of the UK's renewable energy generation targets, an offset equivalent to 750 million tonnes (Mt) of carbon equivalent emissions will be made up to 2030, with wave and tidal stream energy accounting for up to 17Mt of this total (DECC 2010a). UK $CO_2$ emissions were 480.9Mt in 2009. When the wider basket of emissions referred to in the *Climate Change Act 2008* under the 'carbon budget' (i.e. those included in the Kyoto Protocol) are included, this is raised to 574.6Mt. Though renewable energy will not assist the decline of $CO_2$ emissions from the UK in isolation, indeed emissions in 2009 are already 26% below 1990 levels, a dependence on fossil fuels will continue for the foreseeable future. In the wider energy context, renewable energy could offset fossil fuel demand by 10%, and reduce gas imports by 20-30% on what they otherwise would have been by 2020 (DECC 2009c). The increased deployment of renewables is therefore multifaceted, both aiding a reduction in greenhouse gas emissions while contributing to domestic energy supplies. It may be expected that the UK will meet 7.5% of its primary energy generation from renewables (i.e. half way to the 2020 target) within the currency of this SEA (Figure 5.42).

Figure 5.42 – Renewable energy and electricity generation in relation to relevant targets




*Source: DECC (2010j)*

Life Cycle Assessment (LCA) is a methodology used to estimate the likely impact of a device or development from its manufacture, deployment, operation, maintenance and eventual decommissioning, and has been variously applied to developments to assess both their environmental and economic impact and feasibility. The Energy Balance or Energy Payback Time (EPT) refers to the time it takes for a generating station to recover the energy used in its manufacture and installation. The EPT for a number of types of marine renewable technologies considered in the draft plan/programme being assessed by this SEA is summarised in Table 5.37 below. Devices have emissions associated with their manufacture, installation and decommissioning which over the lifetime of a development may be expressed as a unit of $CO_2$ (g) per kilowatt hour produced (i.e. the carbon intensity). For comparison, the 2009 UK carbon intensity of the overall energy generation mix was 496 $CO_2$/kWh (CCC 2010).

Table 5.37 – EPT and carbon intensity for a range of marine energy technologies

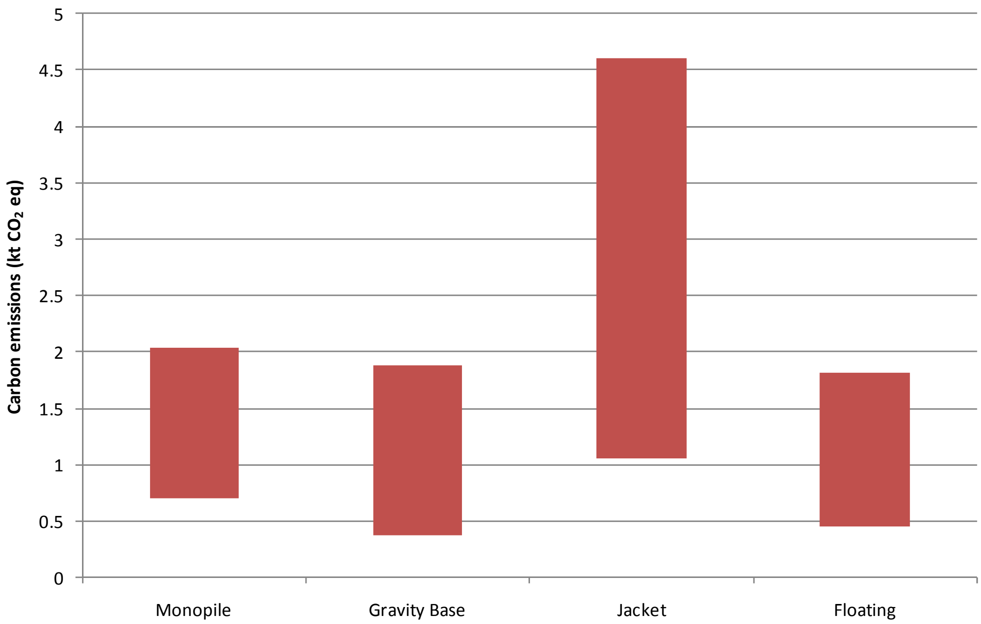
| Device Type | Specifications | Operational lifetime (years) | Carbon Intensity (g $CO_2$/kWh) | EPT (months) |
|---|---|---|---|---|
| Wind | Vestas V90 (3MW)[1] | 20 | 5.23 | 6.8 |
| | Generic fixed offshore turbine (5MW)[2] | 20 | - | 4 |
| | Sway concept floating wind turbine (5MW)[3] | 20 | - | 5.2 |
| Wave | Pelamis (0.75MW)[4] | 20 | 23 | 13 |
| Tidal stream | Seagen (1.2MW)[5] | 20 | 15 | 14 |
| Tidal range | Barrage (e.g. Cardiff-Weston – 8.64GW)[6] | 120 | 2.42 | 5-8 |
| | Barrage (e.g. Shoots – 1.05GW)[6] | 120 | 1.58 | 5-8 |
| | Lagoon (e.g. Swansea Bay – 60MW)[7,8] | 120 | - | 6-12 |
| Coal | Typical UK coal power plant[9] | - | ~990e | - |
| Coal | IGCC post-combustion CCS[10] | - | 170 | - |
| Coal | PC post-combustion CCS[11] | - | 243 | - |

*Note: the values provided should be interpreted as indicative only. Values for individual projects will differ due to the materials used, capacity and generation of the device and distance from shore. Efficiencies in production and economies of scale may be reasonably assumed as technologies progress.*
*Source: [1]Vestas (2006), [2]Tryfonidou & Wagner (2004), [3]Weinzettel et al. (2009), [4]Harrison (2008), [5]Douglas et al. (2008), [6]Sustainable Development Commission (2007), [7]Entec (2007), [8]AEA (2007), [9]Odeh & Cockerill (2008a), [10]Odeh & Cockerill (2008b), [11]Koornneef et al. (2008)*

One of the principal contributors to the embedded emissions of any offshore wind development is foundation manufacture. Black & Veatch (2010) calculated a range of carbon emissions for various types of foundation which are likely to be used in Round 3 developments including monopile, gravity, jacket and floating varieties (Figure 5.43). Jacket type foundations are calculated to produce the greatest emissions due to the large amount of steel required in their construction. In comparison, transport emissions are relatively small though will vary significantly depending on the size of structure and the distance between the site of manufacture and deployment location. Black & Veatch (2010) estimate that for the same scenario[29], the largest $CO_2$ equivalent emissions will arise from the transport of gravity base structures (124 tonnes compared with 8 tonnes for monopile structures and 21 for a steel jacket). The payback period for emissions produced during this part of the development is therefore likely to be most significant for jacket-type foundations, as despite the relatively large transport emissions involved in deploying gravity bases, this is small in comparison to those from steel production.

[29] Construction materials sourced from the UK and transported to onshore site divided as follows: **North** 50% from Scotland and transported by sea, ~1000km, using small bulk carriers, **East** 30% and transported by rail using diesel freight trains, ~150km, **South** 10% and transported by rail using diesel freight trains, ~250km, **West** 10% and transported by rail using diesel freight trains, ~400km. Distance from onshore site to offshore deployment assumed to be ~100km, transported by large bulk carrier.

Figure 5.43 – Range of possible emissions (thousand tonnes $CO_2$ equivalent) for offshore wind foundation types




*Notes: based on emissions factors for material used on foundation construction.* ***Steel****: 1.77 kg* $CO_2$*/kg,* ***concrete****: 0.306 kg* $CO_2$*/kg,* ***sand and gravel****: 0.0053 kg CO2/kg. Assumptions are:* ***monopile****: steel, 400-750 tonnes;* ***gravity base****: concrete (40%), sand and gravel (60%), 3,000-12,000 tonnes;* ***jacket****: steel, 600-2,000 tonnes;* ***floating****: concrete (90%), steel (10%), 1,000-3,000 tonnes.*
*Source: Black & Veatch (2010)*

With specific regard to tidal range developments, a scoping study for the Severn barrage outlined the stages of the project which would have an impact on the sinks or sources of carbon (Table 5.38), and these may be reasonably transposed to any similar development, though the magnitude of changes would be site and project specific. Construction times for barrages and lagoons are typically long (estimates of 4-6 years for Severn proposals and 7 years for La Rance), and will have relatively high emissions associated with construction. The long operation time (~120 years) and high capacity should offset these emissions relatively quickly, though some losses, such as the sequestration of carbon in intertidal sediments (see: Laffoley & Grimsditch 2009) would be offset by the opportunity cost of utilising low carbon energy production, but in the long-term would be a sink which could either not be replaced, or would be replaced over a substantial time period. The creation of suitable replacement habitat would also help to neutralise the reduction in this natural carbon sink.

Table 5.38 – Effect of different stages of a tidal barrage construction, operation and decommissioning which could change scale of a source of sink for carbon emissions

| Description of Change | Magnitude of Change | Significance |
|---|---|---|
| Increase of emissions from raw material supply | Medium | Potentially significant |
| Increase of emissions from manufacturing | Medium | Potentially significant |
| Increase of emissions from transportation/plant equipment during construction and installation | Medium | Potentially significant |
| Increase in emissions during construction from dredging | Low | Not significant |
| Increase in emissions during construction from pumping | Low | Not significant |
| Increase in emissions during construction from waste | Low | Not significant |

| Description of Change | Magnitude of Change | Significance |
|---|---|---|
| disposal | | |
| Increase in emissions during construction due to disruption in traffic and vessels | Low | Not significant |
| Increase in emissions during construction due to workers travelling to site | Low | Not significant |
| Decrease in emissions released due to renewable energy source | High | Potentially significant |
| Decrease in emissions released due to maintenance | Low | Not significant |
| Increase during operation due to continual dredging | Medium | Potentially significant |
| Increase in emissions due to pumping to maintain water levels | High | Potentially significant |
| Increase in emissions due to loss of intertidal habitat for carbon sequestration[1] | Medium | Potentially significant |
| Increase in emissions due to methanogenesis/$CO_2$ direct release/changes in estuarine conditions | Medium | Potentially significant |
| Decrease in emissions due to new habitat creation under Habitats Directive | | Potentially significant |
| Variation in emissions due to decommissioning of option | Medium | Potentially significant |

*Note: [1]see: Laffoley & Grimsditch (2009)*
*Source: (DECC 2008c, 2010c)*

## Oil and gas

In 2001, 70% of energy use in the offshore oil and gas sector was for pumping and compressing with much of the rest made up of power generation (Defra 2010e). Associated emissions of carbon dioxide from oil and gas activities have been relatively stable since 1999. Carbon dioxide accounts for the greatest proportion of emissions to air from offshore oil and gas installations with around 32Mt emitted in the OSPAR area in 2007. Measures taken by operators to reduce fugitive emissions (gas escapes, for example, from leaks or processes) and the use of vapour recovery systems at off-loading facilities have helped reduce emissions of methane and other volatile organic compounds (OSPAR 2010a).

Shipping emissions are a significant proportion of those associated with the offshore sector and there is unlikely to be a shift away from the use of conventional heavy fuel oil in the short to medium term (Gilbert *et al.* 2010). Technical and operational, or market-based approaches may help to curb emissions from shipping with UK Government and chamber of shipping stating a preference for a cap-and-trade approach, and in any case, in order to meet emissions targets with a view to avoiding a 2°C rise by the end of the century, shipping emissions will have to be considered (Gilbert *et al*. 2010).

## Gas storage

Greenhouse gas emissions associated with gas storage may emanate from the consumption of gas, fuel and diesel, flaring and venting and fugitive and other emissions. As an example, $CO_2$ emissions from the Rough gas storage facility in 2002 were 106,172 tonnes (or 0.6% of the total $CO_2$ emissions from offshore facilities), increasing to 109,559 tonnes $CO_2$ in 2005. Emissions from the Easlington gas terminal in 2002 amounted to 94,786 tonnes (which accounted for just over 2% of the total $CO_2$ emissions from onshore facilities) and with the exception of an increase in 2004 (103,883 tonnes, 2.4%), $CO_2$ emissions decreased to 91,046 tonnes (2%) in 2005. Gas compression power requirement can be the major fuel gas user on a facility. From a representative in-house Operator study, assuming plant was online for 365 days per year for 4 years and 349 days per year for 3 years (to allow for planned maintenance) a 20MW compressor would produce 270 t/d of $CO_2$, while a 40MW compressor would generate 540 t/d $CO_2$ (Bacton Storage Company Ltd 2009).

The construction of facilities for the transport and injection of gas will also have associated emissions. For salt cavern construction, Gateway Gas Storage (2007) estimate that for their East Irish Sea facility, 763 tonnes $CO_2$ will be released during the drilling of each well (over 15 days), with a total of 20 wells to be drilled. Additional emissions come from the commissioning of the salt caverns and annual maintenance which is estimated to be 25,776 and 83.2 tonnes $CO_2$ respectively. The Deborah gas storage project (ENI Hewett Ltd 2010) due for commissioning in the Southern North Sea uses depleted gas reservoirs, and is estimated to have installation emissions (i.e. those associated with power generation for the drilling rig and support vessels) amounting to 94,704 tonnes $CO_2$.

## Carbon dioxide storage

As part of the *Energy Act 2010* the government set out a policy requiring all new coal plant to demonstrate full carbon capture and storage (CCS) on at least 400MW (or 25%) of their total output, with CCS of their full capacity expected within 5 years of 2020. The CCS competition initiated in 2007 has now been opened to include both coal and gas fired power generating stations. Estimates of the storage capacity of existing oil and gas reservoirs are in the range of 7-10Gt, with estimates of the additional storage capacity of saline aquifers of between 20 and 200Gt (DECC 2010i). $CO_2$ emissions from fossil fuel power stations equate to approximately 180Mt a year (178Mt in 2007) suggesting that storage within UK waters (at present levels of power generating $CO_2$ emissions) would have sufficient capacity for ~100 years of emissions (DECC 2010i), although the extent and nature of the storage options are presently not fully understood. The result of widescale deployment would be a significant reduction in $CO_2$ emissions to the atmosphere, with benefits for climate change mitigation.

$CO_2$ is captured as a gas and needs to be compressed or cooled for transport and subsequent injection into a storage reservoir, requiring power which will have associated atmospheric emissions. Bulk transport is either by pipeline or tanker, with pipelines favoured for large and near shore installations (over 3,000km of pipelines are currently used to transport several Mt of $CO_2$ per year in the US and Canada (POST 2005)) and shipping for long distances and areas that cannot be accessed easily by pipeline or are unlikely to be operational for long enough to justify infrastructure investment. For offshore sites, with distances greater than 700km (IEA 2004) ship transport becomes economically viable (although only for small volumes) and shipping has atmospheric emissions associated with fuel consumption. The latest LNG ships have a capacity of 200,000m$^3$ and could potentially carry 230kt of liquid $CO_2$ with estimations of losses to the atmosphere from both boil-off and exhaust from the ships engines of 3-4% for 1,000 km (IPCC 2005b).

The abatement of $CO_2$ may also confer other positive air quality mitigation. Other significant atmospheric emissions associated with carbon transport and storage result from potential accidental releases from shipping, pipelines or the storage areas themselves. These are however likely to be rare with monitoring evidence from the Sleipner project suggesting that all the gas injected into the formation has remained *in situ*, spreading throughout the formation (currently covering about 3km$^2$ of the 26,000km$^2$ available), with no leakage to the surface (Statoil website). Any failure would result in a large release of $CO_2$ in gaseous form either into the water or atmosphere. Low concentrations would have minimal effect beyond associated climate impacts and possibly small localised acidification of adjacent waters, but high concentrations could affect human life, ecology and other organisms. Significant survey work would need to be undertaken to avoid formations and storage areas with faults or other features that could cause loss of containment and long term monitoring would need to be carried out on any storage site to make sure that leakages do not occur during operation and once the site is full to capacity.

### 5.12.2.6 Possible climate change impacts

Climate change impacts have been broadly covered in each of the topic specific Appendices (3a-j). Impacts on the physical environment and ecology are summarised below. The IPCC 4th assessment report has a number of principal findings which indicate that it is very likely that since the onset of the industrial revolution, anthropogenic inputs of $CO_2$ and other greenhouse gases has had a positive radiative effect on global air and sea temperatures, with a projected further increase of 0.2°C for the next two decades. More specifically, UKCP09 (see Lowe *et al.* 2009, Murphy *et al.* 2009) project that for the 2020s (2010-2039) under a medium emissions scenario, the annual mean air temperature across the UK will increase by between 0.7°C and 2.0°C on land, and between 0.2°C and 2.0°C in marine areas (for between the 10 and 90 percentile range). Though popularised as 'global warming', the changes in climate which may be experienced in years to come are much more complex than simply increasing temperatures, for instance changes in the frequency and intensity of extremes of heat, cold, droughts, floods, hurricanes, tornadoes and other forms of extreme weather are also likely to occur.

Future climate change may generate alterations which threaten ecological and social systems. For instance the IPCC report 'Linking climate change and water resources' (Bates *et al.* 2008) highlights a number of negative effects which may be generated by both flood and drought events. Crop damage, soil degradation, reduced crop yields, ground and surface water contamination, increased risk of death, injuries and infections and general disruption to infrastructure and loss of property are all likely to increase as a result of flood or drought activity – and this is not to mention the distribution, growth and productivity, and reproduction of plants and animals.

More directly associated with positive radiative forcing is heat related deaths, particularly in Europe and changes in infectious disease vectors (e.g. malaria carrying mosquitoes). Any form of disruption in the food supply due to precipitation events or a change in the growing season is likely to be negative for both local and imported food stocks, despite some advantageous effects of milder temperatures in the mid- to high-latitudes and temperate areas (IPCC 2007). Industries and settlements in coastal locations may be disrupted due to changes in sea-level and coastal erosion and therefore will be more prone to flooding. Increased storminess at sea may also negatively affect offshore operations, with shorter weather windows and increased 'down time'.

## Physical environment

A secondary effect of climate change is the possible enhancement of coastal erosion and flooding from an increase in sea-level (see Appendix 3b and Appendix 3d). Though there has been no recent significant observed change in storm surge frequency or magnitude (Horsburgh & Lowe 2010) and there is a low confidence in any significant change in the UK wave climate (Lowe *et al.* 2009), these cannot be ruled out as possible exacerbating factors in coastal erosion and flooding in years to come. Masselink & Russell (2010) place a low confidence in estimates of what may occur with regard to coastal erosion in the future as a result of sea-level rise, as no general assessment can be made due to the extremely local effects that a change in the coastal system is likely to have, and uncertainties surrounding changes in other variables (e.g. wave and conditions). It can generally be expected that those coasts for which geology is a primary control (see Clayton & Shamoon 2008) on denudation will continue to erode. Certain areas of low elevation or those geographically constrained by defence works (which includes numerous estuaries) and infrastructure will be unable to respond to sea-level rise in the longer term and will therefore be subject to coastal squeeze (Masselink & Russell 2010).

IPCC (2007) notes that a rise in sea-levels can also lead to salinisation of coastal freshwater aquifers, which may be exacerbated by a reduction in freshwater recharge – UKCP09 predict a negligible reduction in the mean annual precipitation across the UK for the 2020s, though seasonally the difference between the wettest and driest months become more extreme, with the south of England showing a reduction of between 6 and 11% in the summer (June, July and August).

## Ecosystem

The Working Group II Report (IPCC 2007) in contribution to the IPCC Fourth Assessment Report considers impacts, adaptation and vulnerability in relation to climate change. Chapter 4 (Fischlin *et al*. 2007) considers the impacts of climate change on ecosystem properties, goods and services; this includes an assessment of likely wide-scale future impacts across many ecosystems, along with descriptions of observed impacts to date and potential future impacts specific to marine ecosystems. The following text summarises relevant information provided by Fishlin *et al*. (2007) and references therein.

### Likely wide-scale future impacts

Some particularly relevant conclusions of Fishlin *et al*. (2007) are provided below, including information on the confidence of such statements:

- During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g. flooding, ocean acidification) and in other global change drivers (especially land-use change, pollution and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates. Confidence = high.
- Approximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels. Confidence = medium.
- Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of more than 2 to 3°C above pre-industrial levels. Confidence = high.
- Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of more than 2 to 3°C above preindustrial levels and the associated increased atmospheric $CO_2$ levels. Confidence = high.
- Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on imminence of exposure to ecosystem-specific, critical thresholds. Confidence = very high.

### Observed and potential impacts to marine ecosystems

Climate change can impact marine ecosystems through ocean warming, by increasing thermal stratification and reducing upwelling, sea level rise, through increases in wave height and frequency, loss of sea ice, increased risk of diseases in marine biota, and decreases in the pH and carbonate ion concentration of the surface oceans.

Decreases in upwelling and formation of deep water, and increased stratification of the upper ocean will reduce the input of essential nutrients into the photic zone reducing phytoplankton growth and productivity. In coastal areas and margins, increased thermal stratification may lead to oxygen deficiency, loss of habitats, biodiversity and distribution of species, and impact whole ecosystems. Changes to precipitation and inputs of nutrients from land may exacerbate hypoxic events.

Changes to planktonic and benthic community composition and productivity have been observed, along with large shifts in pelagic biodiversity and fish community composition. Changes in seasonality or recurrence of hydrographic events or productive periods could be affected by trophic links to many marine populations. Elevated temperatures have increased mortality of winter flounder eggs and larvae, and have led to later spawning migrations. Tuna populations may spread towards presently temperate regions, based on predicted warming of surface water and increasing primary production at mid- and high latitudes.

Marine mammals, birds, cetaceans and pinnipeds, which feed mainly on plankton, fish and squid, are vulnerable to climate change-driven changes in prey distribution, abundance and community composition in response to climatic factors. Changing water temperature also has an indirect effect on the reproduction of cetaceans and pinnipeds, through prey abundance, by either extending the time between individual breeding attempts, or by reducing breeding condition of the mother. Current extreme climatic events provide an indication of potential future effects. For example, the warm-water phase of ENSO is associated with large-scale changes in plankton abundance and associated impacts on food webs, which may be linked to changes to behaviour, sex ratio, and feeding and diet of marine mammals.

Melting Arctic ice-sheets will reduce ocean salinities, causing species-specific shifts in the distribution and biomass of major constituents of Arctic food webs. Migratory whales that spend the summer in Arctic feeding grounds are likely to experience disruptions in their food sources. Nesting biology of sea turtles, in terms of timing and sex ratio of hatchling, is strongly affected by temperature, while a predicted sea-level rise of 0.5m will eliminate up to 32% of sea-turtle nesting beaches in the Caribbean.

Surface ocean pH has decreased due to absorption of anthropogenic $CO_2$ (and other acidifying) emissions and is predicted to continue to decrease. This may impact a wide range of organisms and ecosystems, particularly calcifying benthic organisms and their planktonic larvae.

Cold-water coral ecosystems harbour a distinct and rich ecosystem; they provide habitats and nursery grounds for a variety of species, including commercial fish and numerous new species previously thought to be extinct. These geologically ancient, long-lived, slow-growing and fragile reefs will suffer reduced calcification rates. Cold-water corals depend on extracting food particles sinking from surface waters or carried by ocean currents, they are therefore also vulnerable to changes to ocean currents, primary productivity and flux of food particles.

The paucity of information relating to UK deep-water, and shallow and shelf subtidal ecosystems makes both characterisation of recent trends and any predictions resulting from climate change difficult, and confidence in such projections is low (Birchenough & Bremner 2010, Hughes & Hughes 2010).

### 5.12.3 Spatial consideration

Section 2.5.4 outlines the likely scale and location of activities covered by the draft plan/programme assessed by OESEA2. The increase in offshore renewables deployment is likely to make a significant contribution towards the 2020 carbon budget of 34% carbon equivalent emissions, though CCS is unlikely to be ready for commercial scale deployment until closer to 2020 and therefore $CO_2$ abatement from this sector is likely to be small within the currency of OESEA2. As anthropogenically augmented climate change is a global phenomenon driven by greenhouse gas emissions from all nations, the offsetting of carbon at a UK level is unlikely to have any significant local positive effects within the currency of OESEA2, though activities in the coming years are likely to be key in initiating a transition towards a less carbon intensive economy, and the long-term reduction in emissions. Appendix 3f outlines the probabilistic changes in air temperature and precipitation at sea derived from the UKCP09 programme for the 2020s based on the medium emissions scenario (SRES A1B, Nakićenović & Swart 2000), and Appendix 3d outlines projected change in the wave climate, storm surges and sea-level.

### 5.12.4 Controls and mitigation

A number of elements to the draft plan/programme are designed entirely (in the case of carbon dioxide storage) or partly (in the case of offshore renewables) to help abate or offset carbon emissions, or to produce energy (mainly primary electricity) in a low carbon manner. The policy context to carbon dioxide storage (i.e. the FDCC and provisions made for the retrofit of coal power stations with CCS in the *Energy Act*) is such that the most polluting power stations will have to sequester carbon on at least 400MW (or 25%) of their capacity in the coming decades. Similar provisions for capturing the carbon from large industrial plant have not been made though uptake of the technology is likely to expand following 2020 subject to economic and technical feasibility. With regard to renewable technologies, the production of low carbon energy will continue to contribute to UK targets on the reduction of greenhouse gases, and the present carbon budget reflects current advice from the CCC to Government on what needs to be achieved to avert the worst impacts of climate change.

### 5.12.5 Cumulative impact considerations

There are likely to be few cumulative impacts in relation to climate change from the proposed elements of the draft plan/programme. Certain elements will make a positive net contribution to reducing carbon emissions (e.g. transport and storage resulting from $CO_2$ capture and offshore renewables); while oil and gas, though still providing the bulk of primary energy requirements for the foreseeable future, is unlikely to significantly expand on the UKCS as reserves continue to be depleted. The interaction of sea-level rise, coastal change, and potential impacts from wave and tidal devices should be considered (see Section 5.16).

### 5.12.6 Summary of findings and recommendations

The following provides a summary of the above considerations:

- In the absence of mitigation in the form of energy decarbonisation, the UK will be unable to meet its carbon emissions targets and therefore contribute to the avoidance of the worst effects of climate change.
- Carbon dioxide storage and marine renewable energy will contribute to the net reduction in UK carbon emissions and help contribute to the interim 2020 target of 34% on 1990 levels, though wider scale deployment is not expected until after 2020.

- Oil and gas production is declining on the UKCS, though emissions associated with energy generation and shipping in this sector is likely to continue for the foreseeable future. Future carbon emissions from shipping are likely to decline through operational and technical controls or through emissions trading.
- The UK reliance on fossil fuels for energy generation will continue for the foreseeable future, though a dependence on imports may be reduced through the increased uptake of renewable energy.
- Though there is general scientific consensus that anthropogenic emission of carbon dioxide and other greenhouse gases is having a direct effect on global temperature, knowledge of the climate system and impacts on it will continue to develop.
- The most recent MCCIP Report Card places a low confidence in projections of future climate change effects on most parts of the marine ecosystem.
- Recent UK projections of sea-level change are placed at between 12 and 76cm by 2095 (see Appendix 3d). At a regional to local level the impacts of sea-level rise on the coastal system are uncertain, though are likely to take the form of enhanced flooding of low-lying areas, the exacerbation of coastal erosion and coastal-squeeze. There is no significant evidence for recent changes in storm surge frequency.

# 5.13 Accidental events

## 5.13.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Accidental events - major oil or chemical spill | X | ?[1] | ?[1] | ?[1] | ?[1] | ? | ?[1] | 5.13.2.1 |
| | Accidental events - major release of $CO_2$ | | | X | | | | | 5.13.2.1 |
| | Accidental events - risk of sediment contamination from oil or chemical spills | X | ?[1] | ?[1] | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.2<br>5.13.2.3 |
| | Accidental events – blow out impacts on seabed | X | X | X | | | | | 5.13.2.2<br>5.13.2.3 |
| | Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.2<br>5.13.2.3 |
| | Air quality effects of a major gas release or volatile oil spill | X | X | X | | | | | 5.13.2.3 |
| | Accidental events – potential food chain or other effects of major oil or chemical spills or gas release | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.3 |
| | Accidental events – socio-economic consequences of oil or chemical spills and gas releases | X | X | X | ?[1] | ?[1] | ?[1] | ?[1] | 5.13.2.3 |

*Note: [1] Via shipping collision risks*

Oil spills are probably the issue of greatest public concern in relation to the offshore oil and gas industry, although the majority of large spills in the UK have resulted from shipping casualties; these are relatively infrequent, but more likely to occur in coastal waters where environmental and economic sensitivities are highest. The risks of large oil spills resulting from hydrocarbon exploration and production (E&P) are potentially associated with major incidents on production platforms, export (pipeline and tanker loading sources), with the additional potential for loss of well control and subsequent oil blowout. Previous SEAs have reviewed hydrocarbon spill scenarios and risks associated with exploration and production facilities. The recent *Deepwater Horizon* accident in the Gulf of Mexico has resulted in significant re-examination of operational practices, regulation and contingency planning for E&P, including a Parliamentary Enquiry in the UK into deepwater drilling, which published its findings in January 2011 (Energy and Climate Change Committee 2011). Relevant aspects of the *Deepwater Horizon* event are considered below.

Crude oil spills from E&P are clearly limited to the locations of oil-producing facilities and associated export infrastructure (in the UK, this is predominantly in the central and northern North Sea). Gas production and storage has an intrinsically low risk of liquid hydrocarbon release from the reservoir; and major oil spill risks associated with gas facilities relate principally to shipping collision risks. Smaller, and historically more frequent, spills may result from transfer and handling of fuel, drilling fluids and lubricating or hydraulic oils at E&P facilities. Other accidental events (with environmental consequences) that could potentially occur on offshore E&P facilities, and associated support vessels, include gas releases and chemical spills.

Offshore renewable energy developments generally have a negligible inventory of oils and chemicals, and spill risks are accordingly primarily associated with construction and operational maintenance; or with navigational safety risks to other vessel traffic. The latter aspect is increasingly recognised in view of the scale of offshore wind development envisaged in some parts of the UKCS and adjacent waters.

Accidental events potentially associated with carbon dioxide storage are not well characterised at this stage in the development of CCS, and there is little relevant historic experience. A preliminary assessment of possible risk scenarios and consequences is given below.

Environmental risk is generally considered as the product of probability (or frequency) and consequence. The environmental consequences of oil and chemical spills are associated primarily with seabirds, marine mammals, fisheries and coastal sensitivities; these sensitivities are considered in the appropriate environment description sections (Section 4 and Appendix 3) and supporting studies. The sources, frequency, magnitude and potential consequences of hydrocarbons spills are considered below. Much of the information is common to previous SEAs, and is therefore summarised with updates where appropriate.

Specific issues associated with individual UK Regional Seas include the location of sensitive coastlines, such as breeding bird colonies of international conservation importance, the importance of coastal tourism and recreation, and fisheries generally within the area.

It should be noted that the purpose of SEA risk assessment is not to anticipate the detailed risk assessment and contingency planning which would be required in advance of any development, but to evaluate the overall contribution to risk associated with possible offshore energy-related activity.

## 5.13.2 Consideration of the evidence

### 5.13.2.1 Accidental events – scenarios and historic frequency

#### Accidental events related to exploration and production

Well control incidents (i.e. “blowouts” involving uncontrolled flow of fluids from a wellbore or wellhead) have been too infrequent on the UKCS for a meaningful analysis of frequency based on historic UKCS data. The only significant blowouts on the UKCS to date have been from West Vanguard (1985) and Ocean Odyssey (1988), both involving gas. A review of blowout frequencies cited in UKCS Environmental Statements gives occurrence values in the range 1/1,000-10,000 well-years. These are generally consistent with derived annual frequencies based on the worldwide database maintained by SINTEF and Scandpower.

E&P in deep water presents a range of different considerations related to engineering design, blowout control, spill fate, and environmental consequences (considered in detail in SEA 7, DTI 2007). A 1999 study for the US Minerals Management Service assigned a moderate probability of a deepwater blowout during drilling, completion and workover operations, associated with the wellhead connector, lower marine riser package (LMRP), well flow through the riser, or a broach. Based on industry experience with the very few problems that have been associated with these components, a “catastrophic” rating was assigned to a release through the drill pipe or from a broach, because the drill rig would likely shut down and be abandoned, or move off location. A “severe” ranking was assigned to blowouts originating at the wellhead connector or through the riser; while those associated with the BOP and LMRP were assigned a “minor” ranking. For producing wells, a “catastrophic” consequence was assigned to a deepwater blowout to a broach, and “severe” to blowouts resulting from the wellhead connector or casing hanger seals, while all other components were assigned a low probability. However, it should be noted that all the above scenarios involve multiple system failures and of at least two independent barriers to flow. If the well is in a static condition (i.e., no flow from the reservoir) the primary barrier is usually the hydrostatic pressure exerted by the fluid column (either static or dynamic). The secondary barriers would be the pressure control equipment such as the BOP, the wellhead (innermost casing hanger seal), and the choke/kill line valves. If the well is flowing (i.e. producing oil and/or gas), the primary barrier is that which is closest to the reservoir. This typically includes the packer and associated seal assemblies, the tubing between the packer and the Surface-Controlled Subsurface Safety Valve (SCSSV) and the SCSSV itself. The secondary barriers would then include the tubing above the SCSSV, the master valve of the Christmas tree, the casing and tubing hanger seals and the annulus valves.

The major difference between a blowout during the drilling phase versus the completion or workover phases is the drilling well tendency to "bridge". Bridging is a phenomenon that occurs when severe pressure differentials are imposed at the well/reservoir interface, and the formation around the wellbore collapses and seals the flow path. Completion schemes often include methods to stabilise the reservoir during production in order to reduce the production of solids in the flow stream; therefore a completed well may not have the same tendency to passively bridge off as would a well section being drilled before the steel casing has been cemented in place. The tendency to passively bridge may also be inhibited by the seawater column back pressure which may limit the flow rate and prevent collapse of the well. In these cases, active bridging methods may be used to close the hole. Bridging may have a beneficial effect for spill control by slowing or stopping the flow of oil from the well.

## Deepwater Horizon event

On April 20, 2010, a well control event allowed hydrocarbons to escape from the Macondo well in Mississippi Canyon Block 252, onto Transocean’s *Deepwater Horizon* drilling rig, resulting in explosions and fire on the rig. Eleven people lost their lives, and 17 others were injured. The fire, which was fed by hydrocarbons from the well, continued for 36 hours until the rig sank. The accident involved a well integrity failure, followed by a loss of hydrostatic control of the well. This was followed by a failure to control the flow from the well with the blowout preventer (BOP) equipment, which allowed the release and subsequent ignition of hydrocarbons. Ultimately, the BOP emergency functions failed to seal the well after the initial explosions. Hydrocarbons continued to flow from the reservoir through the wellbore and the BOP for 87 days, causing a spill to the Gulf of Mexico of national significance.

The Accident Investigation Report (BP 2010) produced by BP in September 2010 presents an analysis of the events leading up to the accident, leading to eight key findings related to the causal chain of events and recommendations to enable the prevention of a similar accident. Details of the Macondo well are provided in Figure 5.44 below. The eight key findings related to the causes of the accident were:

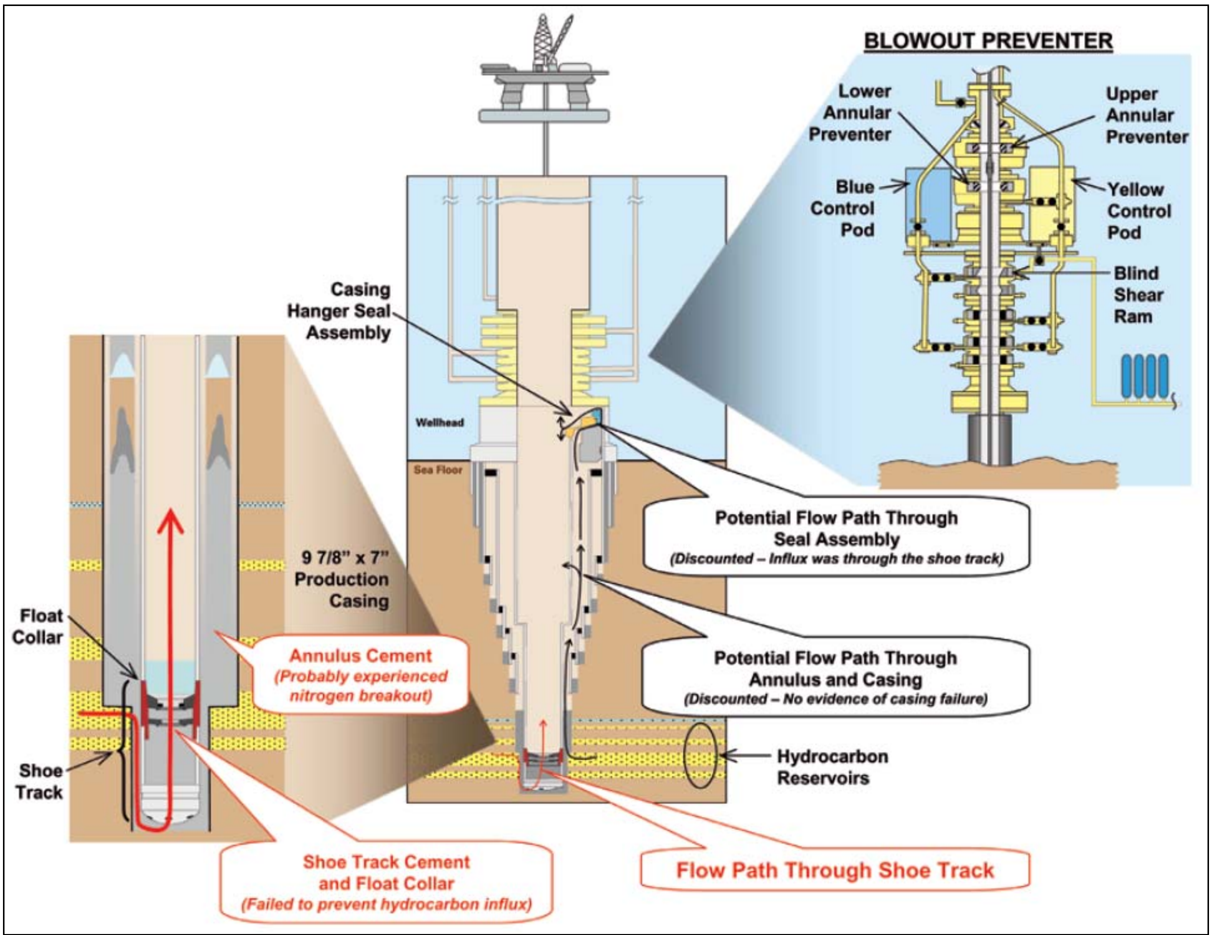
1. The annulus cement barrier did not isolate the hydrocarbons. The day before the accident, cement had been pumped down the production casing and up into the wellbore annulus to prevent hydrocarbons from entering the wellbore from the reservoir. The annulus cement that was placed across the main hydrocarbon zone was a light, nitrified foam cement slurry. This annulus cement probably experienced nitrogen breakout and migration, allowing hydrocarbons to enter the wellbore annulus. The investigation team

concluded that there were weaknesses in cement design and testing, quality assurance and risk assessment.

2. The shoe track barriers did not isolate the hydrocarbons. Having entered the wellbore annulus, hydrocarbons passed down the wellbore and entered the 9⅞ inch x 7 inch production casing through the shoe track, installed in the bottom of the casing. Flow entered into the casing rather than the casing annulus. For this to happen, both barriers in the shoe track must have failed to prevent hydrocarbon entry into the production casing. The first barrier was the cement in the shoe track, and the second was the float collar, a device at the tip of the shoe track designed to prevent fluid ingress into the casing. The BP investigation team concluded that hydrocarbon ingress was through the shoe track, rather than through a failure in the production casing itself or up the wellbore annulus and through the casing hanger seal assembly. The investigation team identified potential failure modes that could explain how the shoe track cement and the float collar allowed hydrocarbon ingress into the production casing.
3. The negative-pressure test was accepted although well integrity had not been established. Prior to temporarily abandoning the well, a negative-pressure test was conducted to verify the integrity of the mechanical barriers (the shoe track, production casing and casing hanger seal assembly). The test involved replacing heavy drilling mud with lighter seawater to place the well in a controlled underbalanced condition. In retrospect, pressure readings and volume bleed at the time of the negative-pressure test were indications of flow-path communication with the reservoir, signifying that the integrity of these barriers had not been achieved. The Transocean rig crew and BP well site leaders reached the incorrect view that the test was successful and that well integrity had been established.
4. Influx was not recognised until hydrocarbons were in the riser. With the negative-pressure test having been accepted, the well was returned to an overbalanced condition, preventing further influx into the wellbore. Later, as part of normal operations to temporarily abandon the well, heavy drilling mud was again replaced with seawater, under balancing the well. Over time, this allowed hydrocarbons to flow up through the production casing and past the BOP. Indications of influx with an increase in drill pipe pressure were discernable in real-time data approximately 40 minutes before the rig crew took action to control the well. The rig crew's first apparent well control actions occurred after hydrocarbons were rapidly flowing to the surface. The rig crew did not recognise the influx and did not act to control the well until hydrocarbons had passed through the BOP and into the riser.
5. Well control response actions failed to regain control of the well. The first well control actions were to close the BOP and diverter, routeing the fluids exiting the riser to the *Deepwater Horizon* mud gas separator (MGS) system rather that to the overboard diverter line. If fluids had been diverted overboard, rather than to the MGS, there may have been more time to respond, and the consequences of the accident may have been reduced.
6. Diversion to the mud gas separator resulted in gas venting onto the rig. Once diverted to the MGS, hydrocarbons were vented directly onto the rig through the 12 inch goose necked vent exiting the MGS, and other flow-lines also directed gas onto the rig. This increased the potential for the gas to reach an ignition source. The design of the MGS system allowed diversion of the riser contents to the MGS vessel although the well was in a high flow condition. This overwhelmed the MGS system.
7. The fire and gas system did not prevent hydrocarbon ignition. Hydrocarbons migrated beyond areas on *Deepwater Horizon* that were electrically classified to areas where the potential for ignition was higher. The heating, ventilation and air conditioning system probably transferred a gas-rich mixture into the engine rooms, causing at least one engine to over speed, creating a potential source of ignition.
8. The BOP emergency mode did not seal the well. Three methods for operating the BOP in the emergency mode were unsuccessful in sealing the well:

- The explosions and fire very likely disabled the emergency disconnect sequence, the primary emergency method available to the rig personnel, which was designed to seal the wellbore and disconnect the marine riser from the well.
- The condition of critical components in the yellow and blue control pods on the BOP very likely prevented activation of another emergency method of well control, the automatic mode function (AMF), which was designed to seal the well without rig personnel intervention upon loss of hydraulic pressure, electric power and communications from the rig to the BOP control pods. An examination of the BOP control pods following the accident revealed that there was a fault in a critical solenoid valve in the yellow control pod and that the blue control pod AMF batteries had insufficient charge; these faults likely existed at the time of the accident.
- Remotely operated vehicle intervention to initiate the auto shear function, another emergency method of operating the BOP, likely resulted in closing the BOPs blind shear ram (BSR) 33 hours after the explosions, but the BSR failed to seal the well.

Figure 5.44 – The Macondo well




*Source: BP (2010).*

Through a review of rig audit findings and maintenance records, the investigation team found indications of potential weaknesses in the testing regime and maintenance management system for the BOP.

The BP investigation team did not identify any single action or inaction that caused this accident. Rather, a complex and interlinked series of mechanical failures, human judgements, engineering design, operational implementation and team interfaces came together to allow the initiation and escalation of the accident. Multiple companies, work teams and circumstances were involved over time. The BP Accident Investigation Report provides a series of recommendations intended to enable prevention of similar accidents in the future, and in some cases, they address issues beyond the causal findings for this accident. These recommendations cover contractor oversight and assurance, risk assessment, well monitoring and well control practices, integrity testing practices and BOP system maintenance, among other issues.

The Energy and Climate Change Committee (2011) indicated that the BP (2010) report (the "Bly Report") did not contain a root-cause analysis of the events that led to the blowout of the Macondo well. The Committee urged the Government not to rely extensively on the Bly Report, given the controversy surrounding the responsibility for the incident and the design of the Macondo well, but rather to consider its conclusions in parallel with the observations of other companies involved with the incident, and with the recommendations of US agencies investigating the incident (see below).

Relevant recommendations from the Committee include:

- The Health and Safety Executive should specifically examine the case for prescribing that blowout preventers on the UKCS are equipped with two blind shear rams.
- For fail-safe devices such as the blowout preventer the Government should adopt minimum, prescriptive safety standards or demonstrate that these would not be a cost-effective, last-resort against disasters.
- The Government must ensure that the UK offshore inspection regime could not allow simple failures—such as a battery with insufficient charge—to go unchecked.
- It is important and necessary that the offshore safety culture is cascaded throughout the supply chain, from existing contractors at all levels, through to new-entrants on to the UK Continental Shelf.

In January 2011, the US Government National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling released a report (National Commission 2011) into the disaster, citing systematic management failures by BP, Transocean and Halliburton and shortcomings in the US government regulatory regime as the principal sources of blame. A series of general recommendations are outlined in the report, primarily related to US regulatory reform[30], with the following being of particular relevance to exploration and production in UK waters:

- The oil and gas industry will need to take its own, unilateral steps to increase dramatically safety throughout the industry, including self-policing mechanisms that supplement governmental enforcement.
- The technology, laws and regulations, and practices for containing, responding to, and cleaning up spills lag behind the real risks associated with deepwater drilling into large, high-pressure reservoirs of oil and gas located far offshore and thousands of feet below

[30] Including a specific recommendation for risk-based, installation and activity-specific, performance approach similar to the Safety Case regime implemented in the UK following the 1988 Piper Alpha disaster

the ocean's surface[31]. Government must close the existing gap and industry must support rather than resist that effort[32].

- Scientific understanding of environmental conditions in sensitive environments in deep waters, coastal habitats, and in areas proposed for more drilling is inadequate[33]. The same is true of the human and natural impacts of oil spills.

Historically, major spill events from UKCS production facilities include the 1986 Claymore pipeline leak (estimated 3,000 tonnes), 1988 Piper Alpha explosion (1,000 tonnes), 1996 Captain spill (685 tonnes) and 2000 Hutton TLP spill (450 tonnes). Estimates of oil inputs from other sources have not been subject to regular reporting within OSPAR, although the 1993 Quality Status Review estimated a total oil input of 85,000-209,000 tonnes per year to the North Sea, including oil-based drilling fluids, riverine sources, shipping and natural seepage (NSTF 1993). The routine inputs from oil-based drilling fluids essentially ceased at the end of 1996, and OSPAR (2000a) noted that reliable estimates on inputs of oil from rivers and land runoff are lacking.

Oil spills on the UKCS have been subject to statutory reporting since 1974 under PON1 (formerly under CSON7); annual summaries of which were initially published in the "Brown Book" series, now superseded by on-line data available from the DECC website[34] (Figure 5.45). Discharges, spills and emissions data from offshore installations are also reported by OSPAR (e.g. OSPAR 2009a).

DECC data indicate that the major types of spill from mobile drilling rigs have been organic phase drilling fluids (and base oil), diesel and crude oil. Topsides couplings, valves and tank overflows; and infield flowlines and risers are the most frequent sources of spills from production operations, with most spills being <1 tonne. A large proportion of reported oil spills in recent years (since about 1990) have resulted from process upsets (leading to excess oil in produced water). Estimated spill risk from UKCS subsea facilities was equivalent to a risk of 0.003 spills/year for an individual facility, with almost all reported spills less than a tonne (<5bbl) in size.

The PON1 reports indicated that remedial actions taken by operators included identification of root causes of spills, improvements in operational control procedures, recommendations concerning preventative actions and carrying out any necessary repairs and modifications to faulty or damaged equipment. In addition, several reports referred to operators sealing systems and shutting down operations in order to prevent any further pollution.

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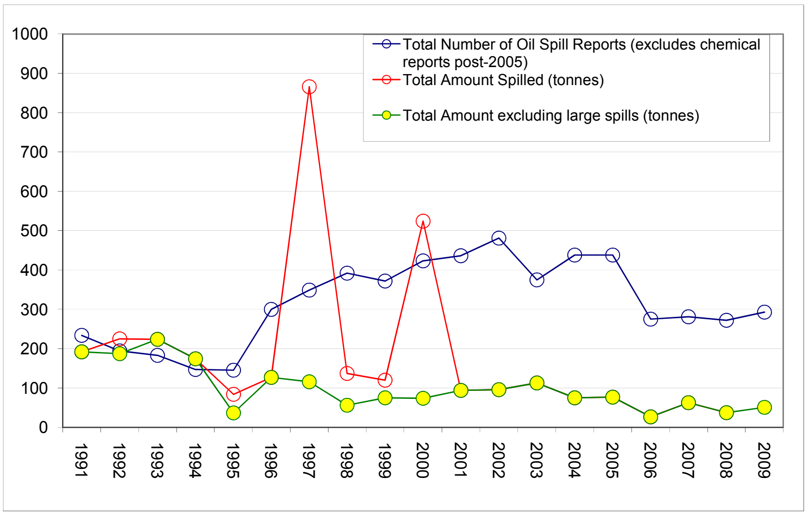
[31] It should be noted in this context that deepwater, High Temperature High Pressure (HTHP) reservoirs comparable to the Macondo well target are not known to be present on the UKCS

[32] Specific recommendations by the US Government National Commission include mandatory funding for oil spill response research and development and incentives for private-sector R&D; new protocols for dispersant use; development and effective planning for well containment capability; and a more robust well design and approval process.

[33] Understanding of marine habitats of the UKCS, including deepwater Atlantic areas, has been significantly progressed over the last fifteen years, notably through the offshore energy SEA programme and collaborative and academic studies

[34] Oil and chemical discharge notifications (accessed October 2010) https://www.og.decc.gov.uk/information/bb_updates/chapters/Table_chart3_1.htm

Figure 5.45 – Reported oil spills on the UKCS, 1991-2009




*Source: DECC website[1], 2009 data – DECC (Pers. comm.)*

Over the preceding decade, DECC data indicate that the reported number of spills has increased until 2005 (Figure 5.45); consistent with more rigorous reporting of very minor incidents, followed by the distinction (in 2005) of hydrocarbon and chemical spills. However, the underlying trend in spill quantity (excluding specifically-identified large spills) suggests a fairly consistent reduction in annual totals to <100 tonnes. In comparison, oil discharged with produced water from the UKCS in 2008 totalled 3,160 tonnes (DECC website[35]).

Globally, the total amount of oil spilled annually depends largely on the incidence of catastrophic spills (Etkin 1999), with less than 300,000 tonnes in most years, but exceptional quantities spilled to sea in 1978 (*Amoco Cadiz*), 1979 (Ixtoc 1 blowout and *Atlantic Empress* tanker spill), 1983 (Nowruz blowout and *Castillo de Bellver* tanker spill) and 1991 (Gulf War). The 2010 Macondo well blowout spilled an estimated 4,900,000 barrels of oil (between 600,000 and 700,000 tonnes depending on the grade of the oil) (The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team 2010). Within Regional Sea 6, the *Sea Empress* spill (1996) resulted in significant bird kill and effects on benthic organisms; apparently, however, without major long-term effects. As with the earlier *Braer* spill in Shetland (Regional Sea 1/8 boundary), the timing of the spill was fortuitous in limiting environmental effects and prevailing weather conditions assisted in natural dispersion.

An annual review of reported oil and chemical spills in UK waters – covering both vessels and offshore installations – is made on behalf of the MCA by the Advisory Committee on Protection of the Sea (e.g. ACOPS 2008 as reported in Dixon 2009). These reviews split the UK Pollution Control Zone into 10 geographical areas plus UKCS (oil & gas installations and vessels); 605 separate discharges from vessels and offshore oil and gas installations were

[35] Oil discharged with produced water 2005 – 2008 (accessed October 2010) https://www.og.decc.gov.uk/information/bb_updates/chapters/Table3_2.htm

identified in the survey area during 2008, with a significant overall reduction of 8% over the previous year's total.

A reduction of 11% in the total number of vessel-sourced accidental discharges reported during 2008, down from 192 during 2007 to 170 during 2008, was consistent with the underlying downward trend observed in the statistics since 2000. During 2008, there was a 6.5% reduction in the total number of offshore oil & gas sourced accidental discharges reported, thereby reversing the underlying upward trend in the annual totals recorded over the previous 4 years. Further analysis of these statistics showed that the reported total of 272 accidental oil discharges from offshore oil and gas installations during 2008 was 8 fewer than the mean annual total of 280 oil discharges reported between 2000 and 2007. The total of 163 accidental discharges of substances other than mineral oils reported by offshore installations during 2008, primarily those involving chemical substances, was 21 less than the total recorded during the previous year (Dixon 2009).

In the wider OSPAR area, the total quantity of dispersed oil (aliphatic oil) discharged to the sea (from produced water, displacement water and accidental spillage) shows a decreasing trend over the last few years, but increased to 9,025 tonnes in 2007 compared to 8,756 tonnes in 2005. The main reason for this increase was a large oil spill of 3,815 tonnes offshore Norway in 2007 (OSPAR 2009b).

## Accidental events related to gas storage

The main accidental risk associated with gas storage developments offshore is considered to be accidental hydrocarbon releases, mainly from spills of fuel oils from fixed installations and support vessels. Gas storage in depleted hydrocarbon reservoirs has an associated risk of reservoir fluid release during drilling operations (qualitatively similar to risk associated with E&P), and a theoretical risk of loss of containment through previously capped wells which may have penetrated the reservoir. The environmental risk is considered to be low, given the geological and engineering understanding of the developments, and the (depleted gas) reservoirs likely to be developed for storage. Gas storage in salt caverns has a negligible risk of liquid hydrocarbon release from well operations.

## Accidental events related to carbon dioxide storage

As with gas storage, the risk of loss of containment of liquid hydrocarbon inventory from offshore development of carbon dioxide storage is considered likely to be low, although there is a very limited basis of experience and quantitative risk assessment on which to base this judgement.

The probability and consequence of a major accidental release of carbon dioxide from the transportation and offshore storage facility is difficult to assess, although the technology and risk sources (e.g. mechanical damage to a pipeline through collision) are similar to those for gas production and transportation (although without the potential consequences of ignition of a gas release). To date, accidents associated with development of the UK's offshore gas reserves have been few and of limited environmental effect. Clearly, however, the engineering of transportation systems and injection facilities for carbon dioxide will need to take due account of the physical properties of $CO_2$ in various phases and consenting of CCS will require predictive assessment of the safety and environmental risks of a large-scale release.

An estimation of the frequency of leaks from $CO_2$ sequestration in geological structures was carried out for BERR (now DECC) by DNV (2003), although this generally concluded that information required for a quantitative assessment was lacking and that it was therefore currently impossible to quantify with any confidence the likelihood of accidental releases from $CO_2$ sequestration reservoirs. Qualitative and quantitative input from a panel of experts suggested that, even though a release from $CO_2$ sequestration in a depleted oil reservoir is quite likely during its life and would probably be large if it did occur, there is a high probability (95%) that the average quantity released during a reservoir life would be a small fraction (less than 2.4%) of the amount sequestered. This takes account of the very large uncertainties in the risk estimates. However, it was emphasised that the estimates were all very speculative, and that the methodology attracted the support of only a minority of the experts that were consulted.

Fourteen years of monitoring of $CO_2$ storage in a subsea geological formation at the Sleipner platform in the Norwegian sector of the North Sea have provided information on the relatively short-term fate of injected $CO_2$. Techniques in monitoring the fate of injected carbon dioxide have developed over this time; 4-D (repeated 3-D) seismic survey of the formation, vertical seismic profiling, multibeam echosounding, bubble stream detection, seawater geochemistry and various downhole measurements are some of a suite of techniques which may be applied to monitor $CO_2$ migration and anticipate and detect leakage. A US Department of Energy report (NETL 2009) outlines many priority monitoring techniques applicable to carbon dioxide storage, with a goal of demonstrating 99% retention of $CO_2$ by 2012, defined by the ability of monitoring at a geological storage site to detect leakage of $CO_2$ at 1% of the stored amount into the atmosphere.

The UK Health and Safety Executive (HSE) has also produced interim guidance on conveying bulk quantities of dense phase or supercritical $CO_2$ in pipelines in connection with carbon capture, storage and sequestration projects. This noted that current UK experience of $CO_2$ pipelines is limited, and only some pipeline design codes include it as a relevant fluid within their scope of application. Moreover, current pipeline codes did not anticipate the bulk transportation of $CO_2$ in the quantities likely to be seen in CCS projects.

Oil and gas companies, particularly in the USA, have some experience of using high pressure injection of $CO_2$ in oilfields for Enhanced Oil Recovery; but the extent of this experience is very limited when compared to hydrocarbon pipelines. $CO_2$ is an acid gas which reacts with water to form carbonic acid and this is familiar to corrosion engineers as "sweet gas corrosion". This means that water content of $CO_2$ transported through carbon steel pipelines needs to be considered and pipeline materials selected accordingly. Other constituents may be present in the transported $CO_2$ depending on its origin and these also need to be considered. These might include oxygen, methane, carbon monoxide, NOx and SOx. Compatibility of all pipeline system materials e.g. elastomeric seals in valves with these contaminants needs to be considered.

When loss of containment from a pipeline occurs, there are a number of highly complex interactions between the pipeline, the surrounding environment and the decompressing fluid. These are complex enough for natural gas, but with $CO_2$ they are further complicated by the potential for phase changes of the fluid which are dependent on the level of impurities, the temperature and pressure along with the geometry of the orifice through which the gas is decompressing. This all adds complexity to the modelling of the release that cannot be easily incorporated into existing outflow models, which makes modelling of the gas dispersion or gas concentration extremely difficult. The behaviour of the pipeline and its ability to arrest a fracture is also very difficult to model. When the pressure of $CO_2$ is reduced, there is a change in temperature. Where a large drop in pressure occurs, the temperature change is likely to be significant, and this could lead to material embrittlement and the risk of brittle fracture. All components, both metallic and non metallic, need to be capable of tolerating temperature deviations without impairment. The toughness of steel to prevent fracture propagation following loss of containment is therefore a key consideration.

The likelihood of loss of containment events occurring also needs to be determined to enable realistic understanding of risk to be developed, and again, given limited experience of transporting $CO_2$ in pipelines, there is a paucity of information on this.

Efforts are underway to review and improve the technical understanding and regulatory framework for both carbon dioxide transport and storage, and the full CCS process as a whole. In 2009, DECC commissioned a series of reports to investigate both the technical aspects (Parsons Brinckerhoff 2009) and regulatory options (NERA 2009a & b) of developing $CO_2$ transport infrastructure. More recently, the International Energy Agency has released a model regulatory framework for CCS (IEA 2010) to assist governments to develop appropriate frameworks by drawing on CCS regulatory frameworks already in place in Australia, Europe the United States.

### Accidental events related to renewable energy developments

Offshore wind and wet renewable energy developments have a generally limited potential for accidental loss of containment of hydrocarbons and chemicals, due to the relatively small inventories contained on the installations (principally hydraulic, gearbox and other lubricating oils, depending on the type of installation). In comparison to E&P developments, there is low anticipated frequency and consequence of spills occurring during fuel or oil transfers, maintenance operations and similar activities.

The major risk scenario for offshore renewable energy developments is collision between a fixed installation and vessel, resulting in loss of fuel or cargo from the latter. Collision risk assessment is therefore a key aspect of site-specific planning and consenting. At a strategic level, it can be noted that the anticipated scale and geographical location of development (specifically of offshore wind) must result in some overall increase in vessel collision risk, either through direct collision with a fixed installation or through confinement of available routes for safe navigation, particularly of larger vessels. Provision of effective National Contingency Planning, and adequate response resources coordinated at a national level, including tugs (see below), are therefore considered to be important mitigation measures to support long-term development of the UK's offshore renewable energy resources.

## 5.13.2.2 Oil spill fate & trajectory

The fate of oil spills to the sea surface is relatively well understood. On the sea surface, there are eight main oil weathering processes: spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation – these are reviewed in SEAs 1, 2 and 3. The rates of individual processes are inter-dependent, and also influenced by hydrocarbon characteristics, temperature and turbulence. In general, oils with a large percentage of light and volatile compounds and low viscosity (such as diesel) will evaporate, disperse and dissolve more rapidly than oil predominantly composed of higher molecular weight compounds (e.g. crude oils).

Following the recent *Deepwater Horizon* accident, the National Incident Command (NIC) assembled a number of interagency expert scientific teams to estimate the quantity of oil that has been released from the well and the fate of that oil. One team calculated the flow rate and total oil released, and estimated that a total of 4.9 million barrels of oil had been released from Macondo well. A second interagency team developed an Oil Budget Calculator to determine what happened to the oil. The calculator uses the 4.9 million barrel estimate as its input and uses both direct measurements and the best scientific estimates available to date, to determine what has happened to the oil. In summary, it is estimated that burning, skimming and direct recovery from the wellhead removed one quarter (25%) of the oil released from the wellhead. One quarter (25%) of the total oil naturally evaporated or dissolved, and just less than one quarter (24%) was dispersed (either naturally or as a result of operations) as microscopic droplets into Gulf waters. The residual amount — just over one quarter (26%) — is either on or just below the surface as light sheen and weathered tar balls, has washed ashore or been collected from the shore, or is buried in sand and sediments. Oil in the residual and dispersed categories is in the process of being degraded. These estimates will continue to be refined as additional information becomes available.

Oil on the sea surface will move due to a combination of tidal currents and wind stress. Generally, the slick front will be wind-driven on a vector equivalent to current velocity plus approximately 3% of wind velocity. Surface oil spill trajectory modelling can be carried out using commercial models deterministically (i.e. with defined arbitrary metocean conditions, usually "worst case") or stochastically (i.e. using statistical distributions for wind and current regimes). To support environmental assessments of individual drilling or development projects, modelling is usually carried out for a major crude oil release, corresponding to a blowout, and for smaller diesel or fuel oil releases which are expected to be less persistent. Following the *Deepwater Horizon* incident in the Gulf of Mexico, operators are now required to carry out additional modelling for deep water drilling operations, which includes an extended time frame for oil spill beaching predictions. The OSIS model that is used industry wide has limitations with regard to predicting long-term spill and deep water predictions. The OSPRAG Oil Spill and Emergency Response Group (see below) is undertaking a review of the model and comparing oil spill scenarios with OSCAR, a Sintef developed model which appears better suited to deep sea oil releases.

Previous SEAs have reviewed and summarised risk assessment, including stochastic and deterministic modelling, carried out for Oil Spill Contingency Planning (OSCP, now Oil Pollution Emergency Plans ) in Regional Seas 1/2 (SEA 2, 3, 5); Regional Sea 6 (SEA 6); and Regional Seas 8/9 (SEA 4, 7). "Time to beach", estimated using deterministic modelling, is an important factor in contingency planning, since it relates to the required response time and therefore the geographic availability of response resources.

For SEAs 2 and 3, deterministic calculations were carried out to estimate the time to beach from the most prospective areas within the area (central and southern North Sea), to either the closest landfalls or to adjacent significant coastal sensitivities. These calculations assume that a slick front will move at 3% of wind speed, and have assumed constant 30 knot wind speed (consistent with "Essential Elements" criteria for oil spill response measures used in UKCS licence conditions). The shortest distances to land from the prospective SEA 2/3 locations were around 20km, with a corresponding "Essential Elements" time to beach of ~10h. The Mid North Sea High and Carboniferous Trend prospective areas in the central North Sea are considerably further offshore, with "Essential Elements" time to beach in excess of 100h, indicating that a diesel or low persistence spill would not beach. For all of the North Sea, with the exception of inshore parts of the southern area, tidal current velocities are relatively low and oil spill trajectory will be most influenced by wind. Most frequent wind directions vary seasonally, but are generally offshore (i.e. away from adjacent UK coastline) with the exception of the southern North Sea in summer, when E/SE winds are most frequent. Estimated "Essential Elements" time to beach at various points in Belgium, the Netherlands and Denmark range from 105 to 180 hours.

SEA 2 noted that the closest landfall to any part of the relevant area, Flamborough Head, holds a kittiwake colony of world stature on the Bempton Cliffs accompanied by internationally important populations of guillemots and razorbills, and is accordingly designated as a Special Protection Area. However, hydrocarbon reserves in the Regional Sea 2 are gas, and the risk of a significant spill from E&P sources of persistent oil is low. Foreseeable oil spills advected into this area could be managed using chemical dispersion, subject to the agreement of conservation and fisheries agencies. In Regional Sea 1, the northern area of hydrocarbon prospectivity is within 72km of major seabird breeding colonies on the east coast of Shetland, including those on Unst, Fetlar, Whalsay and the Shetland mainland (beaching possible in 42h assuming a constant 30 knot wind). Populations of national and international importance at these east coast sites include fulmar, gannet and skuas with the exception of Noss, which also holds large numbers (ca. 40,000) of guillemots.

Areas of relatively high prospectivity in Regional Sea 1 are close to the east Caithness shore and east of Orkney, and to a lesser extent north of the "Banff fault zone". These areas are most likely to attract exploration activity and potential production, and spill risks are consequently higher (although low in absolute terms). A persistent oil spill in these areas is likely to move to the northeast driven by the prevailing winds although it could potentially be transported westwards via the Pentland Firth, with consequent risks to north mainland and south Orkney shores. Prospectivity adjacent to the Shetland coast and mainland coastline south of the Moray Firth are lower, and E&P spill risks are correspondingly reduced.

In order to indicate the likely fate and trajectory of oil spills within Regional Sea 6 (the Irish Sea), two representative cases were considered. Stochastic modelling of representative 22 tonne (100bbl) spills from a Liverpool Bay field indicates a relatively high (10-50%) probability of shoreline oiling associated with proximity of these installations to the coast (this modelling does not take account of evaporation and weathering and therefore overestimates beaching probability, BHP Billiton 2001). In view of the very short distances (for example, the Lennox field is about 8km from the coast), deterministic times to beach are very short (worst case <4h). Deterministic trajectory modelling was undertaken for the Dragon appraisal well in the centre of the St George's Channel (Block 103/1) using a scenario involving instantaneous loss of the maximum fuel inventory for the proposed rig; this indicated, as expected in view of the location's proximity to land (34-39km), relatively short times to beach (12-15h). The modelled proportions of total oil beaching were low, mainly due to the low persistence of diesel. Results of stochastic modelling for the Dragon location indicated a low probability (1-5%) of beaching as a result of the 1,177 tonnes instantaneous diesel spill, and negligible probability (<1%) as a result of either a 64 tonne instantaneous kerosene spill (base fluid spill scenario) or $3m^3$ instantaneous diesel spill (bunkering spill scenario). In all cases, stochastic probability contours were elliptical, indicating a higher probability of surface oiling to the northeast (associated with prevailing wind and residual current directions), with a higher probability of oiling in the central St George's Channel (i.e. the vicinity of the Celtic Sea Front) than in coastal waters of Pembroke, Cardigan Bay or Carnsore Point. For the smaller spill scenarios, which represent a higher frequency of occurrence, there was therefore considered to be a very small probability (<1%) of surface oil affecting the immediate vicinities of major seabird and seal breeding colonies of the Irish and Welsh coasts. For the larger spill scenario, which has an extremely low probability of occurrence, there is a low probability (1-5%) of local effects at breeding colonies.

A review of trajectory modelling carried out in twelve representative Environmental Statements for exploration wells and developments west and north of Shetland (Regional Seas 8 & 9) was carried out as part of the SEA 4 process. Deterministic estimates of time to beach were reasonably consistent and indicated, unsurprisingly, that time to beach to Orkney, Shetland and the Faroes are broadly comparable with a minimum of 40-50h. Stochastic modelling has also been carried out for west of Shetland locations; available results indicate probabilities of surface oiling resulting from uncontrolled crude oil blowout scenarios of 30% along the northeast Shetland coast, <10% south of St Magnus Bay and <5% for Orkney, the Faroes and mainland Scotland. Diesel spills had an insignificant (<1%) probability of surface oiling of coastlines. The predicted distribution of spill trajectories was dominated by prevailing southwesterly winds, with limited tidal influence.

Deterministic modelling for two locations within the SEA 7 area (west of Lewis), under conditions of sustained 30 knot wind, indicated minimum times to beaching of 34-85h, depending on direction. Minimum times are in the direction of Sula Sgeir. Stochastic modelling indicated a low probability of spill movement to the south.

### 5.13.2.3 Effects of spills

#### Ecological effects

The most vulnerable components of the ecosystem to oil spills in offshore and coastal environments are seabirds and marine mammals, due to their close association with the sea surface. These sensitivities are discussed below. Benthic habitats and species may also be sensitive to deposition of oil associated with sedimentation, with mortality of intertidal organisms occurring as a result of direct oiling; while subtidal communities may be affected by dissolved hydrocarbons (e.g. SEEEC 1998). Disruption of intertidal communities over a range of timescales has been observed following many major oil spills; typically with disturbance of the balance between algal populations, grazing species and predators on rocky shores. Effects on sediment communities are typically associated with deoxygenation and organic enrichment. In both cases, the effects of chemical dispersants and attempted physical clean-up may be more severe than those of oil.

Direct mortality of seabirds in the event of oil spill is undoubtedly the most widely perceived risk associated with the proposed licensing and subsequent activities. Spills affecting waters near major colonies during the breeding season could be catastrophic (Tasker 1997). Seabirds are affected by oil pollution in several ways, including oiling of plumage and loss of insulating properties, and ingestion of oil during preening causing liver and kidney damage (Furness & Monaghan 1987). Offshore seabird vulnerability to surface pollution in individual Regional Seas is summarised in Section 5.6.3. Vulnerability is seasonal, with a general trend of high vulnerability in coastal areas adjacent to colonies during the breeding season. In winter, vulnerability in inshore waters can also be very high in some areas.

Fortunately, there is little experience of major oil spills in the vicinity of seabird colonies in the UK. Census of seabird colonies in southwest Wales following the *Sea Empress* spill concluded that only guillemot and razorbill populations were impacted by the spill (Baines & Earl 1998). The *Sea Empress* spill occurred in February, when seabird numbers at colonies were relatively low, but the density of wintering birds including common scoter was high. Some species, particularly puffins, Manx shearwaters and storm petrels, had not returned to the area to breed and so avoided significant impact. Around 7,000 oiled birds were washed ashore following the spill, although it is likely that the total number of birds killed was several times higher than this (SEEEC 1998). Examination of seabird corpses suggested that most died directly from oil contamination rather than, for example, food chain effects. Over 90% of the oiled birds were of three species – common scoter, guillemot and razorbill. Counts of the breeding populations confirmed the impact on guillemots and razorbills. There were 13% fewer guillemots and 7% fewer razorbills counted at breeding colonies in the area in 1996 compared with 1995, while numbers for both species increased at nearby colonies. The SEEEC (1998) report concluded that by the 1997 breeding season, numbers had recovered significantly. Banks *et al*. (2008) report the results of annual surveys of common scoter within Carmarthen Bay, an area partially affected by the spilled oil. While numbers were greatly reduced following the spill, and changes in distribution suggested the use of potentially sub-optimal foraging zones, rapid revival was observed with numbers increasing to pre-spill levels and a return to previous distributions within three winters of the event. At ten years following the incident, numbers of common scoter were not different to those recorded immediately before the spill (Banks *et al*. 2008).

Oil spill risks to marine mammals have been reviewed by Hammond *et al*. (2008). Direct mortality of seals as a result of contaminant exposure associated with major oil spills has been reported, e.g. following the Exxon Valdez oil spill in Alaska in 1989. Animals exposed to oil over a period of time developed pathological conditions including brain lesions. Additional pup mortality was reported in areas of heavy oil contamination compared to unoiled areas.

More generally, marine mammals are considered to be less vulnerable than seabirds to fouling by oil, but they are at risk from hydrocarbons and other chemicals that may evaporate from the surface of an oil slick at sea within the first few days. Symptoms from acute exposure to volatile hydrocarbons include irritation to the eyes and lungs, lethargy, poor coordination and difficulty with breathing. Individuals may then drown as a result of these symptoms.

Grey and harbour seals come ashore regularly throughout the year between foraging trips and additionally spend significantly more time ashore during the moulting period and particularly the pupping season. Animals most at risk from oil coming ashore on seal haul-out sites and breeding colonies are neonatal grey seal pups, as these rely on their thicker fur for insulation during the first few weeks of their life before developing blubber and moulting into a sea-going coat. They are also restricted to their breeding colony until they are weaned, and are therefore more susceptible than adults to external oil contamination.

Intertidal habitats and species are vulnerable to surface oil pollution, and to windblown oil in the case of onshore maritime habitats (e.g. machair). After seabirds and wildfowl, seals and otters are probably the most obvious potential casualties (and the most emotive in terms of media coverage), with vulnerability of intertidal habitats also high, particularly in the event of oiling of sheltered coastlines. The vulnerability of different shore types to oil pollution is largely dependent on substrate and wave exposure, and is reviewed below (after Gundlach & Hayes 1978):

- **Exposed rocky headlands** – wave reflection keeps most of the oil offshore
- **Eroding wave cut platforms** – wave swept. Most oil removed by natural processes within weeks
- **Fine grained sand beaches** – where oil penetrates into sediment, may persist over several months. Penetration can occur due to wave action and tidal movements
- **Coarse grained beaches** – oil may sink and/or be buried rapidly. Under moderate to high energy conditions, oil will be removed naturally from most of the beachface
- **Exposed compacted tidal flats** – oil will not adhere to, nor penetrate into compacted sediments
- **Mixed sand and gravel beaches; shingle beaches** – oil may penetrate rapidly and be buried resulting in persistence over years. Solid asphalt pavement may form under heavy oiling conditions
- **Sheltered rocky coasts** – reduced wave action. Oil may persist for years
- **Sheltered tidal flats** – low wave energy; and high productivity, biomass and possibly bioturbation. Oil may persist for years
- **Salt marshes –** highly productive and vulnerable. Oil may persist for years.

The ecological effects of chemical spills are clearly dependent on the physical properties and toxicity of the chemical involved. Since chemical selection and use on offshore facilities is tightly regulated and the majority of chemicals are in low risk categories, the potential risk is considered to be relatively low (e.g. in contrast to bulk shipping of hazardous chemicals).

Accidental subsea gas releases can result in seabed disturbance and crater formation, although such events are extremely rare. Wright (2006) reports a gas kick during drilling to deepen a depleted production well which resulted in well broach and uncontrolled gas flow for 10 hours; this lead to the formation of a seabed crater some 25m x 15m and 8m deep. Minor gas releases subsea would be expected to result in significant dissolution in the water column, with a proportion of gas released to atmosphere (dependent on various factors including water depth and gas flow rates). Major releases, and all releases direct to atmosphere, will contribute to local air quality effects and to global greenhouse gas concentrations. The relative contribution of all foreseeable releases is minor.

It is likely that natural $CO_2$ seeps and large-scale releases in volcanic regions could provide useful information on ecological effects, although a review commissioned by the International Energy Agency (IEA) Greenhouse Gas R&D Programme from BGS and CRIEPI in Japan found no recorded incidents involving sudden large emissions of $CO_2$ from sedimentary basins. Seepage has been detected from some natural $CO_2$ fields along faults or as a result of boreholes, which in a few cases has resulted in very localised environmental damage, for example through local acidification of the water column. Examples of natural emissions of $CO_2$ from the seabed are found in the Tyrrhenian Sea offshore from the Aeolian Islands in Italy. At a field site near a shallow submarine $CO_2$ vent in the Mediterranean, a suite of crustose coralline algae species was absent near the vent (where average pH <7.7), which supports the findings of laboratory experiments (Hall-Spencer *et al*. 2008; Martin *et al*. 2008).

The environmental implications of subsea accidental releases of dense phase or supercritical $CO_2$ are poorly understood; it is anticipated that the ecological effects of large scale accidental releases would be local, although potentially severe, with the majority of the $CO_2$ passing rapidly through the water column to the atmosphere.

Blackford *et al*. (2009) performed a modelling study to produce an initial assessment of the potential environmental impact of $CO_2$ escape from CCS in sub-sea geological formations. They assessed a range of leak scenarios, with a focus on fairly extreme (large) releases of $CO_2$. Whilst recognising many assumptions, they suggested that the chemical perturbation of a sequestration leak, when regionally integrated, is likely to be insignificant when compared with that from continued non-mitigated atmospheric $CO_2$ emissions and the subsequent acidification of the marine system. It was noted that many key unknowns exist, particularly the fine-scale dispersion of leaked $CO_2$ and the ability of ecological systems to recover from perturbation.

A three year NERC-funded project to study environmental impacts of carbon storage was initiated in May 2010[36]. The study, undertaken by a consortium lead by Plymouth Marine Laboratory, will focus on understanding ecological risks and potential ecosystem impacts associated with geological carbon storage and consideration of mechanisms for their mitigation. Key issues to be addressed are:

- analysis of environmental risks associated with geological carbon sequestration (e.g. whole systems analysis of the environmental implications of CCS on aquifer integrity and marine geological resources);
- monitoring and tracking potential leaks from reservoirs;
- improvements to the understanding of rates, pathways and mechanisms by which $CO_2$ may migrate from storage reservoirs;

[36] See: http://www.nerc.ac.uk/research/themes/resources/events/documents/ccs-ao.pdf

- evaluation of the impacts to surrounding ecosystems of $CO_2$ leaks as informed by geological/hydrological studies.

The study will also provide information on the effects of CCS in relation to wider research into ocean acidification.

### Socio-economic effects

All hydrocarbon spills have the potential to affect fish and shellfish populations by tainting caused by ingestion of hydrocarbon residues in the water column and on the sea bed. If large-scale releases of oil were to reach the sea bed, there is potential for smothering of habitats used by fish either as spawning, feeding or nursery grounds. In addition to direct toxicity of oil and dispersants, oil and certain chemicals have the potential to introduce taint (defined as the ability of a substance to impart a foreign flavour or odour to the flesh of fish and shellfish following prolonged and regular discharges of tainting substances). Possible effects on human consumers of seafood are also an issue of concern in relation to accidental spills and industrial discharges.

Government may issue exclusion orders preventing marketing of seafood from areas considered to be contaminated following a spill or other incident, resulting in economic impacts on local fisheries and associated processing. Historical experience (e.g. the *Braer* spill) indicates that irrespective of actual contamination levels, spills may result in significant loss of public confidence in seafood quality from the perceived affected area, and therefore in sales revenue. Either perceived or actual contamination of target species with hydrocarbons or other chemicals may therefore result in economic damage to the fishing industry (and associated industries).

Impact on the recreational, tourism and amenity appeal in the event of a major oil spill would be influenced both by the severity of oiling and by the extent, duration and tone of media reporting and resulting public perception of the severity of the event. For example, following the *Sea Empress* spill, the local economic impact on tourism was relatively minor (SEEEC 1998). Analysis of the impact on tourism throughout Pembrokeshire suggested a downturn of about £2 million in the commercial service sector in 1996 set against an estimated £160 million contributed by tourists to the economy in 1995. Nevertheless, despite satisfaction with the quality of the environment by those visiting the area, there was evidence from further questionnaires that for one in five who actually considered visiting Pembrokeshire in 1996, the *Sea Empress* spill was significant in leading to rejection.

Major gas releases and chemical spills both have some potential for significant effects in terms of short-term safety issues and longer-term socio-economic effects. As noted above, chemicals used in offshore E&P are generally in low risk categories, and the socio-economic effects are generally similar in nature, but of lower severity, to oil spill. Potential safety issues of gas releases include explosion and (for subsea releases) loss of buoyancy for vessels and floating installation, although recent studies (e.g. May & Monaghan 2003; Beegle-Krause & Lynch 2005) suggest that the latter may not be a significant concern.

## 5.13.2.4 Oil spill response preparedness

Spill prevention and mitigation measures are implemented for offshore exploration and production through the *Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999* and the *Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Conventions) Regulations 1998*. Under the Regulations, all operators of an offshore installation or oil handling facility must have an Oil Pollution Emergency Plan, OPEP) in place. The plans are reviewed by DECC, MCA and relevant environmental consultees, such as the Marine Management Organisation or relevant Devolved Authority, the Joint Nature Conservation Committee and the relevant inshore statutory nature conservation body, e.g. Natural England, before approval by DECC. OPEPs set out the arrangements for responding to incidents with the potential to cause marine pollution by oil, with a view to preventing such pollution or reducing or minimising its effect. The plans are relevant and particular to a specific field or installation and cover activity such as drilling rigs carrying out exploration, appraisal and development drilling, production installations, pipelines, subsea tiebacks and new installations that are on site but not yet producing.

Offshore, primary responsibility for oil spill response lies with the relevant Operator, although the Secretary of State's Representative (SOSREP) may intervene if necessary, under terms laid out by the *Offshore Installations (Emergency Pollution Control) Regulations 2002*. The Maritime and Coastguard Agency (MCA) is responsible for the National Contingency Plan for Marine Pollution from Shipping and Offshore Installations (NCP) in consultation with other relevant departments, agencies and stakeholders, the latest version of which was issued in August 2006 and is currently under further review. The MCA is the competent UK authority that responds to pollution from shipping and offshore installations, although offshore installations have a statutory responsibility for clean-up in their jurisdictions, up to and including a Tier 3 incident (a large spill requiring national assistance and resources). Local authorities (and in Northern Ireland, the Environment Agency) have accepted a non-statutory responsibility for shoreline clean-up.

To test the effectiveness of the NCP, and its interaction with other major incident plans, including OPEPs submitted by operators of offshore installations, a major oil pollution exercise involving a shipping casualty is held annually and an offshore installation exercise is held every five years. The last such exercise involving the offshore industry was Exercise Unicorn, held on 10 June 2008, involving BP as the operator. The exercise was designed to test all the facets of incident response, such as key roles being identified and understood, utilising a challenging scenario which incorporated a number of foreseeable risks, all of which had the potential to occur on and/or around an offshore oil and gas production facility.

Whilst the next date for a national exercise involving an offshore asset was not due until 2013, this has been brought forward to Spring 2011 and exercise planning has commenced, through the auspices of OSPRAG (see below). In addition to the NCP exercise, operators are obliged to hold an exercise with the SOSREP every five years and during the last cycle of such exercises, the OPEPs of 22 operators were tested. The latest cycle of SOSREP exercises is presently being undertaken and to date 13 have been held since 2008.

Oil & Gas UK has established the Oil Spill Prevention and Response Advisory Group (OSPRAG) to provide a focal point for the sector's review of the industry's practices in the UK, in advance of the conclusion of investigations into the Gulf of Mexico incident. The Group has four specialist review groups whose remit is to focus on:

- technical issues including first response for protection of personnel;
- oil spill response capability and remediation including national emergency response measures;
- indemnity and insurance requirements;
- pan-North Sea regulations and response mechanisms.

The OSPRAG Technical Review Group (TRG) is reviewing several key processes for primary, secondary and tertiary well control. The main areas of focus are well examination, verification and primary well control, competency, behaviours and human factors, blowout preventer inventory and improvements including secondary control, well capping and containment and well flowing status. In October 2010, OSPRAG commissioned detailed designs and procurement for a modular device which could close off or 'cap' a well in the event of a blowout, preventing oil from leaking into the environment. The recommended design is considered to be the most appropriate solution given the met-ocean conditions typically found in the UK, and specifically to the west of Shetland.

The capping device could be installed at various points of the subsea well head, the blow-out preventer (BOP) or lower marine riser (LMRP) assembly to stop the flow of oil and buy valuable time for engineers to develop a permanent solution for killing the well. The approach is likely to utilise a variety of adapters, connectors, a main body incorporating two gate valves, choke and kill manifolds and a variable flow ported sub/cap with an overall system rating for 15,000psi working pressure. Such a device could be deployed in sea states of up to 5 metres, depending on the vessel used, and capping could be achieved within 20–30 days of the incident, depending on weather and well site conditions.

The detailed design phase and procurement will be project-led by BP, working closely with the TRG and other UK operators. Estimated manufacturing time is currently 11 months but there is a possibility of shortening this once the final equipment configuration is agreed and priorities are set. Importantly, this work will inform the development of a longer-term regional or global (non-US) response which is being co-ordinated by the Global Industry Response Group under OGP (the International Association of Oil & Gas Producers).

The Oil Spill Response Group (OSRG) of OSPRAG was established to review the UK's oil spill response capability and industry co-ordination with the national response mechanism. Its areas of focus are spill scenarios and modelling, review of physical response capability, sensitivity and protection mapping in relation to clean up and restoration, Oil Pollution Emergency Plans (OPEPs) and exercising OPEPs. An early action of the OSRG was to facilitate planning for an early exercise of the NCP (see above).

In terms of UK response capability, the MCA maintains a contractual arrangement for provision of aerial spraying and surveillance, with aircraft based at Coventry and Inverness. Within two days, aircraft can deliver sufficient dispersant to treat a 16,000 tonne spill within 50 miles of the coast anywhere around the UK (National Audit Office 2002). DECC is a partner in this arrangement and undertakes regular aerial surveillance of offshore installations. MCA holds 1,400 tonnes of dispersant stockpiled in 11 locations around the UK, in addition to counter-pollution equipment (booms, adsorbents etc) which can be mobilised within 2-12 hours depending on incident location.

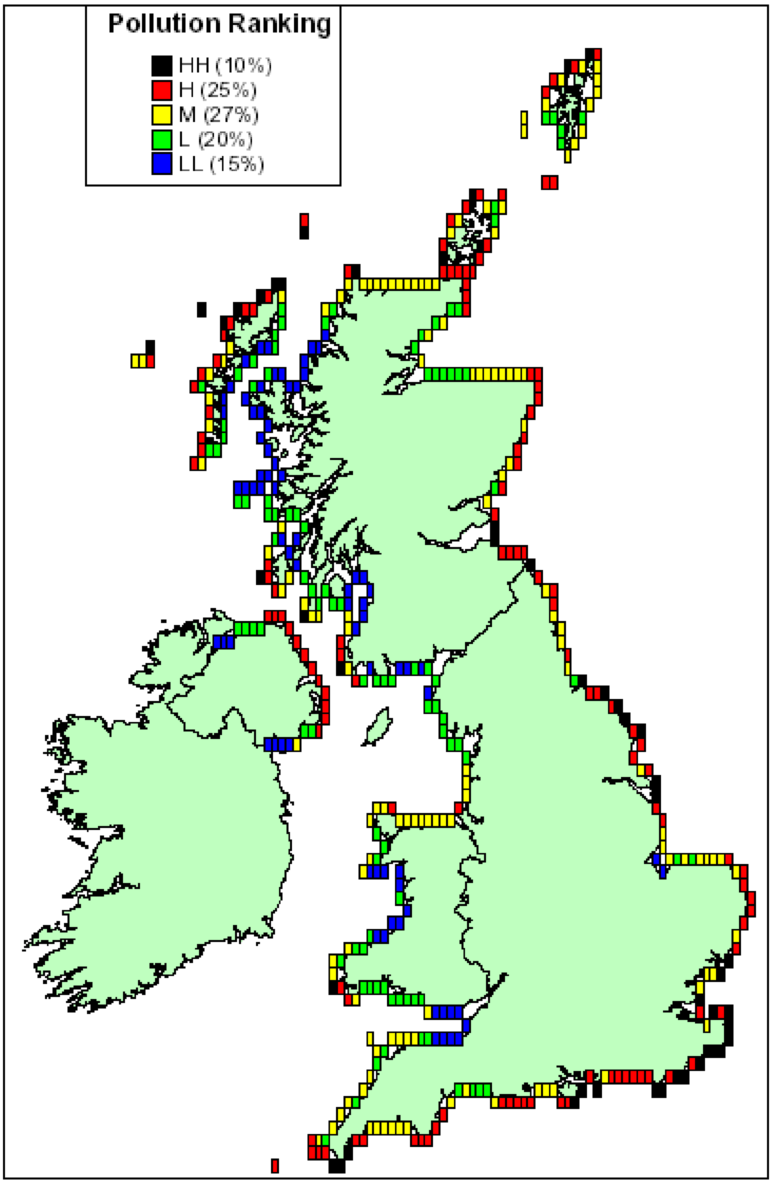
Similar response capabilities, providing a tiered response capability, must be available to Operators prior to commencing drilling or production activities. These provisions are made under various long-term commercial contracts with specialist contractors, supplemented where necessary (e.g. for remote locations) with additional stockpiles. Site-specific OPEPs must also be submitted to DECC for approval prior to operations. Additional conditions can be imposed by DECC, through block-specific licence conditions (i.e. "Essential Elements").

In 2000, the Maritime and Coastguard Agency (MCA) commissioned a study to provide data to assist the MCA with regard to decision making on the placement of Emergency Towing Vessels (tugs or ETVs) in different locations around the UK coastline. This involved an assessment of incident frequencies and the likelihood of different types of accidental events in causing pollution which would then impinge on the coastline (Safetec 2000), including both incidents which occur at the coastline (e.g. grounding incidents), as well as incidents that occur at sea but could encroach on the coastline. The relative risk of oil spills resulting from shipping casualties is summarised in Figure 5.46. This assessment facilitated the designation of Marine Environmental High Risk Areas (MEHRAs) and identified the best locations for ETVs in the Northern Isles, the Minches, the South-west approaches and the Dover Straits (which is run on a joint management and finance basis with the French Authorities). Following the Spending Review of October 2010, the MCA will no longer provide ETVs at taxpayers' expense from September 2011[37]. Tugs are mainly deployed when vessels break down and the Government believes state provision of ETVs does not represent a correct use of taxpayers' money and that ship salvage should be a commercial matter between a ship's operator and the salvor. Removing ETVs will save £32.5m over the Spending Review period.

Offshore wind farm and other developments over the last decade, and those projected in the near future have, and will, alter the collision and spill risk profile around the UK; the availability of rapid tug response is considered to be a significant mitigation of such risks. Consequently it is recommended that periodic reviews of the availability of tugs should be undertaken to ensure that adequate response capability is maintained. Specifically, the location of tugs must continue to be based on periodic strategic assessments of risk.

37 http://nds.coi.gov.uk/clientmicrosite/Content/Detail.aspx?ClientId=202&NewsAreaId=2&ReleaseID=416118&SubjectId=36

Figure 5.46 – Pollution risk ranking of the UK coastline




*Source: Safetec (2000)*

In general, the response policy in the UK for offshore spills is to allow natural dispersion processes to occur, except where chemical dispersion is clearly advantageous (usually to protect birds). This contrasts with a generally more interventionist approach in some other jurisdictions, for example in the US where *in-situ* burning of surface oil is considered as advantageous in some circumstances. The feasibility of containment and recovery in offshore locations is generally considered low in the UK; there is currently no capacity for large-scale containment and recovery in the offshore UKCS (or in adjacent national waters, including Norway and Ireland).

A recent report, "Deepwater Horizon Containment and Response: Capabilities and Lessons Learned," has been prepared by BP for the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) in order to provide a preliminary outline of some of the important lessons learned in the course of responding to the explosion on the Deepwater Horizon drilling rig, focusing in particular upon the key equipment, facilities and planning tools that were deployed in responding to this event. Highlights of key capability advancements identified by BP include:

- Containment (the effort to disperse, cap, close and ultimately stop the release of hydrocarbons at the source):
- A variety of new open containment systems proven in deepwater conditions with demonstrated techniques to mitigate hydrate formation.
- The proven capacity to engineer and construct closed systems allowing not only for the collection of hydrocarbons but also the control of flow and the introduction of well-control fluids
- Safe simultaneous operation of a large number (16 or more) Remotely Operated Vehicles (ROVs) in close proximity to perform a wide range of novel interventions on open and closed containment systems
- Development of advanced visualization techniques enabling the simultaneous operation for extended periods of a large number (19 or more) major vessels in a narrow radius and hazardous conditions without incident
- Rapid retrofit of multipurpose vessels for subsea installation, high-volume containment, faring, Dynamic Positioning (DP) vessel to DP vessel offloading, and top kill and hydrostatic kill operations
- Initial development of more robust non-wireline ranging technologies for faster well intercept in the context of the deepsea drilling of a relief well
- Development in a compressed time period of a robust system for long-term containment featuring the first installation of free-standing riser, hydrate inhibition and emergency hurricane disconnection capability
- Novel subsea systems to inject dispersant efficiently at source (see below)
- Experience in coordinating industry, agency and academic expertise to efficiently produce reliable, high-quality data on subsurface, seabed and water column conditions.

During response to the *Deepwater Horizon* spill, BP, working closely with the U.S. Coast Guard and the U.S. Environmental Protection Agency (EPA), reviewed and undertook a subsea deployment of dispersants with the objective of reducing the environmental and safety impact of the release of oil from the *Deepwater Horizon* well. The EPA has permitted use of dispersants subsea to remediate oil spills since the 1990s. Although there have been limited trials and some discussion in technical papers of applying dispersant to the source, industry practice in general has been to deal with subsea oil spills by first allowing the hydrocarbons to rise to the surface and then dispersing the oil through aerial application of dispersant. However, most oils evaporate quickly, leaving a waxy residue which is unresponsive to chemicals and limits the times at which dispersants can be successfully applied at the surface. In addition, there is an indication that injecting dispersants into colder oil on the surface or into a mixture of oil and seawater requires more chemical to achieve the desired effect.

Novel aspects of dispersant use in response to the *Deepwater Horizon* spill included:

- Following multiple tests and computer modelling soon after the incident, subsea injection of dispersant directly into oil at the source, using newly engineered tools at the site of the Riser Insertion Tube Tools (RITT) and later, at the open top hat containment device
- Reduction of dispersant use at the surface by almost 70 percent with good results, as measured by observation of lower amounts of oil and lower measurements of VOCs at the surface, enhancing safety of containment operations at the site
- The testing of alternative subsea dispersant mechanisms, such as the use of subsea bladders in the Subsea Autonomous Dispersant Injection (SADI) and automatic injection of dispersant in the event of hurricane evacuation

- The development of surface observational tests of subsea dispersant effect.

A new cross-government initiative, PREMIAM, has been established to improve the response and effectiveness of environmental impact assessment following marine oil and chemical spills in the UK. PREMIAM (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) is a Defra funded project aiming to produce guidelines for post-incident monitoring and also provide a co-ordinating mechanism to ensure that this is conducted efficiently (both with respect to cost and scientific robustness); PREMIAM is being co-ordinated by the Centre for Environment, Fisheries and Aquaculture Science.

With respect to oil spill response preparedness, the recent Energy and Climate Change Committee (2011) report on the implications for UK deepwater drilling of the Deepwater Horizon event concluded that:

- It was concerned that the offshore oil and gas industry is responding to disasters, rather than anticipating worst-case scenarios and planning for high-consequence, low-probability events.
- The environmental impacts of a sub-sea well blowout need to be understood and taken into account when a drilling licence is issued in the UK. The licensing regime must take full account of high consequence, low probability events.
- As part of the drilling-licence process, the Government require companies to consider their responses to high-consequences, low-probability events - such as a blowout. The Government should not automatically accept claims that companies have mitigated away the risk of such worst-case scenarios.
- Oil spill response plans often share procedures for dealing with oil spills. There is some concern that in the past this may have led to a culture of copying-and-pasting rather than the production of site-specific plans which recognise the drilling environment and the risk of high-consequence, low-probability events. The Government should re-examine oil spill response plans to ensure that this is not the case.
- The Government should draw up clear guidelines on the sub-sea use of dispersants in tackling oil spills, based on the best available evidence of both their effectiveness and their environmental impact. The Government should monitor the effects of sub-sea dispersants in the Gulf of Mexico to inform these guidelines.
- There are serious doubts about the ability of oil spill response equipment to function in the harsh environment of the open Atlantic in the West of Shetland. The Government should ensure that any capping, containment and cleanup systems are designed to take full account of the harsh and challenging environment West of Shetland.

## 5.13.3 Summary of findings and recommendations

The environmental risks of accidental spill events associated with proposed activities following further rounds of oil & gas licensing are qualitatively similar to those of previous and ongoing activities in the North Sea, Irish Sea and west of Shetland, and mitigation in the form of risk assessment and contingency arrangements is well established (although currently under review following the Macondo well spill in the Gulf of Mexico). Offshore wind farm developments (and in the future, wave and tidal stream developments) are not considered to represent a significant source of accidental spills where navigational safety risks have been fully considered in the planning and siting of such developments.

E&P project-specific risk is highly associated with reservoir fluid type (e.g. heavy oil compared with condensate or gas), distance from sensitive coastal habitats and locations, and prevailing winds and currents. The areas of enhanced risk are therefore west Shetland (Regional Sea 8) and to a lesser extent the northern North Sea (Regional Sea 1). Project-specific risk of major incidents in Regional Seas 2, 3, 4 and 6 are moderated by prospective fluid type (condensate or gas).

Subsea drilling equipment has evolved over the years into reliable systems with multiple redundancy. The subsea drilling pressure control system comprises several inter-related components including the wellhead assembly, BOP stack, choke & kill line system and riser. There have been very few drilling incidents resulting in loss of well control, and historic improvements in spill prevention and mitigation have stabilised the volume of oil spilled from E&P operations on the UKCS at a relatively low level, primarily through identification of root causes of spills and improvements in operational control procedures. The causes of the recent *Deepwater Horizon* blowout have been identified and a combination of technical, operational and regulatory measures are in place to effectively control the risk of a similar event in UKCS operations. These are being implemented through initiatives by HSE, DECC, OSPRAG and individual operators.

The risk context to the activities resulting from proposed licensing and leasing includes other hydrocarbon discharges and spills associated with shipping. In general, the UKCS area has few hydrocarbon discharges and a low incidence of accidental spills. However, in a national context, areas of high or very high risk of oil spills resulting from shipping casualties (MEHRAs) have been identified by MCA. It is recommended that the decision to remove the provision of government-funded Emergency Towing Vessels, which is considered to significantly reduce the available mitigation of risk of vessel collision, should be reviewed and mechanisms established to ensure adequate provision of response capability maintained.

In some cases, there is strong seasonality in specific species' sensitivities, in particular in relation to bird populations and breeding/moulting seals. Existing regulatory controls emphasise the risk management and contingency planning aspects of environmental management, including the timing of operations; and additional controls at an SEA level are not considered to be necessary.

Oil spill response planning and capability, by the MCA, the oil industry and relevant authorities is generally consistent and as effective as practicable. It is clear that prevailing weather conditions will rarely facilitate offshore containment and recovery of surface oil (also that the emphasis should be on prevention rather than cure).

Operational risks, principally of large-scale $CO_2$ risk from transportation or offshore injection facilities, require further consideration prior to authorisation of developments, although risk scenarios are broadly similar to those associated with gas production and relevant experience and effective control will be possible under existing regulatory systems. The environmental consequences of large $CO_2$ releases are not considered likely to be severe (i.e. comparable with a large hydrocarbon release), although further consideration is needed of the potential consequences of loss of containment from storage reservoirs over long timescales.

## 5.14 Ancillary development

### 5.14.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | $CO_2$ Storage | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Other interactions with shipping, military, potential other offshore renewables and other human uses of the coastal and marine environment | X | X | X | X | X | X | X | 5.7.2.1<br>5.7.2.3<br>5.15.2 |
| | Potential visual impacts and seascape effects of development including change to character | X | X | X | X | X | X | X | 5.8.2.4<br>5.8.3 |
| | Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access. | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Physical damage to habitats from infrastructure construction, vessel/rig anchoring etc | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Physical effects of anchoring and infrastructure construction (including pipelines and cables) on seabed sediments and geomorphological features (including scour) | X | X | X | X | X | X | X | 5.4.2.1<br>5.4.2.2 |
| | Local air quality effects resulting from exhaust emissions, flaring and venting | X | X | X | X | X | X | X | 5.11.2 |

Although the focus of this SEA is principally the marine environment, the issue of ancillary development and related potential environmental effects is an important strategic consideration. This section focuses on onshore works directly associated with offshore energy development as specified in the draft plan/programme, and also notes potential offshore grid development which may be required to distribute new capacity around the UK. The onshore distribution of imported gas in the UK is not part of this plan/programme. The sources of potentially significant effect identified above are those which may be relevant to ancillary developments, particularly those offshore. Given that ancillary developments are not covered directly by the draft plan/programme but are linked closely to the successful implementation of some aspects of it, these ancillary development effects are considered to be secondary in nature. Therefore, the relevant assessment section in the table above (right hand column) identifies where each of the potentially significant effects are more fully considered.

## 5.14.2 Consideration of the evidence

### Oil and gas, gas and carbon dioxide storage

Given the scale of hydrocarbon activity and location of existing oil and gas terminals, in general, major additional shore-based infrastructure is not anticipated as a result of future offshore oil and gas licensing; it is envisaged that maximum use would be made by reusing/adapting existing infrastructure.

To some extent, natural gas and carbon dioxide storage projects will utilise existing infrastructure in terms of existing offshore platforms and onshore power stations; however, some new development will be required, with modifications to existing facilities necessary. For many projects involving the transport of gas or carbon dioxide from onshore facilities to subsea geological storage sites, new pipelines, with onshore sections, will be required. This is particularly true of carbon dioxide transport and storage, with a low proportion of existing pipelines suitably constructed to transport supercritical phase carbon dioxide. Additional onshore works may involve the construction of compressor booster stations for gas transport.

### Grid reinforcement

At a European level, in 2009 the UK signed up to the North Sea Countries' Offshore Grid Initiative along with Belgium, France, Denmark, Germany, Ireland, Luxemburg, The Netherlands, Sweden and Norway (NSCOGI 2010). The initiative aims to provide a framework for regional cooperation to find common solutions to questions related to current and possible future grid infrastructure developments in the North Seas. A Memorandum of Understanding signed in December 2010 recognises the strategic importance of present and future on- and offshore infrastructure developments for security of supply, the development of renewable energy sources and the integration of national electricity markets. It recognises that the scale of the appropriate offshore infrastructure as well as reinforcement of the onshore grid required development needed to facilitate the plans for installation of wind farms offshore, requires a strategic, coordinated approach at national, regional and EU-level.

A series of working groups will cover the following areas: Grid configuration and integration; Market and regulatory issues, and Planning and authorisation procedures. Of perhaps most relevance are the planned deliverables of the grid configuration and integration working group which include:

- Identifying relevant policy considerations and constraints for the development of possible future technical grid configurations, based on energy, environmental, planning and other policies, should look to at least 2030 (by June 2011).
- Completing a baseline overview of grid considerations, based on grid reinforcements envisaged for the European electricity grid in the long term network development plans. This should take into account national offshore wind ambitions and look to at least 2030 (by end 2011).
- The identification of 3-4 plausible scenarios for the onshore and offshore grid infrastructure in 2030. These scenarios should help overcome bottlenecks envisaged for the long term development of onshore and offshore electricity production and integration of the electricity markets in the region (by June 2012).
- Carrying out a case study on an individual project for interconnection of offshore wind farms in different national jurisdictions (by December 2012).

- Presenting some assessments of the costs and benefits of plausible offshore grid configurations to which individual energy production facilities may directly be connected and which allow for integration of the electricity markets in the region (by December 2012).

The recently published 2010 Offshore Development Information Statement (NGET 2010) by the National Grid Electricity Transmission plc (NGET) represents the most recent description of UK development plans for electricity transmission networks to support anticipated offshore renewables development until 2025. This is the second such annual statement which provides a wide range of information relating to the possible development of the National Electricity Transmission System (NETS) in offshore waters, including applicable technology, potential offshore transmission design and onshore transmission co-ordination. The 2010 statement considers four different development scenarios of approximately 10.5GW (17), 19GW (25), 25GW (47) and 35GW (44) of generation capacity by 2020 (2025 figures in parentheses); these figures are inclusive of generation connecting to the onshore electricity distribution system (NGET 2010).

The statement also includes a number of conceptual desktop design strategies for different technology assumptions; these illustrate how different transmission network configurations can impact the optimisation of offshore transmission development. Additionally, figures are presented for the different regions of the UK where development is occurring / anticipated to occur. While this statement provides a greater level of detail on the issue of offshore grid reinforcement than has previous been available, it does not consider ancillary onshore works in great detail. It is considered that the assessment of potential effects based on the National Grid Company’s study for the previous OESEA (National Grid 2008) remains valid for the current plan/programme in relation to ancillary onshore grid reinforcements.

For OESEA, National Grid analysed the impact of connecting 25GW of offshore wind generation in addition to the 8GW already built or planned to the onshore transmission system and identified where reinforcements to the transmission system would be required (National Grid 2008). The analysis was carried out against a set of electricity generation and demand scenarios agreed with DECC – the contracted background and the ‘Non-Contractual Scenario’.

To analyse the impact of connecting 25GW of offshore wind generation, National Grid (2008) assumed that potential wind farm development sites would be in Regional Sea 1 (2GW), Regional Sea 2 (16GW), Regional Sea 4 (2GW) and Regional Sea 6 (5GW). These locations were based on water depth (areas less than 60m deep) and also areas of sea bed where developers have shown an interest through The Crown Estate’s indicative potential Round 3 areas map (September 2008 version). Although no offshore wind generation was assumed to be located in Regional Sea 3, connection sites were investigated for this region because of developer interest.

More information on the likely distribution of this development became available in January 2010, when The Crown Estate announced the exclusivity zone agreements for nine Round 3 offshore wind zones: Moray Firth zone (1.3 GW); Firth of Forth zone, (3.5 GW); Dogger Bank zone, (9 GW); Hornsea zone (4 GW); East Anglia (Norfolk Bank zone), (7.2 GW); Southern Array (Hastings zone), (0.6 GW); West of Isle of Wight zone, (0.9 GW); Atlantic Array (Bristol Channel zone), (1.5 GW); Irish Sea zone (4.2 GW). In May 2010 The Crown Estate awarded extension projects at a number of existing offshore windfarms, namely; Galloper Wind Farm at Greater Gabbard, Kentish Flats 2, Walney extension, Burbo Bank extension, totalling some 1.5 GW. Agreements to lease have also been arranged for two demonstrator projects in English waters and two also in Scottish waters.

This equates to a total (excluding Round 1/2 extensions and demonstrator sites) of 32.2GW, with regional figures of: Regional Sea 1 (4.8GW), Regional Sea 2 (20.2GW), Regional Sea 3 (1.5GW), Regional Sea 4 (1.5GW) and Regional Sea 6 (4.2GW)[38]. While the total capacity exceeds the 25GW considered by National Grid (2008), the distribution is very similar with the exception of greater forecast capacity in Regional Sea 1.

Under this scenario, the majority (>60%) of capacity is sited in Regional Sea 2 (southern North Sea), with areas off the east coast of Scotland and Irish Sea also being important. If actual development takes place on a similar pattern, these three areas will require the largest amount of reinforcement of the transmission system. However, this will also depend on other sensitivities that may affect generation and including power generation from new coal, gas and nuclear power stations as well as other marine renewable energy developments.

Based on the generation capacities described above, the requirements for reinforcements can be divided into two categories. Regional Seas with only a few offshore wind farms and relatively small overall capacities of 2GW or less would not require significant reinforcement work apart from extensions to existing substations or the establishment of new substations at the onshore interface point. Regional Seas with the potential for several offshore wind developments and overall capacities greater than 2GW (Regional Seas 2, 6 and possibly 1) would require significant reinforcement to both substations and the wider network including overhead power lines. The areas of potential major onshore reinforcements that have been were identified include northwest Wales, south East Anglia, Lincolnshire, Yorkshire and Derbyshire. Scenarios presented in NGET (2010) suggest similar areas of major reinforcement, also including northeast and southeast Scotland and further areas in East Anglia.

The main components of the transmission system are substations (connection and/or bussing points) and the overhead lines or underground cables that connect them. Transformers are used to change the generated power between different voltages used on the system. A number of new cables from offshore wind farms are expected to utilise direct current (DC) technology which will require converter stations to interface with the onshore alternating current (AC) system.

Switchgear forms a large spatial component of substations. Air Insulated Switchgear (AIS) are the predominant type in the UK and are made up of 6 to 15 bays each measuring approximately 21m x 40m. Gas Insulated Switchgear (GIS) is more costly than AIS but requires less space with each bay measuring approximately 4m x 7m. They are usually only constructed close to the coast (within ~5km). To accommodate offshore wind generation, both types of switchgear would require at least 2 extra bays to be built in existing substations. In addition a typical substation also requires space for supporting equipment, access roads and site facilities.

At the onshore interface (between the offshore and onshore transmission systems), land will be required for the underground cable termination, transformers and reactive compensation equipment. These will most likely be located outside of the substation boundary fence and include buildings for control and communication and access roads within a fenced area. Where offshore wind farms are located at a significant distance from the coast, DC connections are likely to be required. It is expected that Voltage Source Converter (VSC) technology is most economically suited to offshore High Voltage Direct Current (HVDC)

[38] It should be noted that these capacities are indicative, comprising exclusivity agreements between developers and The Crown Estate, with planning applications and associated environmental assessment yet to be submitted; consented capacities may differ.

connections. The land area needed for VSC-HVDC converter termination is more than for an AC connection with a single 1000MVA VSC-HVDC installation occupying 125m x 95m with the converters housed in buildings approximately 24m high. The potential connection solutions used to gauge the onshore impact of offshore wind generation indicate that 2 or 3 of these converters may be installed at one site.

Where an offshore submarine cable from a wind farm arrives onshore there is a need for a transition joint bay where it is joined to the onshore underground cables. There are usually three cables for an AC connection and two for DC. Along the onshore cable routes, cable joint bays will be needed at every 800 to 1,000m; these are wider than the normal cable trench. For more than one connection from a wind farm, or where multiple wind farms will connect to the same substation, separate routes will be necessary for each connection.

To connect offshore wind generation to the onshore transmission system, upgraded or new 400kV overhead power lines may be required to accommodate the changes in power flows, especially across congested areas. The most recent towers used to carry the power lines are the L12 design which vary in height (46.5m to 49m) and width (7m to 14.5m) depending upon whether they are a suspension, deviation or terminal tower. The size, height and spacing of the towers are also determined by the type of conductor required, safety, route topography and environmental considerations.

Taking into account the assumptions made and the complexity of the transmission system, the study found that there is sufficient capacity within the onshore system to accommodate up to 10GW of the possible 25GW of offshore wind energy without the need for major reinforcement. Beyond 10GW and with the development of the southern North Sea offshore wind resource, major reinforcements will be needed, including the requirement for one upgraded and one new substation and four new sections of overhead power lines in the Regional Sea 2 area.

An additional study carried out by National Grid and Econnect for The Crown Estate has investigated the feasibility and costs of installing an east coast subsea transmission cable from Shetland to the south east of England using VSC HVDC technology. The proposed network layout (which is not definitive) would have several connection nodes at various locations on the east coast of Britain where they can accumulate power from new onshore and offshore developments, and provide an interface with strong points on the existing transmission system. Similar offshore transmission cables may be required in the eastern Irish Sea and off west Wales (NGET 2010). This would require new infrastructure on land in the form of upgrades to existing substations or the construction of new substations to accommodate the AC interface switchgear. If HVDC converter stations are located away from the substations then HVAC cables or overhead lines would also be required to connect the converter station to the AC grid. The distance involved would affect the choice of cable voltage used and the number of cables required (between 2 and 5 to transfer 1GW). The offshore transmission network would not be built in a single phase but rather as individual links connecting new generation plants as required and links acting as reinforcement of the onshore grid.

The potential environmental effects of reinforcing the onshore grid transmission system to accommodate new offshore connections are related to the main components of the grid, which are: the substations and related equipment, buried land cables and overhead power lines. The National Grid study on the impact of offshore wind development on the onshore transmission system has identified potential sites and locations where reinforcement work and new onshore grid infrastructure may be required in the future. While some environmental sensitivities at the sites have been taken into account, it should be noted that no environmental impact studies have been carried out at this stage; the actual location, size and configuration of the onshore infrastructure is dependent upon the configuration of future offshore wind farms - which are currently at the planning stage. More detailed studies of the onshore environmental impacts would be carried out as part of the planning process for any development and would take account of the latest policies, legislation, guidance etc.

In general, each component of the transmission system will have an impact to varying degrees on several different aspects of the environment during construction and operation. These impacts may include but are not limited to:

- visual intrusion in the landscape, especially from substation and overhead power lines and towers which may cause visual obstructions and changes to the skyline
- loss, damage or disturbance to habitats and species (which may be protected) and
- loss or damage to historical and archaeological features through excavation and construction works, and by altering the visual setting of certain features
- changes to current land-use and hydrology by taking extra land for building works (substations) and infrastructure (towers) and by altering run-off patterns and possibly introducing pollutants during construction

The extent and magnitude of these impacts will be dependent upon the scale of the development taking place and their proximity to areas that have been designated for their ecological, cultural and landscape value. Some of the impacts such as the building of new infrastructure will introduce permanent changes to the environment whereas others that occur during construction phases will allow for full or partial recovery of the environment after reinstatement.

The offshore impacts of developments to the offshore grid (i.e. trunk lines) to distribute new renewables and other capacity around the UK, and potentially abroad, will be comparable to those of cable or pipeline installation as described in Section 5.4.2. The UK has a long history of experience in subsea cable and pipeline installation, and the locating and environmental effects of such projects are extensively managed through various regulatory and consenting processes including EIA. Any such development will represent a small increment on existing cable and pipeline infrastructure in UK waters.

With industry and government envisaging an installed capacity of 1-2GW by 2020[39] from wave and tidal devices, ancillary grid reinforcements resulting from wet renewables development will be on a much smaller scale than those associated with offshore wind. However, wave and tidal developments may be located off relatively remote sections of coastline where, at landfall, additional transmission infrastructure may be required to provide connections into the grid.

Despite the range of potential effects described above, the impacts of such activities in the terrestrial environment are generally well understood and their assessment and management are supported by a strong evidence base. Consequently, existing planning procedures and regulatory controls, including project-specific EIA, are considered appropriate for managing any potentially significant effects.

## Port and manufacturing facilities

The achievement of offshore wind generation capacities considered in the draft/programme will require development to port facilities. A greater number of ports around the UK have the

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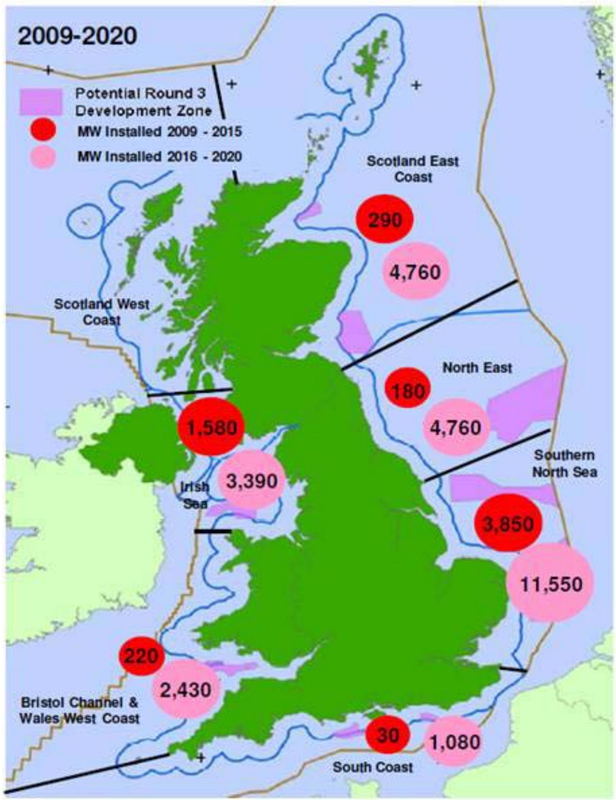
[39] See: The UK Marine Energy Action Plan

potential to assist project construction, but currently lack suitable facilities for services such as turbine assembly and manufacture of towers, blades, key nacelle components and foundations. The UK Renewables Service has produced recommendations (UK Renewables 2008) which include the requirement to develop at least 8 ports around the UK by 2014 for wind farm construction in order to meet the UK's 2020 renewable energy target. More recently, DECC commissioned an independent study (DECC 2009d) to consider: the requirements of the offshore industry for ports; current UK port capabilities; the opportunity for UK ports and potential port expansion or development to meet the needs for the offshore wind sector.

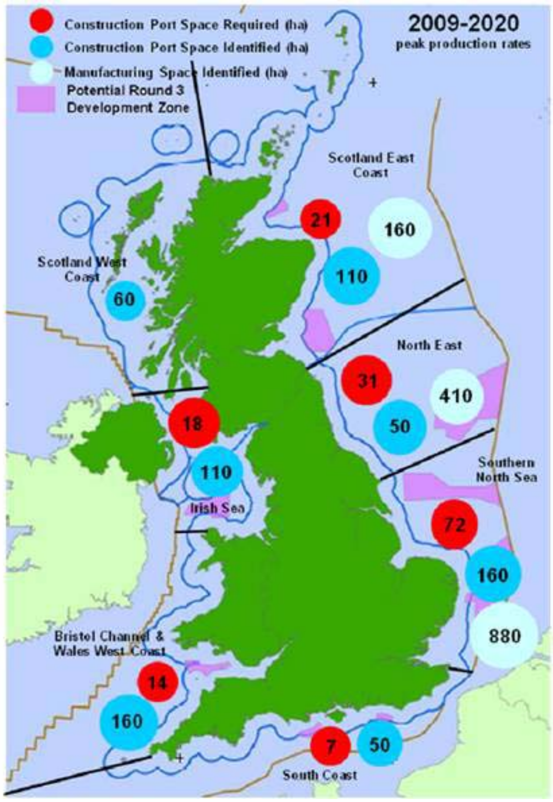
In terms of meeting the obligations of Rounds 1-3 of offshore wind farm development by 2020 and the anticipated number of turbines required; 6,440 turbines are expected to be installed in UK waters (excluding Scottish and Northern Ireland territorial waters) by 2020; the study outlined a series of requirements for both manufacturing and construction, details of which are described in Appendix 3h. The most significant issue identified in the report is adequacy of port capacity for construction of projects, due mainly to a lack of additional land of the scale required. Figure 5.47 details the expected geographical distribution of offshore wind capacity to be installed and the port space required for its construction.

Figure 5.47 – Expected offshore wind capacity to be installed and port space required

a) Expected capacity to be installed[1]




b) Space required for construction[2]




*Note: (1) Offshore wind capacity (MW) expected to be Installed off UK (split by coastal region), excluding projects in Scottish and Northern Irish territorial waters. (2) Based on 25 ports identified as having the capacity to support the expected offshore wind capacity to be installed. These ports and their facilities are detailed in the UK Offshore Wind Ports Prospectus (DECC 2009d).*
*Source: DECC (2009d)*

DECC (2009d) suggest that to meet the 2020 renewable energy target at least six locations distributed around the UK need to be available for use from 2014 onwards. These locations will need to be offered to developers by 2011 at the latest, to be factored into project plans. Additionally, Scottish Enterprise and Highlands and Islands Enterprise (2010) have produced a National Renewable Infrastructure Plan Stage 2 which indicates that an investment of £223 million would create a set of 11 clustered port sites which could support the manufacturing of 750 complete offshore wind units a year.

In terms of infrastructure requirements for wave and tidal installations which are still evolving, The Crown Estate has commissioned a report on the 'Build Out' of the Pentland Firth and Orkney Waters leasing programme, due in November 2010, in partnership with Scottish Government, Highland and Islands Enterprise and Local Authorities. The plan acknowledges that the delivery of the Pentland Firth and Orkney Waters commercial scale leasing programme from 2016 will require development of port infrastructure proposals alongside development of the technology and deployment techniques (Scottish Enterprise and Highlands and Islands Enterprise 2010).

The expected changes to port facilities and the increase in number of ports required for offshore marine energy manufacturing, construction and installation will have some environmental impacts. These could include acquiring land (loss of possible habitat and reclamation), noise impacts, changes in sediment regime through dredging, increased road and marine traffic, waste discharges and the construction of coastal defences to protect the ports and surrounding vulnerable areas (OSPAR 2010a).

As with the discussions of grid reinforcements above, the influence of wave and tidal development within the scope of OESEA2 on port and manufacturing facilities development will be comparable in nature, but considerably smaller in scale, than that associated with offshore wind.

Despite the range of potential effects described above, the impacts of such activities in the coastal and terrestrial environment are generally well understood. Existing planning procedures and regulatory controls, including project-specific EIA and Habitats Regulation Assessment, are considered appropriate for managing any potentially significant effects.

### 5.14.3 Cumulative impact considerations

Gird reinforcement will impact incrementally to existing electricity transmission networks, with noise, habitat loss/modification, landscape impacts and interactions with other users among the key issues. Almost all other forms of terrestrial land use and development have the potential to act cumulatively with grid reinforcements in respect of these key issues.

The majority of port development associated with the draft plan/programme will be extensions of the capabilities of existing facilities. Impacts from these activities can therefore be described as incremental to existing/past impacts. There may also be cumulative impacts in terms of association with other coastal activities such as shipping traffic and adjacent construction (e.g. coastal defences, coastal squeeze). Other users of the marine environment are likely to be major considerations in the assessment of cumulative effects, as is the presence of adjacent conservation designations and existing pressures on such features.

Though beyond the direct scope of OESEA2, ancillary development associated with joint renewable energy projects with other countries involving direct interconnection with the UK may occur in the future. A recent DECC-commissioned report (SKM 2010) undertook a high-level review of the, costs and benefits from a UK perspective, of potential joint project scenarios with Norway, the Republic of Ireland, continental Europe and Iceland.

For both grid reinforcement and port development, the existing planning and regulatory framework, including the EIA (and potentially SEA) process, will consider the aforementioned cumulative considerations in detail to ensure appropriate management of any potentially significant effects.

### 5.14.4 Summary of findings and recommendations

Major additional shore-based infrastructure is not anticipated as a result of future offshore oil and gas licensing; it is envisaged that maximum use would be made by reusing/adapting existing infrastructure.

Some new onshore development will be required for natural gas and carbon dioxide storage projects, namely modifications to existing facilities, new pipelines, and potentially the construction of compressor booster stations for gas transport. From a strategic perspective, this will be of relatively small scale and likely limited to a very small number of projects, all of which will be subject to planning procedures and regulatory controls, including project-specific EIA and Habitats Regulation Assessment.

Considerable ancillary onshore development will be necessary to facilitate the achievement of the offshore wind element of the draft plan/programme, with reinforcements to the national electricity transmission system and enhancements to the capacity of the UK's port facilities required. Some ancillary offshore grid reinforcements will also be required. The influence of wave and tidal development within the scope of OESEA2 on port and manufacturing facilities development will be comparable in nature, but considerably smaller in scale, than that associated with offshore wind. These will have some environmental impacts, with habitat loss/modification, noise, landscape impacts and interactions with other users among the key issues to be considered.

However, both the onshore grid reinforcements described, for example, in NGET (2010) and enhancement of port facilities recommended in DECC (2009d) remain uncertain in terms of scale and location; in this respect, there are no specific plans, programmes or projects which are sufficiently developed to be fully assessed. These potential developments and their associated environmental effects are secondary effects to the draft plan/programme currently under assessment; they are a series of projects which will be subject to project-specific EIA, or perhaps even separate plans/programmes to be subject to their own SEA(s). These processes, along with the existing planning and regulatory framework, will contribute towards appropriate management of any potentially significant effects.

## 5.15 Overall spatial considerations

### 5.15.1 Introduction

| Assessment Topic | Sources of potentially significant effect | Oil & Gas | Gas Storage | CCS | Offshore Wind farms | Tidal Stream | Tidal Range | Wave | Assessment Section |
|---|---|---|---|---|---|---|---|---|---|
| | Other interactions with shipping, military, potential other offshore renewables and other human uses of the offshore environment | X | X | X | X | X | X | X | 5.7.2.1<br>5.7.2.3<br>5.15.1<br>5.15.2 |

The *Marine and Coastal Access Act 2009* is intended to simplify and strengthen strategic management of the marine environment by enabling economic, social and environmental impacts and objectives to be considered simultaneously. A key objective of the Act is to implement a nationwide system of marine planning that will clarify marine objectives and priorities for the future, and direct decision-makers and users towards more efficient, sustainable use and protection of marine resources. The Marine Policy Statement (MPS) which is expected to be released in spring 2011 will direct marine planning activities. It will be jointly adopted by the UK Government, Scottish Government, Welsh Assembly Government and the Northern Ireland Executive and will apply to all UK waters. The Act also established the Marine Management Organisation (MMO) with responsibility for marine plan making covering English territorial waters and UK offshore marine areas on behalf of Government as a whole. Defra have consulted on 10 proposed plan areas within the English inshore and English offshore regions and will begin plan making for the first two plan areas in spring 2011. In Scotland, Wales and Northern Ireland, plan making will be taken forward by the devolved administrations (MMO website), with inshore areas for Scotland and Northern Ireland covered by their own legislation (UK Government 2010d).

In advance of the implementation of formal marine spatial planning and as part of the offshore energy SEA process, an initial high level screening of spatial constraints, issues and data gaps was carried out in 2007 for use in consideration of a potential 3rd Round of leasing for offshore wind energy developments. This project was carried out in two phases: Phase 1 consisted of the development of a Geographic Information System (GIS) to map environmental and socio-economic characteristics, sensitivities and constraints (for both wind farm development and operation), and to identify strategic level data gaps. Phase 2 was undertaken to further analyse potential generation capacities from future offshore wind leasing under different constraint scenarios. The geographical scope of Phase 2 was restricted to UK waters of England and Wales. Subsequently the spatial mapping and coverage was extended to include Scottish waters (although wind farms in Scottish territorial waters are not included in this SEA). A similar exercise was also undertaken in late 2009, prior to OESEA2, to help understand the potential spatial constraints to wave and tidal energy development within the Renewable Energy Zone (REZ) of England and Wales and to provide a high level indication of the potential energy generation capacity available from wave and tidal devices (AEA & Hartley Anderson 2010). An updated analysis for both offshore wind and wave and tidal energy has been carried out for OESEA2 and is described later.

The following key spatial issues have been identified in the context of offshore energy developments (for additional background information, see Appendix 3h):

- Navigation – maintenance of free and unconstrained navigation routes is clearly vital to the UK as an island nation, and is a requirement for both territorial waters and the EEZ under the terms of United Nations Convention on the Law of the Sea. Other key issues include the minimisation of any increase to the risk of collision and on vessel passage time through route deviation.

- Fishing activities (including their cultural and economic values) - these are highly variable in space and time; while the vast majority of UK waters are fished to some extent, fishing effort is often focussed in specific areas of prime importance to the industry. Vessel Management System (VMS) data has substantially improved understanding of the spatial and temporal distribution of larger fishing vessels (>15m from 2005); however, the distribution of smaller vessels (which dominate the UK fleet by numbers) is less well understood. Detailed information on smaller vessels is held by Sea Fisheries Committees (to be replaced by Inshore Fisheries and Conservation Authorities – IFCAs in April 2011), although this is restricted to nearshore waters (typically to 6nm offshore), and is not available in a consistent spatial format. Aerial surveillance provides some information on the distribution of vessels of all sizes and nationalities throughout UK waters, although survey effort is highly variable in space and time. The distribution of vessels <15m length beyond 6nm is poorly understood, as is the distribution of non-UK vessels throughout UK waters. Fishing grounds exploited by smaller vessels with a limited home range and/or of prime importance to a local community may be of particular sensitivity to spatial conflict; such areas may exhibit apparently low effort and value relative to the UK as a whole. It is recognised that as the UK moves towards a system of formal marine spatial planning, there is a need to better understand fishing practices, particularly in inshore areas where to date, information is lacking. Defra is currently funding a project by Seafish to develop a system to monitor inshore fishing activities on vessels not currently fitted with VMS. The project will report in July 2011 following a 12 month data collection phase (Defra 2010g).

The selection and designation of nearshore and offshore Natura 2000 sites (and extension of coastal SPAs) is ongoing, and both the spatial locations and extents of a number of sites have not yet been finalised. The designation of a particular area as a Natura 2000 site does not necessarily preclude the development of offshore renewable energy installations within or close to the Natura 2000 site boundaries, however, the potential effect that a development may have on a site must be considered. In England and Wales, a series of National Policy Statements (NPSs) have been created which set out national policy on significant infrastructure facilities (offshore windfarms >100MW but presently not wave or tidal stream). NPS EN-1 (Overarching National Policy Statement for Energy) and EN-3 (Renewable Energy Infrastructure) provide the primary basis for decisions by the Infrastructure Planning Commission (IPC)[40] on applications for renewable energy infrastructure. Section 4.3 of NPS EN-1 states that prior to granting a development consent order, the IPC must, under the Habitats Directive and the Birds Directive, consider whether a project (alone or in combination with other projects) may have a significant effect on the management of a European (Natura 2000) site or any other site to which the same protection is applied. An applicant must provide the IPC with the information required to determine whether an Appropriate Assessment (AA) is required under the Habitats Regulations Assessment/Appraisal (HRA) process. Where an AA is required, the applicant must provide

[40] The Infrastructure Planning Commission will be replaced by A Major Infrastructure Planning Unit once new primary legislation is in place. Until then the IPC will continue to consider and determine applications.

the information necessary for the IPC to carry out an AA. In Scotland and Northern Ireland, offshore energy installations are also subject to an HRA. The European Commission has also created specific guidance on how best to ensure that wind energy developments are compatibility with the provisions of the Habitats and Birds Directives and Natura 2000 sites (EU 2010). Work is ongoing to establish protected areas under the EU Marine Strategy Framework Directive, the Marine and Coastal Access Act (Marine Conservation Zones) and Marine (Scotland) Act (Marine Protected Areas), and OSPAR Marine Protected Areas (Recommendation 2003/3). The location, size and interrelationships between potential future sites are not currently known. The vision of the Government's strategy on delivering a UK network of marine protected areas (UK Government 2010c) is to conserve the marine environment without "putting up barriers to development" and that the two policy areas of marine protection and offshore renewables development should not be seen as competing.

- Other present and potential future uses of the seabed including aggregate extraction, communication cables, oil and gas infrastructure, carbon capture and storage, and other marine renewable energy generation may represent spatial constraints. In some cases, including exploited aggregate and hydrocarbon resources, currently constrained areas may be relaxed in future due to decommissioning.

- Visual intrusion – there are various socio-economic drivers, including the importance of coastal tourism, to minimise significant visual impact of offshore developments.

- The extensive spatial extent of MoD practice and exercise areas; and constraints associated with civilian aviation and helicopter-based Search and Rescue (SAR).

The footprint of offshore wind farms is extensive, in that the total area occupied by a development may be very large; but not intensive, in that individual turbines are usually separated by large distances (>1,000m in some cases); or exclusive, in that a variety of other marine activities may be possible within the boundaries of an operational development. The SEA has used guidance on predicted spacing of turbines (and therefore generating capacity and density), and array configurations, produced by the British Wind Energy Association (now RenewableUK) (BWEA *pers. comm.*). Information about the likely spatial extent of wave and tidal devices is not widely available due to the relative infancy of the technology which is still largely restricted to demonstration sites rather than full commercial deployment. The deployment and configuration of wave and tidal devices will be governed by the physical environment in which they are placed; further, wave devices will, on the whole, impact the sea surface (although tethering to the seabed is required), whereas tidal current devices will mostly affect the seabed and water column (dependent upon water depth). In a recent marine energy screening survey carried out for DECC, respondents suggested that for commercial arrays of wave and tidal current devices, wave device density would range from <=50/km$^2$ up to 80-200/km$^2$. For tidal devices, one developer indicated a maximum array size of 78 devices covering ~1km$^2$ (AEA & Hartley Anderson 2010). Other estimates for the footprints of wave and tidal device arrays are 2km$^2$ (wave) and 0.5km$^2$ (tidal) (AECOM & Metoc 2009). Tidal barrages are large physical structures and their overall spatial impact is potentially extensive.

The concept of a coastal buffer for offshore wind development was introduced in Round 2, with 0-8km and 8-13km used to assess seascape sensitivity. The OESEA recommended that a coastal buffer of 12nm (22km) should be used within which the bulk of major new wind farm development should not occur (based upon ecological and landscape/seascape sensitivities), although this is not intended as an exclusion zone (DECC 2009b). As international context, Belgium and the Netherlands have adopted wind farm zones beyond 12nm from the coast; Denmark has sited developments of limited size up to 20km from the coast; nearly all consented developments in Germany are at 30km or further from the coast (see Section 5.8). Studies have been carried out for wave and tidal devices (see Appendix A3c) which will introduce a number of new visual components into the landscape and seascape, based upon their design and location. The impact of arrays of devices will become more apparent as the technology progresses towards commercialisation. Currently there are no guidelines for a development buffer.

Activities considered in this draft plan/programme are subject to a number of leasing/licensing and other consenting regimes, some of which are presently under review as part of the new marine spatial planning system introduced primarily through the *Marine and Coastal Access Act 2009* (see above) and as part of wider changes introduced through the *Planning Act 2008* and *Energy Act 2008*. Coordination is necessary between the various consenting bodies mentioned above, particularly for activities which require both a Crown Estate lease and a licence from the responsible authority (e.g. DECC). This is particularly important with regard to gas storage and carbon dioxide storage offshore, and the possibility that such activities could spatially overlap both with one another, and with existing oil and gas extraction activities (DECC 2010s). As the location of prospective basins for gas/$CO_2$ storage are largely coincident with those basins which have been, or are subject to ongoing oil and gas exploration and production, it may be expected that (also considering other activities such as aggregate extraction, and the location of Round 3 leasing zones – see Appendix 3h), the greatest degree of coordination will be required in the Southern North Sea and East Irish Sea.

In considering the need for coordination with regard to marine spatial planning, the responsibilities of the devolved administrations also need to be accounted for. The territorial waters of Scotland, Wales and Northern Ireland are variously the remit of Scottish, Welsh and Northern Irish Ministers respectively, though for certain functions (e.g. renewable energy), the MMO and IPC are the consenting (e.g. Electricity Act consent, Harbour Order) authority in Welsh waters. As the MMO is the responsible authority for issuing marine licences for a range of activities in offshore waters (e.g. dredging, marine renewable arrays of <100MW), territorial waters in England (e.g. harbour developments), and for certain functions in Wales (in addition to being the Marine Plan authority in England), a high level of spatial coordination may be expected. Guidance in relation to the role of the MMO with regard to applications to the IPC for projects within their remit is provided by Defra (2010h).

A higher degree of coordination and cooperation may also be required for ancillary developments which take place in offshore waters which traverse territorial waters of a devolved Government or indeed in English territorial waters, where a Crown Estate lease or other consents may also be required. Similarly, oil and gas exploration and development is not a devolved matter, and so the licensing of blocks in the territorial waters of devolved administrations, and any subsequent activities, will need to take account of existing and possible future marine operations subject to devolved consenting regimes. Examples of such an interaction are blocks previously licensed for oil and gas in the Moray Firth which now coincide with/are adjacent to a Scottish territorial wind exclusivity area and an offshore Round 3 Crown Estate leasing zone. Potential future interactions may also arise in Northern Irish waters. The offshore energy SEA conducted for Northern Irish waters (AECOM & Metoc 2009) indicates that the waters around Rathlin Island in the North Channel have a significant tidal range resource, though this coincides with blocks applied for (though withheld following screening) in the 26$^{th}$ seaward oil and gas licensing Round. The withholding of these blocks for further assessment prior to licensing also highlights the interaction of marine activities with present and possible future offshore designations or those with marine components (e.g. SACs), which may become an increasingly pertinent issue as Marine Conservation Zones and their devolved equivalents are progressed.

## 5.15.2 Spatial constraints mapping

A phased screening of spatial constraints, issues and data gaps was carried out to support the OESEA process (DECC 2009b). A similar analysis was also carried out for wave and tidal energy prior to OESEA2 (AEA & Hartley Anderson 2010); both have been updated for inclusion in this SEA. Spatial data (sourced from a number of organisations and agencies in the UK) representing various environmental and socio-economic characteristics, sensitivities and constraints (for offshore renewable energy development and operation) were input to ESRI's ArcGIS. The different data layers were overlaid enabling spatial relationships between the different features to be visually analysed and mapped, and also allowing the identification of possible strategic level data and information gaps.

This analysis also distinguished between “hard” constraints (which would definitively and consistently exclude development) and “other” constraints (which would presume against, but not definitively exclude development). These are considered to be the primary constraints at a strategic level, although it is recognised that other studies have included other users and uses of the sea area (see for example Begg and Wadsworth 2009, PMSS 2010, Royal Haskoning 2010c and The Offshore Valuation Group 2010). For more localised studies, some additional constraints may need to be taken into account for a particular area. For completeness and to enable comparison with the analysis carried out for the OESEA, constraints in the territorial waters of Scotland and Northern Ireland (e.g. Pentland Firth wave and tidal licence areas) have been included, although these territorial waters are not part of the current plan. The constraints used in this analysis are shown in Table 5.39.

Table 5.39 – “Hard” and “Other” constraints used in spatial constraint mapping

| “Hard” constraints | “Other constraints” |
|---|---|
| Round 1 (R1) and R2 lease areas and extensions, R3 development zones[2], Scottish Exclusivity Agreements[2], Blyth offshore wind farm[2], offshore wind demonstration sites[2] | Natura 2000 sites: designated, candidate, possible, draft, where boundaries known |
| Licensed dredging areas, application and option areas | MCA ‘siting potential with comprehensive assessment’ areas (draft and unpublished OREI 2 areas)[1] |
| Oil and gas infrastructure plus 6nm buffer (for wind), 500m buffer[2] (for wave and tidal) | MoD practice and exercise areas: other areas |
| IMO vessel routing areas with 1nm buffer. | NATS radar areas[1] |
| Primary Navigation Routes 1 (PNR1)[2] with 1nm buffer (derived from MCA ‘siting not recommended’ areas (draft and unpublished “OREI 1” primary navigation routes) and OESEA AIS data analysis) | |
| MoD practice and exercise areas: danger areas | |
| Pentland Firth and Orkney wave and tidal lease areas, EMEC wave and tidal (Orkney) and WaveHub demonstration sites[2] | |

*Note: 1 - Not used for wave and tidal screening, 2 - Updated/added for Wave and Tidal Screening and OESEA2. All data layers have been updated for currency since the original screening exercises.*

In the original analysis for offshore wind, bathymetry was considered within three categories: 0-20m, 20-25m and 25-60m depth. For OESEA2, water depths of 0-60m (representing the current commercially exploitable area) and 60-200m (representing potential future areas for e.g. floating turbines) have been considered. For tidal current, the area where the mean spring peak flow is greater than 2m/s has been taken as the potential unconstrained resource and for the unconstrained wave resource, the area where the annual mean wave power is greater than 20kW/m wave crest.

In the analysis summarised below, an assessment was made of indicative generation capacities for the different resources after hard constraints have been applied. This was achieved using the following technology scenarios:

- 2.5MW/km$^2$ for offshore wind assuming a 5MW turbine size (BWEA *pers. comm*) (now RenewableUK)
- 30MW array estimated to take 0.5 to 5km$^2$ for tidal current devices of 1MW (see Section 2.5.4)
- 30MW array estimated to take 1 to 10 km$^2$ for wave devices of 1MW (See Section 2.5.4)

Representative GIS outputs from the spatial constraints mapping are shown in Figures 5.48 – 5.53. These include the influence of a 12nm coastal buffer for offshore wind in England and Wales. Using the generation capacity scenarios noted above, estimates for total theoretical output for wind, wave and tidal devices have been calculated, based upon the total area of sea (seabed and/or surface) available after hard constraints have been applied. These estimates are shown in Tables 5.40 and 5.41 and do not make any allowance for reductions in available area as a result of "other" constraints, which may be appreciable.

Table 5.40 - Indicative maximum wind power generation (MW) after hard constraints applied

| | **Area remaining(km$^2$)** | | **MW** | | |
|---|---|---|---|---|---|
| **Resource** | **Eng & Wales** | **Scotland REZ** | **Eng & Wales** | **Scotland REZ** | **Combined** |
| 0-60m | 31,554 | 2,002 | 78,885 | 5,005 | 83,890 |
| 60-200m | 70,810 | 95,595 | 177,025 | 238,988 | 41,6013 |
| 0-60m with 12nm buffer | 10,876 | 2,002 | 27,190 | 5,005 | 32,195 |
| 60-200m with 12nm buffer | 68,830 | 95,595 | 172,075 | 238,988 | 411,063 |

Table 5.41 - Indicative maximum tidal current and wave power generation (MW) after hard constraints applied (England and Wales only)

| **Resource** | **Area remaining (km$^2$)** | **MW (0.5km$^2$)** | **MW (5km$^2$)** |
|---|---|---|---|
| Tidal current >2m/s | 234 | 14,040 | 1,404 |
| | | | |
| **Resource** | **Area remaining (km$^2$)** | **MW (1km$^2$)** | **MW (10km$^2$)** |
| Wave power > 20kW/m | 52,628 | 1,578,840 | 157,884 |

*Notes:*
*Hard constraints do not include European conservation sites although these may present significant consenting hurdles*
*The total area available does not take account of the size needed for an individual commercial scale wind farm or wave or tidal array. For wave and tidal arrays, the space required between arrays has also not been factored in.*
*For offshore wind, the 12nm buffer was not applied to Scotland or Northern Ireland, however, their territorial waters are not included in the figures above.*
*The generation capacities for existing rounds of offshore wind leasing are: R1 & R2 (8GW); R3 (25GW).*

Figure 5.48 – Percentage of block within 0-60m depth remaining following application of hard constraints (excludes territorial waters of Scotland and Northern Ireland)

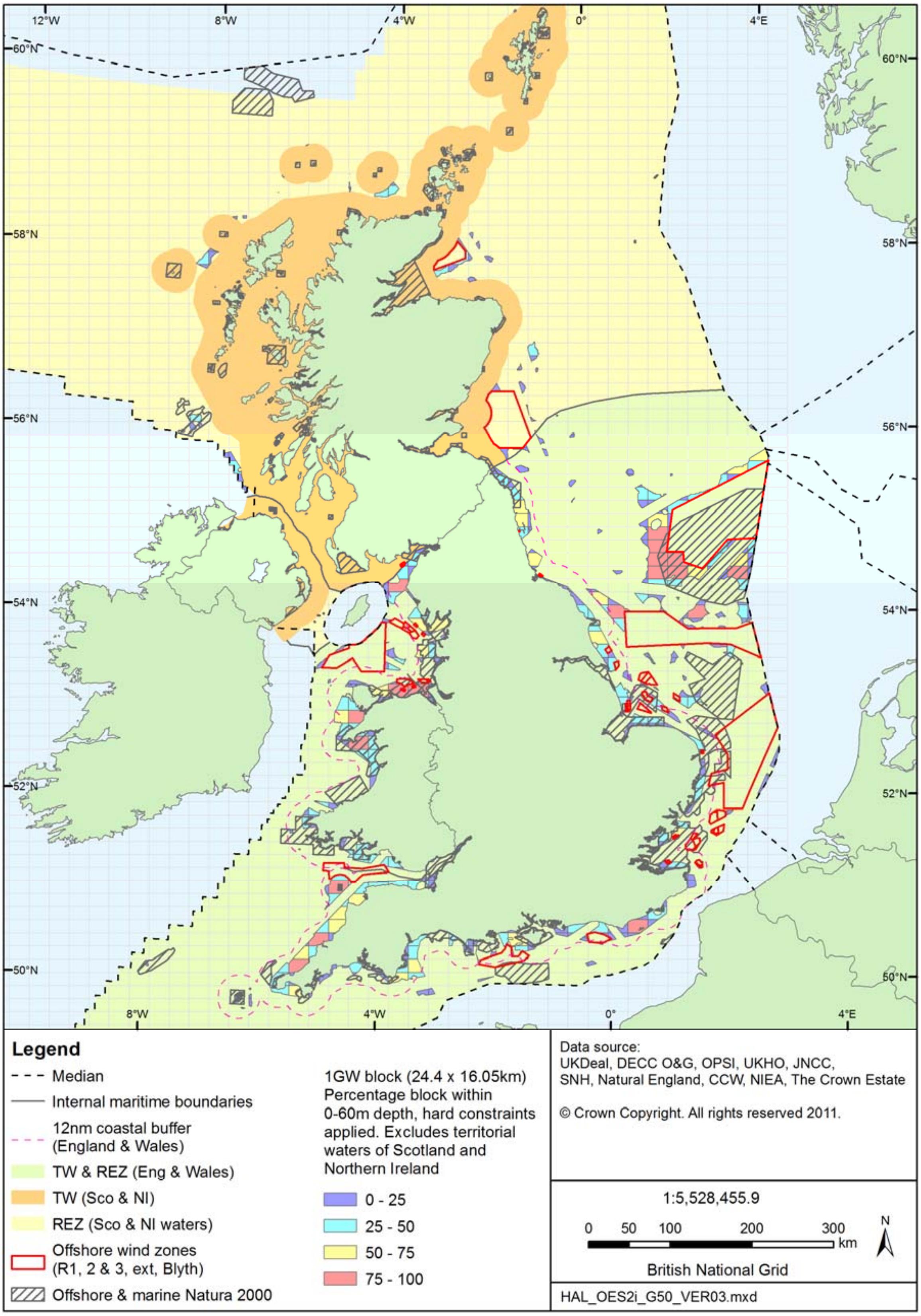


Figure 5.49 – Percentage of block within 0-60m depth remaining following application of hard constraints (excludes territorial waters of Scotland and Northern Ireland) with a 12nm coastal buffer for England and Wales

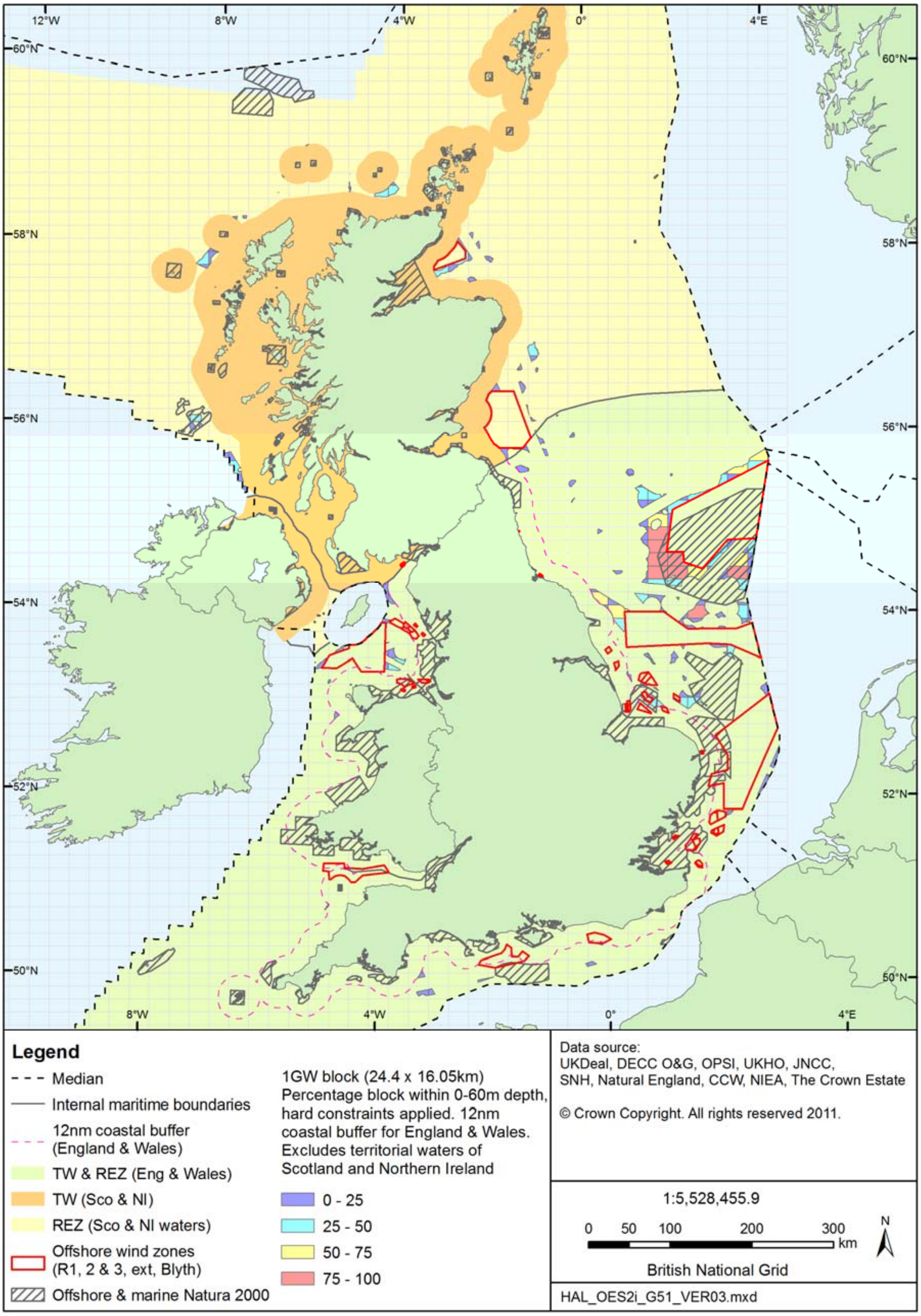


Figure 5.50 – Percentage of block within 60-200m depth remaining following application of hard constraints (excludes territorial waters of Scotland and Northern Ireland)

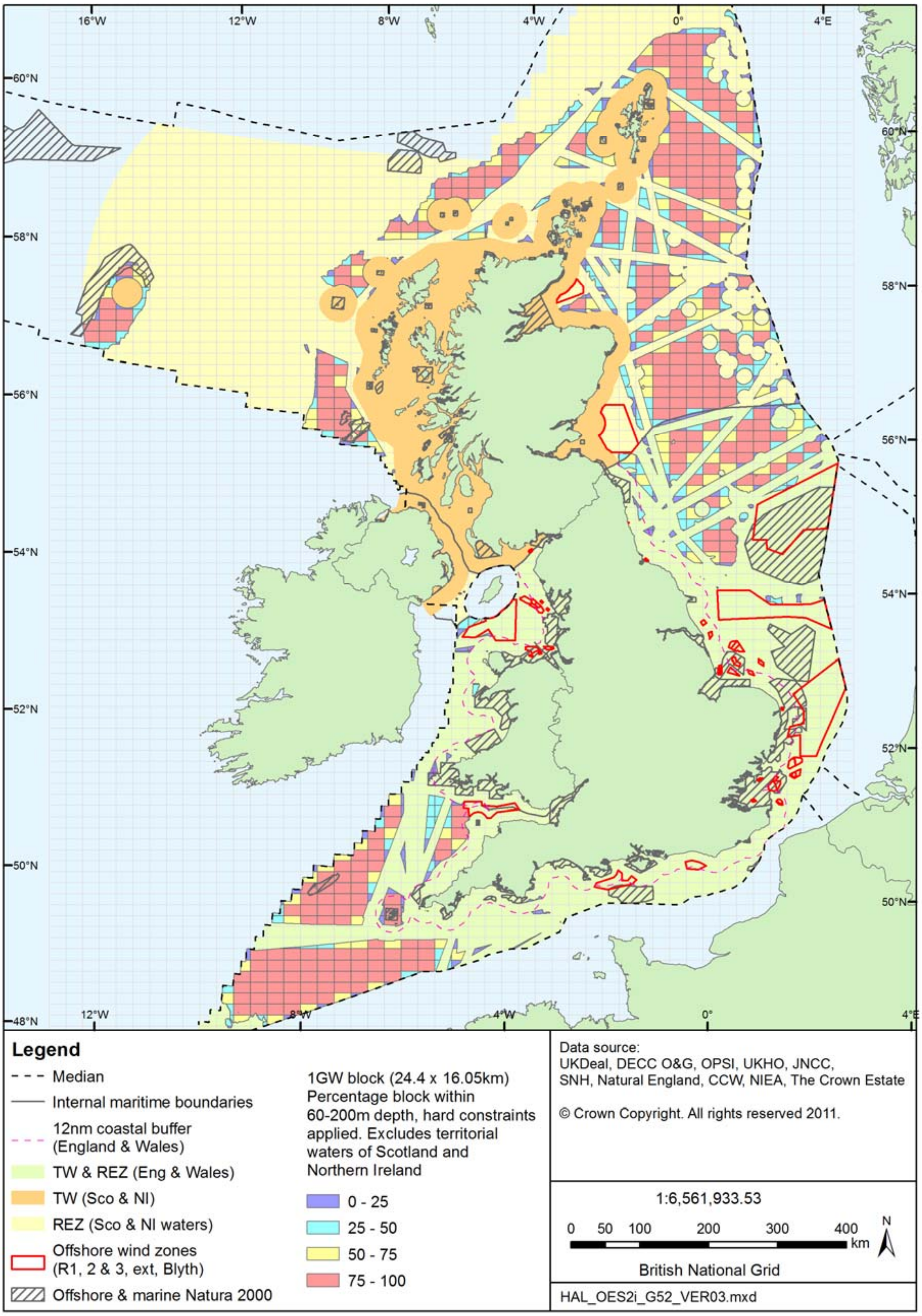


Figure 5.51 - Percentage of block within 60-200m depth remaining following application of hard constraints (excludes territorial waters of Scotland and Northern Ireland) with a 12nm coastal buffer for England and Wales

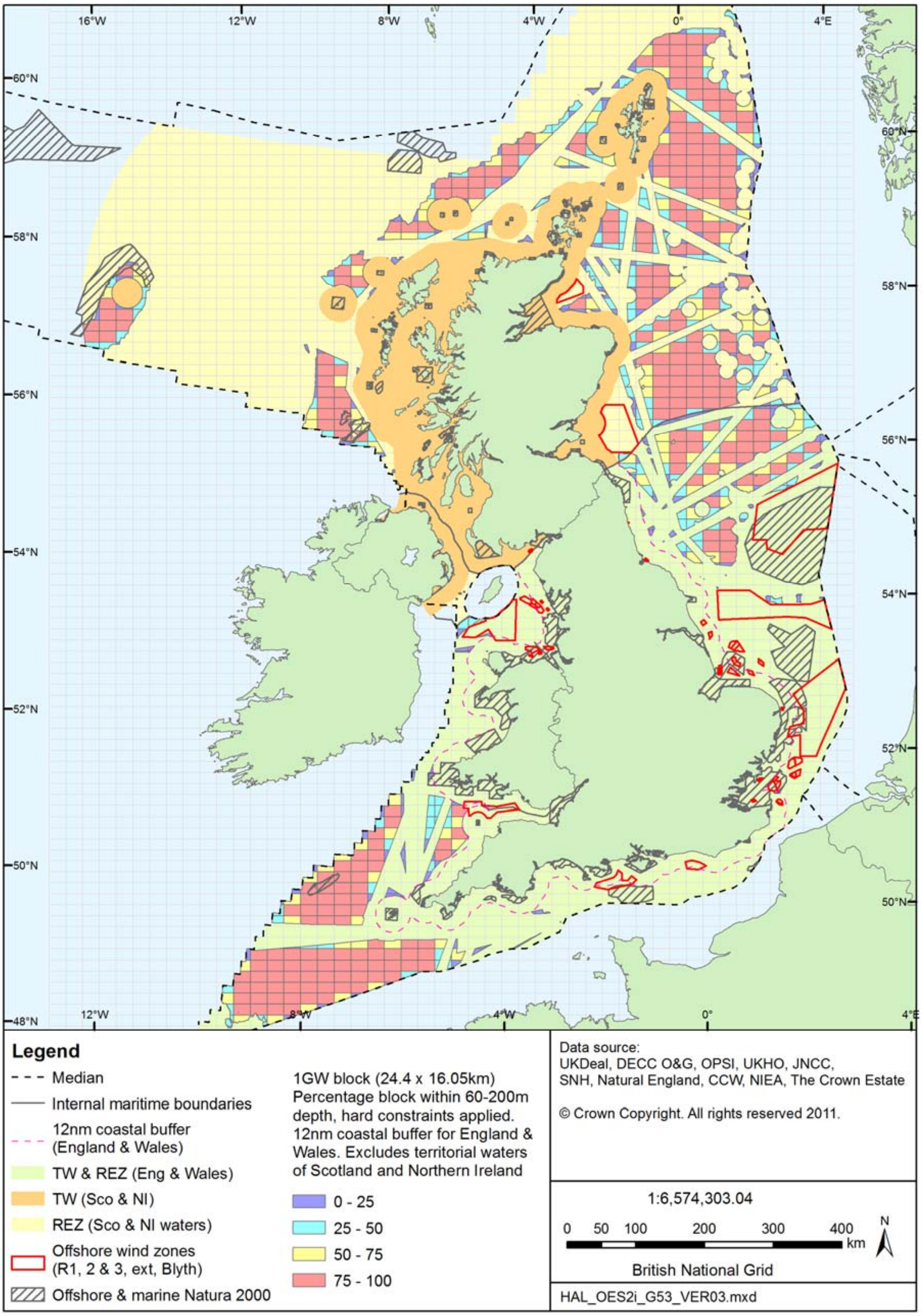


Figure 5.52 – Seafloor area remaining where peak flow for mean spring tide is greater than 2m/s following application of hard constraints (England and Wales only)

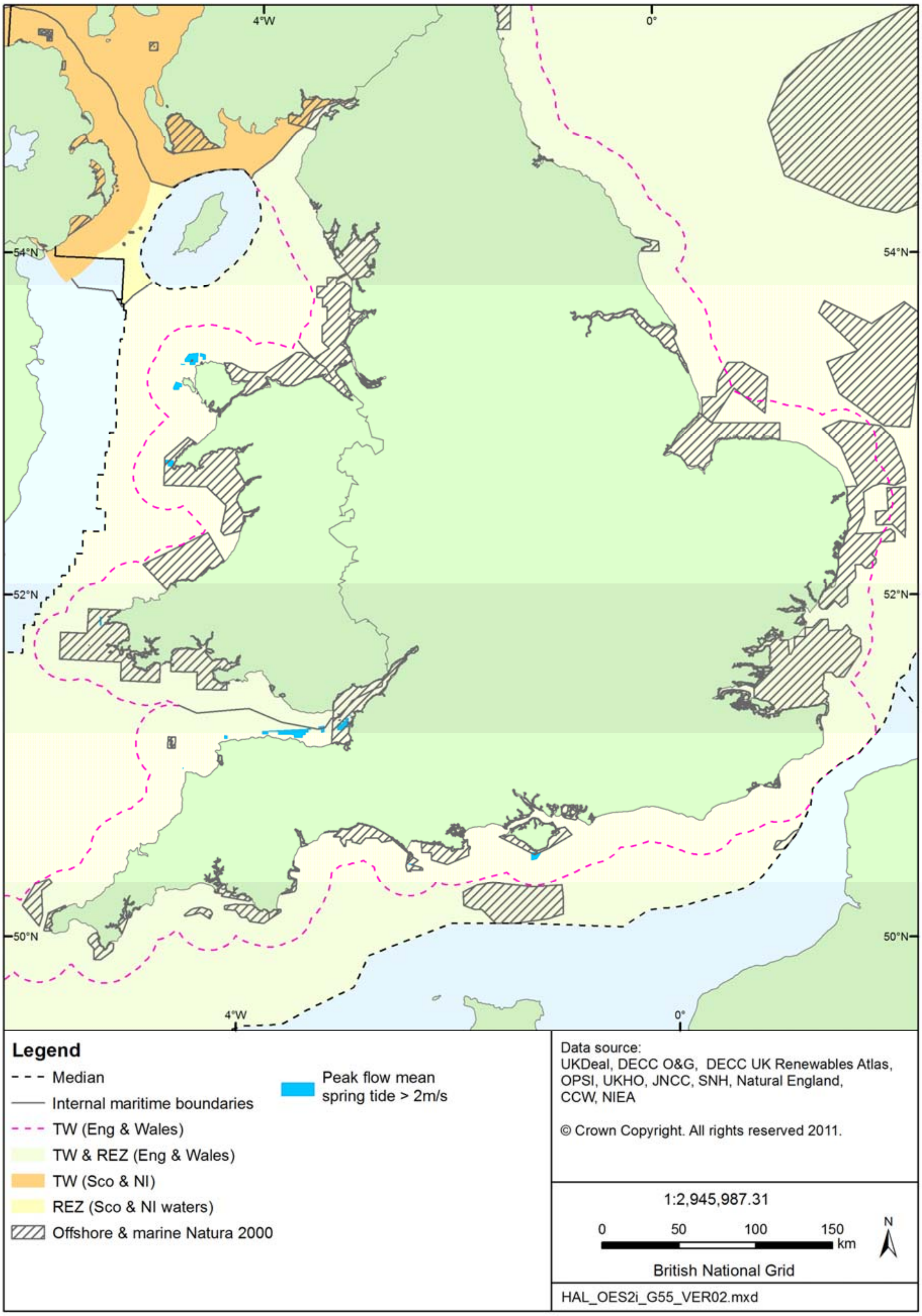
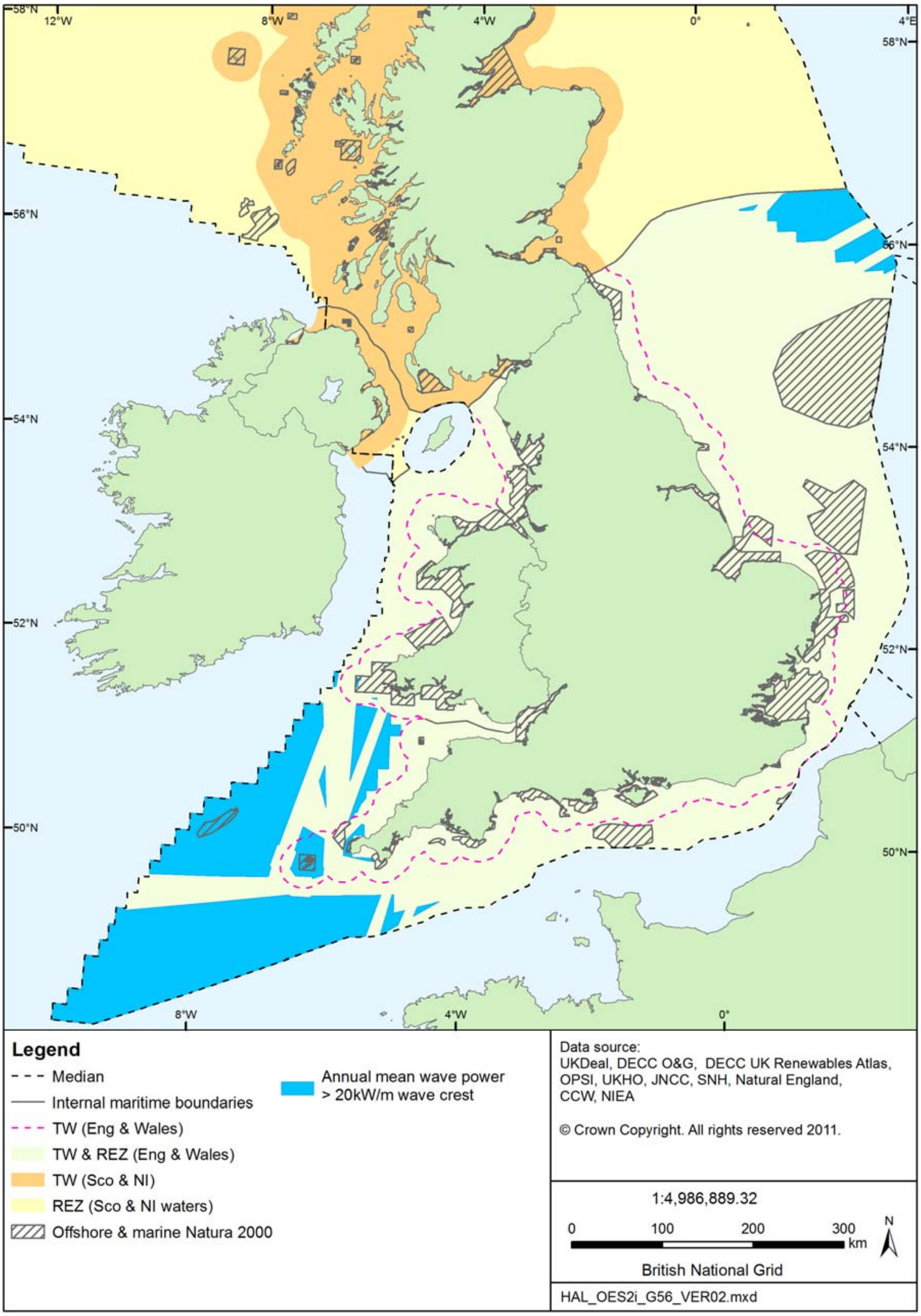


Figure 5.53 – Seafloor area remaining where annual mean wave power is greater than 20kW/m wave crest following application of hard constraints (England and Wales only)



The constraints analysis carried out for OESEA indicated that a generation target of 25GW (additional to 8GW from rounds 1 & 2) would be possible from R3 leasing, giving a combined capacity of 33GW in this plan. For this SEA (OESEA2), the analysis suggests that there is available capacity out with the current lease areas in the 0-60m depth range and a further potential exploitable resource in 60-200m depths. Under present technological and environmental constraints, the area indicated as available for tidal current devices in the waters of England and Wales (234km$^2$) is relatively small and confined to sites off Anglesey, the Lleyn Peninsula, the Severn Estuary/Bristol Channel and the Isle of White. Adjusting the tidal current speed to include areas of >1.5m/s would increase the potential resource area to 1,128km$^2$. For wave devices, the analysis shows that the areas of greatest practical resource are off the coasts of south west Wales and south west England with a smaller area available in the north east adjacent to Scottish waters. Under the technological and environmental constraints used, the total area available is calculated as 52,628km$^2$. It should be noted that the figures presented here are subject to technical and commercial feasibility and other site specific constraints. The following points are also considered in relation to potential conflicts with "other" constraints, and with other legitimate activities (notably fishing) not included in the spatial analysis:

- Conservation sites – several areas identified as unconstrained for potential development fall within marine and offshore Natura 2000 sites. Development in designated sites would be required to meet Appropriate Assessment criteria. A study by ABPMer (2009b) has investigated the environmental issues regarding site location and impacts on conservation features with regard to wave and tidal devices and also provides a GIS analysis of the potential overlap between offshore renewable resources and current and proposed designated site boundaries.

- MCA "siting potential with comprehensive assessment" – Maritime and Coastguard Agency note MGN 371 together with BERR (2007) guidance on applying for safety zones around offshore renewable energy installations provide information on the site-specific considerations which would be applied during the consenting process. This issue is considered in more detail below.

- MoD PEXAs: other areas – with the exception of danger areas identified as "hard constraints", the presence of a PEXA does not preclude other activities. Planning and consultation between the offshore energy industries and the MoD should help to minimise any conflicts of interest where PEXAs exist.

- NATS radar areas (offshore wind) – with the exception of the Dogger Bank, a large proportion of the possible development area is identified by NERL as "likely to interfere" with air traffic control radar. Technical measures may alleviate this issue to some extent.

- Fishing – interactions between fishing activities and offshore wind farms are complex, and experience in Round 2 development locations indicates that the effects are dynamic and not always predictable. In summary, stakeholder dialogue with the fishing industry indicated that typical offshore wind farm development would effectively preclude demersal trawling with conventional gears, but not necessarily fixed gear or possibly specialised trawl gears. Exclusion of fishing effort would be likely to have a local beneficial effect on fish stocks, but a negative effect on other fishing grounds through displacement of effort. The implementation of a coastal buffer zone is expected to substantially mitigate conflict with the most sensitive fishing sector (small inshore vessels, which cannot easily relocate and are often of marginal commercial viability). This issue is considered in more detail below. The potential effects of wave and tidal devices on the fishing industry are less well understood due to the lack of commercial development so far. As with offshore wind, the installation of devices on the sea surface and sea floor will constrain fishing activities carried out in the development areas both during construction and operation. For tidal current devices in particular, the areas indicated as suitable for development, although relatively small, are within 12nm of the coast and are not mitigated by a coastal buffer.

- Recreational users – for offshore wind, conflicts with recreational activities are expected to be substantially mitigated by a coastal buffer zone. The vast majority of recreational vessels (including yachts, diving and angling) would not be excluded from offshore wind farm development areas. As for fishing, there is potential for interaction between recreational boating and wave and tidal current development, again particularly for tidal current devices which are likely to be situated within the 12nm zone. The guidance available from the Maritime and Coastguard Agency (see MGN 372 (M+F)) suggests that wave and tidal devices may be more difficult to see than wind turbines and that navigation within an array may not be possible, meaning that a development area should be avoided.

- Offshore renewables – there may in the future be competition for sea surface/sea floor space between the different offshore energy sectors, including wind, wave and tidal, oil & gas and CCS.

In 2008 the Carbon Trust carried out a study to investigate how offshore wind in the UK could contribute to the UK's target of delivering 15% of its energy consumption from renewable sources by 2020 (Carbon Trust 2008). The study assessed:

- How much offshore wind power capacity would be required to reach the 2020 renewable energy target?
- What would be required to deliver this?
- What should the UK Government, industry and other stakeholders do to achieve this?

The study concluded that the UK would need to build 29GW of offshore wind by 2020 to meet its target.

The Carbon Trust used the spatial constraint criteria and GIS developed for the DECC Offshore Energy SEA to determine the area of seafloor available for offshore wind farm development and to analyse the costs and risks associated with different sites. This was done by segmenting the available seabed (0-60m depth) into 33 combinations of distance from shore, depth and wind speed, calculating the capital expenditure ('capex') per MW of capacity and levelised costs for each segment.

The analysis showed that the most important factor in siting a wind farm is wind speed, followed by depth and then distance. Economically, the most attractive sites are those that are near-shore with shallow water and mid-distance, mid depth sites with higher wind speeds. However, the effect of applying all of the constraints (including for example offshore Natura 2000 sites), would be to restrict development sites for offshore wind farms to the most expensive site types such as north of the Dogger Bank. In order to locate all of the 29GW of capacity on the most economically attractive sites the study suggests that a seaward buffer zone would need to be reduced in some places and some constraints (including those that are currently considered 'hard' or 'fixed') would need to be relaxed, especially the 6nm exclusion zone around oil and gas installations.

In 2010, the Offshore Valuation Group (an informal collaboration of government and industry organisations) published a report on the economic value of Britain's offshore renewable resource (The Offshore Valuation Group 2010). As part of the report, an assessment was carried out to quantify the extent of the practical offshore renewables resource. This took into account resource quality, competing uses of the sea and accessibility constraints and was based on five electricity generating technologies: wind with fixed and floating foundation; wave; tidal range and tidal stream. From their analysis, the Group estimated the total practical resource to be 531GW (2,131TWh). Of this, fixed wind accounts for 116GW (floating wind 350GW), wave 18GW, tidal stream 33GW and tidal range 14GW. Of the fixed wind total, 61GW is additional to the 47GW of existing leases with 8GW assumed for extensions within these leases.

The figures produced by the Offshore Valuation Group show some differences to those calculated in the analysis used for this SEA. It should be noted however that while the general methodology used for the analysis by the Group is similar to that used in the SEA, the group took into account other factors, including:

**Wind**

- Depth and distance from shore.
- Site specific load factors based upon wind speed and an estimated increase in wind power density of 3-4MW/km$^2$ by 2050.
- A larger range of hard and other constraints, also applying a measure of weighting to the other constraints.
- Excluding areas of less than 10km$^2$ on the grounds that they would be too small to warrant development.

**Tidal stream/current**

- An assumption that tidal stream devices will operate in areas of depths between 20 and 60m and with a mean spring peak current of >1.5m/s.
- A power density range of between 530MW/km$^2$.
- Inclusive of Scottish Territorial Waters.

**Wave**

- That wave energy cannot be calculated based on the suitable area for development, as the maximum extractable power is per unit length of wave crest, not per area.
- That subsequent rows of devices would produce less energy than the first row (as the first row will remove some of the available wave energy).
- There would be one row of devices which in total would be approximately 1,000km long.
- A large share of the generation would be located in three regions; off the coasts of western Scotland, south-west Wales and Cornwall.

For tidal range, the Group used published figures for the largest eight sites in the UK (see Burrows *et al.* 2009). The Severn Estuary was included in this group, but is not included in this SEA and is not currently being considered for development.

### 5.15.3 Consideration of a coastal buffer for offshore wind

The waters around the UK coast are of major ecological, economic and cultural importance. Unless appropriately planned and controlled, the possible developments of the scale encompassed by the draft plan/programme could result in adverse effects on coastal features, safety, and present day and foreseeable future uses, including:

- Coastal navigation routes and port access
- Navigation safety e.g. vessel refuges, charted and safe anchorages and scope for manoeuvre/towage of vessels in distress near the coast

- Inshore fisheries
- Aerodrome safety
- Civilian radar interference
- Military radar interference
- Coastal PEXA danger areas
- Recreational and racing yachting
- Coastal tourism (importance and value)
- Visual intrusion (in general and on designated landscapes)
- Sea- and waterbirds (which typically occur in greater densities in coastal waters)
- Natura 2000 sites, either designated or under consideration
- Potential for conflict between different renewable energy generation technologies

The Round 2 SEA recommended a coastal buffer of 8 or 13km based on the sensitivity of seascape units to OWF visual intrusion.

At present, regional spatial strategies for marine areas are lacking. However, the principles of Integrated Coastal Zone Management (ICZM) are integral to relevant proposals in the *Marine and Coastal Access Act*. The Act proposals offer the opportunity to link marine management with existing arrangements on land. Marine planning is set to give coastal regulators and communities the chance to have a say in the way the marine environment is managed, and conversely for marine management to give proper consideration to land planning. Similarly, the European Commission (COM(2007) 308 final) has emphasised the importance of the development of ICZM strategies in close co-ordination and co-operation with the Marine Strategy Directive and the related work of regional seas conventions.

The complexity of the decisions regarding major developments near the coast are distilled in the Department of the Environment/Welsh Office Planning Policy Guidance: Coastal Planning (PPG 20 September 1992) which noted the importance of the coast as a national resource and stated that "it is the role of the planning system to reconcile development requirements with the need to protect, conserve and, where appropriate, improve the landscape, environmental quality, wildlife habitats and recreational opportunities of the coast. This is achieved through development plans and planning decisions, which implement policies for the conservation and improvement of the coastal environment, acknowledging the special character of the coast."

This is amplified by the ODPM Planning Policy Statement 22 National Planning Policies which states that "In sites with nationally recognised designations (Sites of Special Scientific Interest, National Nature Reserves, National Parks, Areas of Outstanding Natural Beauty, Heritage Coasts, Scheduled Monuments, Conservation Areas, Listed Buildings, Registered Historic Battlefields and Registered Parks and Gardens) planning permission for renewable energy projects should only be granted where it can be demonstrated that the objectives of designation of the area will not be compromised by the development, and any significant adverse effects on the qualities for which the area has been designated are clearly outweighed by the environmental, social and economic benefits."

The draft NPS EN-1 (the Overarching National policy Statement for Energy) and NPS EN-3 (Renewable Energy Infrastructure) provide guidance on the impacts of renewable energy infrastructure (for offshore windfarms over 100MW) on ecology, biodiversity and the historic environment and the considerations to which the IPC and applicants for development consent should have regard. The NPSs further highlight the importance and sensitivities of biological and ecological networks and designated areas and the need to protect them, but also that with careful monitoring, design and siting, wind turbines can be located in environmentally sensitive areas and may also have positive benefits to ecology and biodiversity.

Reflecting the relative sensitivity of multiple receptors in coastal waters, the OESEA report (DECC 2009b) concluded that the bulk of the future generation capacity should be sited well away from the coast, generally outside 12 nautical miles (some 22km). The proposed coastal buffer zone was not intended as an exclusion zone, since there may be scope for further offshore wind development within this area, but as mitigation for the potential environmental effects of development which may result from this draft plan/programme. The environmental sensitivity of coastal areas is not uniform, and in certain cases new offshore wind farm projects may be acceptable closer to the coast. Conversely, a coastal buffer in excess of 12nm may be justified for some areas/developments. Detailed site-specific information gathering and stakeholder consultation is required before the acceptability of specific major wind farm projects close to the coast can be assessed. The Marine Policy Statement (MPS) and the Marine Plans currently being developed will give coastal regulators and communities further opportunities to have a say in the way the marine environment is managed, in addition to the existing routes for consultation as part of the development consent process.

This consideration applies primarily to OWF because of their large spatial footprint. For hydrocarbon developments, technical measures are potentially available to allow mitigation e.g. through direction drilling from shore as in the development of the offshore extension of the Wytch Farm oilfield into Poole Bay, Dorset. For all developments, site specific information, consultation and planning will be required before they can take place.

It is noted that the Carbon Trust (2008) study concludes that there are some economic benefits to siting OWFs away from the immediate vicinity of the coast as a result of improved quality of the wind resource offshore and hence more efficient generation.

### 5.15.4 Summary of findings and recommendations

This SEA has been carried out in advance of implementation of formal marine plans under the *Marine and Coastal Access Act* (and related initiatives) and conclusions must therefore be considered as provisional pending development of a more comprehensive strategic marine planning system.

The OESEA spatial constraints analysis (DECC 2009b) concluded that a generation target of 25GW for offshore wind (additional to Rounds 1 & 2 capacity of 8GW) could be achieved with the implementation of a nominal 12nm coastal buffer and no relaxation of the “hard” constraints identified above (and subject to technical and commercial feasibility). The updated constraints analysis presented above indicates that there are further areas of offshore wind resource available beyond the R3 lease areas within the 0-60m depth areas and also the 60-200m depth zone (technology dependent). Additionally, the analysis has identified potential resource areas for both tidal current and wave devices, subject to technological and environmental constraints. The above assessment does not support the alternative not to lease or license areas for development (Alternative 1). Constraints mapping has indicated that there are areas of the UKCS in which “hard” constraints currently preclude feasible development (e.g. MoD danger areas, oil and gas platform/infrastructure, existing offshore wind farms), and therefore leasing in these areas will of necessity be spatially restricted. At a local site specific level, other constraints may be significant while some hard constraints mentioned here may be less exclusive dependent upon mitigation measures employed. Some hard constraints (e.g. platform 6nm buffers, aggregate extraction zones) are anticipated to be relaxed in the future as infrastructure is decommissioned or resources depleted. Forecasts of the projected timing of oil and gas installation removal are available from the DECC oil and gas website; these are normally updated annually and indicate significant "space" becoming available within a few years. It is recommended that there should be certain spatial restrictions on the areas offered for leasing and licensing and that Alternative 3 is the preferred option.

# 5.16 Consideration of potential for cumulative impacts

## 5.16.1 Introduction

As noted above, the SEA Directive (footnote to Annex I) and the *Environmental Assessment of Plans and Programmes Regulations 2004* require *inter alia* that secondary, cumulative and synergistic effects should be considered. Stakeholder consultation has emphasised the importance of cumulative effects within the overall process. The approach adopted for assessment of cumulative effects within the DECC SEA process has developed over successive SEAs, reflecting experience, consultation responses and guidance from a range of sources within the UK, EU and internationally, including guidance to the SEA Directive (e.g. ODPM 2005). A range of approaches, techniques and guidelines for assessing cumulative impacts of offshore wind farms were reviewed in April 2007 in a discussion paper for the Offshore Renewable Energy Environmental Forum (Hartley Anderson 2007); and there are a number of ongoing initiatives, both sectoral and generic, which are relevant.

Much of the published guidance and discussion of Cumulative Impact Assessment (CIA) relates to process (with extensive use of flow diagrams) – how and when to incorporate CIA into SEA, EIA and planning; the need for an integrated and precautionary approach; identification of the need for CIA screening, baseline and trend definition for valued resources; reporting and consultation. There is also wide recognition of the difficulties of CIA in terms of identifying pathways of change and contribution of actions to the environment, and a large literature speculating on causal mechanisms which could, potentially, result in cumulative effects. There is a corresponding deficit of empirical data which actually demonstrate and quantify cumulative effects (relevant to offshore energy); and in the absence of this, little practical experience or guidance on how to assess the significance of specific effect mechanisms on specific receptors, particularly at a strategic level. There are some case studies, although not directly applicable (for geographic reasons) to this SEA; for example in the US, the development of cumulative effects assessment received considerable attention through the Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope (2003). The committee report gave an example of retrospective analysis of cumulative impacts of oil and gas activities on Alaska's North Slope (including social and cultural effects), and also made an assessment of likely future impacts.

Following the Round 2 OWF leasing, developers of potential sites in the Greater Wash commissioned an initial scoping assessment of potential cumulative (and in-combination) effects in this area (Wash Developers 2004). This was aimed at improving consistency and collaborative opportunities for data gathering; and identified potential cumulative effects under the receptor headings navigation and shipping, commercial fisheries, natural fishery resource, ornithology, cetaceans and marine mammals, landscape and visual character and socio-economic effects. A number of receptors/issues, including marine benthos, noise and vibration, marine archaeology, water and sediment quality and tourism and recreation were "scoped out", that is, excluded from further consideration in that context.

Other recent initiatives in the UK include the COWRIE project *Developing Guidance on Ornithological Cumulative Impact Assessment for Offshore Wind Farm Developers* (King *et al.* 2009). This guidance follows an earlier workshop (Norman *et al*. 2007, Maclean & Rehfisch 2008) and is intended to recommend methodologies robust enough to meet statutory requirements and practicable for developers within the time frames and resources normally available for environmental impact assessment. In practical terms, the guidance describes generic approaches to CIA (in a marine ornithological context) and identifies some of the key parameters for use with analytical tools (e.g. avoidance rates for collision risk modelling). Of the key mechanisms of effect discussed, cumulative collision mortality, cumulative disturbance, cumulative barrier effects and indirect effects; the first is most amenable to quantitative assessment and preparation of a specific guidance note on collision risk calculations for offshore projects, incorporating acceptable avoidance rates is recommended. The extent to which disturbance and barrier effects (due to visual intrusion or physical disturbance) accumulate is likely to be non-linear, and an informative assessment of the cumulative impacts of disturbance (which may require detailed study of energy-budgets of birds within the area, and their variability over time) are likely to be costly and time-consuming, but the only way in which cumulative disturbance impacts can be quantified (King *et al.* 2009). The report recommends that such an assessment is made only if the cumulative impacts of disturbance are likely to be significant. Where disturbance impacts are minimal, subjective treatment of the issue is adequate.

At a UK-level, several workshops have been held where a variety of stakeholders have discussed the issues surrounding cumulative effects assessment. For example, the outcomes of a 2003 stakeholder workshop on the implementation of marine spatial planning and cumulative effects assessment are reported in Gilliland *et al*. (2004). This concluded that the fundamental components of cumulative effects assessment are spatial, and that there is a need for improved, more targeted guidance on cumulative effects assessment in the marine environment; and recommended that urgent practical steps should be taken to collate and make widely accessible marine data from a range of sources. The offshore SEA programme, and this SEA in particular (since it has a UKCS-wide focus), have contributed towards the latter requirement.

OSPAR has piloted an approach that aims to determine the status of ecosystems building on the identification and quantification of the main pressures and their cumulative impacts on species groups and habitat types. The results of a trial assessment are presented in the Utrecht workshop report (OSPAR 2009m).

The Utrecht workshop focused on assessing, at the scale of OSPAR regions, the impact of pressures from human activities, as listed in the EU Marine Strategy Framework Directive, and those driven by climate change, on a selection of four species groups (fish, cetaceans, seals, seabirds) and four habitat types (rock and biogenic reef habitats, shallow sediment habitats, shelf sediment habitats, deep-sea habitats). The assessment process followed a series of steps:

- Map the geographic distribution of human activities and describe the spatial and temporal extent, intensity and frequency of the pressures resulting from these activities.
- Define the geographic distribution of species groups and habitat types that are sensitive to these pressures.
- Estimate the degree of impact, where pressures and ecosystem elements overlap in space and in time. For this purpose, generic criteria and associated threshold values were developed for geographic range, population size and condition for species groups, and on range, extent and condition for habitats. The threshold values were based on those given in EU guidance for assessing favourable conservation status of species and habitats under the Habitats Directive. The degree of impact, following these criteria, was assessed against a reference status (based on an absence of the pressure). The percentage deviation from this reference status was used to classify the outcome as ‘low’, ‘moderate’ or ‘high’ impact.
- Summarise the different impacts from human activities in order to derive an overall status assessment per species group and habitat type (Figure 5.54 for example output).

- The impacts on all species groups and habitat types were summarised to assess the total impact per pressure (Figure 5.54) and consequently their relative contribution to the total impact in each region.

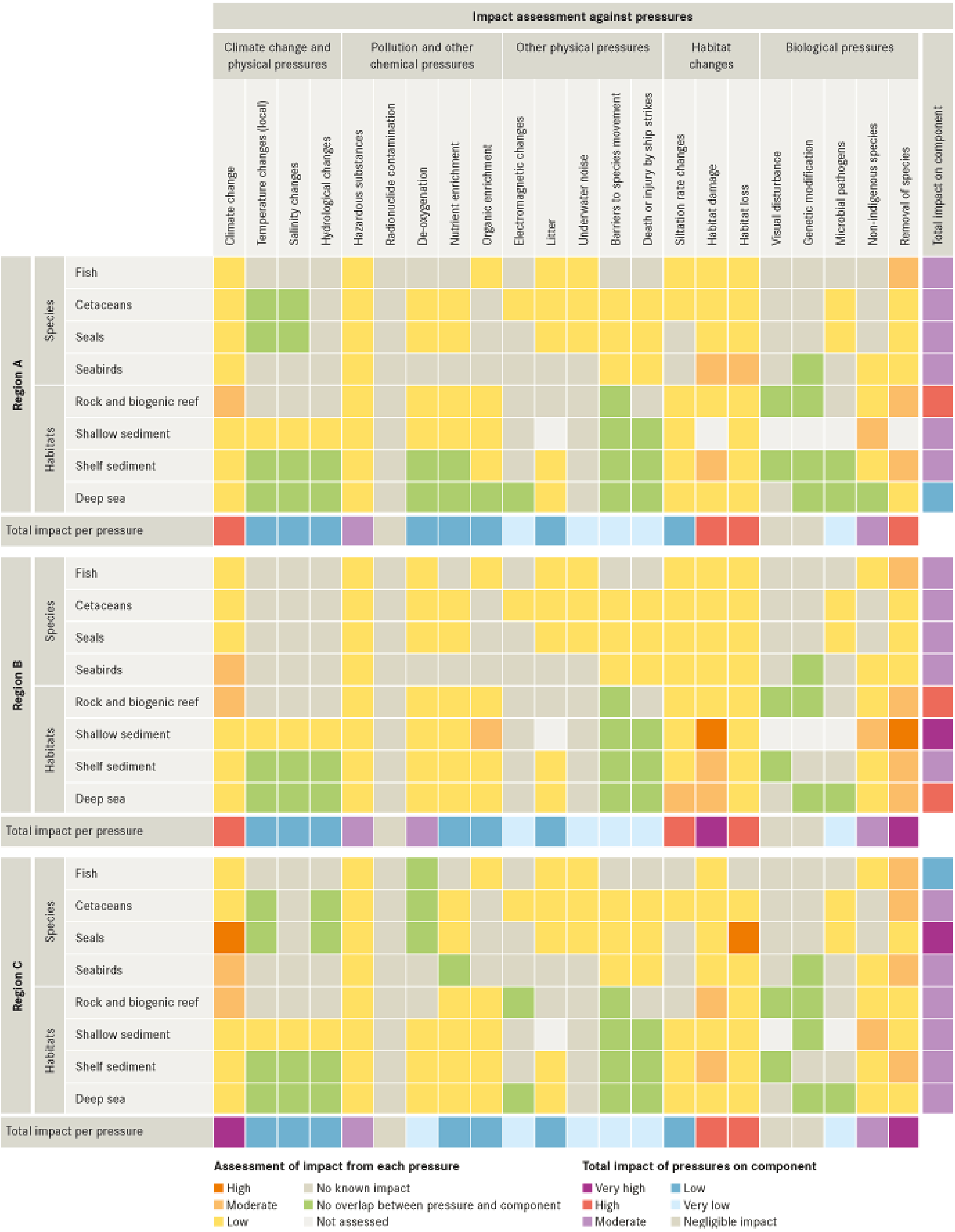
The Utrecht workshop trialled a generic, large-scale approach to ecosystem assessment. Relevant lessons from the workshop included:

- Mapping of human activities and ecosystem components is promising for the assessment of separate and cumulative impacts on habitats and related sessile species (which are bound to a particular area) but less applicable to mobile species.
- Assessments at the scale of OSPAR Regions are too coarse to identify properly the often area-specific impacts of human activities. Many habitats also occur at a smaller geographical scale. It is therefore important that assessments of human impacts are undertaken at the appropriate scale, which may vary on a case by case basis.
- Generic assessment criteria and thresholds do not take into account the variation in life history characteristics for some species groups. The assessment criteria should be refined to allow for more differentiation in species and also habitat groups.
- The pilot assessment yields a first indication of cumulative effects. Further development of the method is needed to improve the assessment of cumulative effects.
- Judgement by a designated group of experts following well-defined procedures can complement limited datasets. The credibility of the outcome is enhanced by recording the confidence level and by describing how gaps in data were treated and how issues were addressed for which there was insufficient consensus (OSPAR 2009m).

The ICES Working Group on Holistic Assessments of Regional Marine Ecosystems (WGHAME) (ICES 2009) critically reviewed the Utrecht workshop process and suggested an assessment framework to improve the overall effectiveness of the assessment. This was based on a review of existing methods for assessing the cumulative impacts of multiple human activities on large marine ecosystems. The ICES report highlighted the complexities involved in linking the status of ecosystems and ecosystem components with pressures and recommended that a workshop be held in collaboration with other expert groups in the ICES Regional Seas Programme to develop protocols and guidelines for the conduct of Integrated Ecosystem Assessments such as CIA.

In general, the assessment approach used in this SEA has been cumulative in the sense that although individual (usually operational) sources of effect have been identified, the mechanism and significance of effect has been considered in a generic way (e.g. all sources of visual disturbance; pulse noise from seismic and pile-driving sources; physical disturbance of seabed habitats), and in the context of other anthropogenic activities (notably fishing). Much of the approach described is aimed at CIA of specific projects or development areas (for example, the definition of functional areas/reference population) and it is unclear how this could be extended to a strategic (UK) level. Future developments in integrated ecosystem assessment from OSPAR, ICES and others are likely to inform the development of strategic level CIA in the UK.

Figure 5.54 - Illustration of results from a pilot assessment of four species groups and four habitat types.




*Note: A total impact assessment was made per region from the sum of the individual impacts per ecosystem component (last column) and per pressure (last row).*
*Source: OSPAR (2009m)*

## 5.16.2 Definitions

Secondary, cumulative and synergistic effects are not defined by the SEA Directive, and a range of definitions have been used. ODPM (2005) notes that the terms are, to some extent, not mutually exclusive and that often the term cumulative effects is taken to include secondary and synergistic effects. An additional term, incremental effects, has been used by previous DECC oil & gas SEAs to distinguish those effects resulting from activities which may be carried out under the proposed licensing; together with activities carried out under previous licensing. This definition is extended below to include activities (oil, gas, gas storage, CCS, OWF and marine renewables) which may be carried out under the proposed licensing and leasing.

**Secondary effects** comprise indirect effects which do not occur as a direct result of the proposed activities, but as a result of a more complex causal pathway (which may not be predictable).

**Incremental effects** have been considered within the SEA process as effects from licensing E&P activities (including gas and carbon dioxide storage), and leasing OWF and marine renewable developments; which have the potential to act additively with those from other licensed/leased activity.

**Cumulative effects** are considered in a broader context, to be potential effects of activities resulting from implementation of the plan which act additively or in combination with those of other human activities (past, present and future); in an offshore SEA context notably fishing, shipping (including crude oil transport) and military activities, including exercises (principally in relation to noise).

**Synergistic effects** occur where the joint effect of two or more processes is greater than the sum of individual effects – in this context, synergistic effects may result from physiological interactions (for example, through inhibition of immune response systems) or through the interaction of different physiological and ecological processes (for example through a combination of contaminant toxicity and habitat disturbance).

In contrast to other elements of the plan, to some extent, all potential sources of effect (i.e. disturbance, emissions and discharges) resulting from oil and gas activity within an area with a long (40 year) history of exploration activity are cumulative, insofar as they are incremental to previously existing sources (although the net trend of overall source level may be a reduction, due to improved environmental management and/or declining production levels).

Therefore, effects are considered secondary, incremental, cumulative or synergistic only if:

- the physical or contamination “footprint” of a predicted project overlaps with that of adjacent activities; or
- the effects of multiple sources clearly act on a single receptor or resource (for example a fish stock or seabird population); or
- if transient effects are produced sequentially.

Although the sequential effect concept is considered by the SEA mainly in the context of acoustic or other physical disturbance, a different use of the term sequential effect has been developed primarily in the context of visual impact (e.g. for onshore wind farms, from the point of view of a moving observer: SNH 2005).

The SEA Directive (Annex II) also requires, as a criterion for determining the likely significance of effects, consideration of environmental problems relevant to the plan or programme (see Section 4). On the assumption that environmental "problems" are a result of some anthropogenic effect, this section of the SEA document considers the potential interactions between these problems and any activities arising from the proposed licensing/leasing.

Those potentially significant effects, which are also considered to be cumulative are assessed below.

### 5.16.3 Underwater noise

The potential effects of underwater noise associated with the draft plan/programme are considered at length in Section 5.3; this includes cumulative impact considerations of the most high intensity noise emitting activities of pile-driving and seismic survey.

Incremental effects on marine mammals resulting from the proposed licensing/leasing are considered likely. Activity levels are likely to be concentrated in Regional Seas 1, 2 and 6, with additional oil and gas activity likely in Regional Seas 8/9, and offshore wind activity in Regional Seas 3 and 4. Consideration of this likely activity, in combination with propagation ranges for noise, concluded that it is likely that multiple sources (including simultaneous surveys and pile-driving) will occur at the same time, that both activities may extend throughout much of the year, and be audible to marine mammals over much of the coastal Regional Seas. However, it seems improbable (given the spatial ranges discussed above) that injurious or strong behavioural levels of effect will coincide, and also improbable that significant effects, as regulated under the Habitats Regulations and Offshore Marine Regulations, will occur; with the possible exception of effects on coastal populations of bottlenose dolphins, which would be controlled through the Appropriate Assessment process.

The assessment concluded that in view of the probable increase in pulse noise generation associated with the proposed combination of oil and gas licensing and offshore wind leasing, and concerns over cumulative effects (as yet not clearly understood), operational criteria should be established to limit the cumulative pulse noise "dose" (resulting from seismic survey and offshore pile-driving) to which key areas of marine mammal sensitivity are subjected.

Cumulative acoustic effects on other receptors are not considered to be probable.

Cumulative acoustic effects are more likely to result from continuous operational noise, than from pulse noise, although it is possible that seismic, pile-driving and military sonar noise may be qualitatively comparable and under exceptional circumstances may interact.

Synergistic effects – such as the potential for energetic costs of behavioural displacement, added to reduced foraging efficiency (due to for example competition for prey stocks with commercial fishing) – can be speculated but without evidential basis. Similarly, indirect effects of underwater noise – which would primarily be through prey species interactions, or displacement of competing species or individuals – have not been demonstrated or even suggested by field data.

| | |
|---|---|
| **Incremental** | Simultaneous and sequential seismic surveys and pile-driving |
| **Cumulative** | Seismic survey and pile-driving noise and broadband impulse noise, for example military sonars, and continuous mobile sources e.g. shipping |
| **Synergistic** | None known |
| **Secondary** | None known |

### 5.16.4 Physical damage/change to features and habitats

Potential sources of physical disturbance to the seabed, and damage to biotopes, associated with oil and gas activities were identified as anchoring of semi-submersible rigs; wellhead placement and recovery; production platform jacket installation and piling; subsea template and manifold installation and piling; pipeline, flowline and umbilical installation and trenching and decommissioning of infrastructure (Section 5.4). Given the forecast scale of exploration and production, it is likely that there would be considerable spatial separation between disturbance "footprints" and a low probability of incremental overlap of affected areas. Recovery of affected seabed through sediment mobility, and faunal recovery and re-colonisation, is expected to be rapid where the source of effects is transient (e.g. anchoring), less than five years. Incremental effects are therefore not considered significant.

Existing control and mitigation measures are provided through the *Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations, 1999* or (in the vicinity of an SAC) from *The Offshore Petroleum Activities (Conservation of Habitats) Regulations, 2001*. The required consenting procedure for specific projects ensures that biotopes of particular conservation or ecological value are identified and afforded appropriate protection.

Scour is a significant issue in relation to wind farm, wave and tidal stream foundations, with potential demonstrated at some sites (e.g. Scroby Sands) for incremental overlap of the spatial footprint of adjacent foundations. Levels of scour are expected to vary for differing foundation types. Scour can be largely mitigated (at cost and with associated ecological effects) using various forms of physical protection. Benthic monitoring at constructed Round 1 and 2 OWF sites in the UK indicates that in general, community disturbance outside the immediate area around piles has been minimal, and difficult to distinguish from natural variability and the beneficial effects of exclusion of fishing activity.

Physical effects associated with cable and pipeline laying are expected to increase over the time period of this report with the construction and installation of Round 1 & 2 extensions and Round 3 OWF, wave and tidal stream demonstrator and small commercial scale arrays and gas storage and demonstrator scale carbon capture and storage projects. Where cable and pipeline routes interact with other activities utilising the seabed then deep burial or extensive protection may be required, which will potentially cause greater disturbance to the seabed and associated biotopes

Tidal range schemes have the potential to greatly impact the physical environment and permanently change physical hydrography characteristics. This would have an effect on the resource and physical characteristics of an area available for further renewable energy installations, although no tidal range schemes are expected to be constructed within the lifetime of this report.

Effects of seabed disturbance resulting from proposed activities will be cumulative to those of other activities, notably demersal fishing. In a UKCS context, the contribution of all other sources of disturbance are minor in comparison to the direct physical effects of fishing, and it can be argued that the positive effect of fisheries exclusion offsets any negative effects of exploration and production and OWF, wave and tidal stream development. On balance, however, the spatial extents of both positive and negative effects are probably negligible for most seabed habitats.

**Incremental** Physical footprint incremental to existing offshore activity – minor increment from oil and gas and gas storage and carbon capture and storage in existing hydrocarbon reservoirs; higher from OWF and potentially wave, tidal stream and gas and carbon capture and storage in other geological formations, although data is currently poor; very high for tidal range

**Cumulative** Cumulative effects dominated by trawling. In these areas the disturbance effect of oil and gas and OWF, wave and tidal stream development is likely to be offset by fishing exclusion.

**Synergistic** None known

**Secondary** None known

### 5.16.5 Consequences of energy removal

The consequences of energy removal by wave and tidal stream devices on the physical and biological environment (predominantly through the change in wave heights and tidal stream velocities and associated ecological effects) are not well understood, although provisional modelling evidence suggests that effects are increasingly significant in close proximity to devices and marginal at far field distances (Section 5.5). The spacing and layout of arrays of devices may affect the size of the wake effect, potential energy available for subsequent devices and cumulative impact of energy removal on far field areas. Modelling studies suggest that environmental impacts are potentially larger in arrays designed to maximise power generation, although currently the lack of large commercial scale arrays of these devices means that monitoring evidence is scarce and the effects remain largely unquantifiable.

**Incremental** Currently demonstrator scale arrays of wave and tidal devices provide little information on incremental effects, although modelling evidence suggests the array layout will have a significant effect especially on the incremental overlap of energy removal on subsequent devices within an array.

**Cumulative** Likely to be minimal at significant distanced from devices and arrays, although evidence base is very limited.

**Synergistic** Unquantified but potentially significant in relation to wave and tidal devices whereby additional devices cumulatively remove more energy from the water column than the sum of the same number of single devices.

**Secondary** Unquantified – but potential impact on other users (e.g. surfing communities) from the reduction in wave height downstream of devices

## 5.16.6 Physical presence

The spatial interactions of offshore wind and other marine renewable developments with other users are considered in Sections 5.7 and 5.15. The physical presence of offshore infrastructure (with associated safety exclusion zones) required for exploration and production in shallow waters can have significant direct effects on other users of the affected areas (notably the fishing industry). The predicted incremental effect of exploration and production following proposed licensing is not significant.

Physical presence of offshore infrastructure and support activities may also potentially cause behavioural responses in fish, birds and marine mammals (Section 5.6). Previous SEAs (SEAs 1-7) have considered the majority of such interactions resulting from interactions with offshore oil and gas infrastructure (whether positive or negative) to be insignificant; in part because the number of surface facilities is relatively small (of the order of a few hundred) and because the majority are at a substantial distance offshore, in relatively deep water. This assessment is considered to remain valid for the potential consequences of a further round of oil and gas licensing, including for gas storage. However, the larger numbers of individual surface or submerged structures in offshore wind and other marine renewable developments, the presence of rotating turbine blades and considerations of their location and spatial distribution (e.g. in relation to coastal breeding or wintering locations for waterbirds and important areas for marine mammals), indicate a higher potential for physical presence effects.

In addition to Round 1 & 2 wind leasing developments and those proposed from Round 3, The Crown Estate announced in February 2009 10 development zones for offshore wind in Scottish Territorial Waters. Exclusivity agreements have been signed by development partners for sites on both the east and west coasts of Scotland, which are expected to yield a combined generating capacity of 6.4GW. The timescale for construction of Scottish Territorial Water development sites is likely to be similar to that of Round 3. There is obviously the potential for these developments to generate cumulative effects with possible developments resulting from future offshore wind farm leasing (and other coastal and offshore activities). Similarly, potential offshore wind developments in the waters of Northern Ireland, Republic of Ireland and adjacent Crown dependencies (such as the Isle of Man) would contribute to overall cumulative impacts.

Overall, the assessment concludes that the available evidence from existing OWF developments – principally the extensive monitoring studies conducted at Horns Rev and Nysted, and monitoring at UK OWFs – suggests that displacement, barrier effects and collisions are all unlikely to be significant to bird populations at a strategic or a local level. Some important uncertainties remain in relation to bird distribution (and temporal variability), the statistical power of monitoring methods and the sensitivity of this conclusion to modelling assumptions (notably avoidance frequency in modelling of collision risk; and several important factors in modelling of population dynamics). The COWRIE project Developing Guidance on Ornithological Cumulative Impact Assessment for Offshore Wind Farm Developers (King *et al.* 2009), noted above, makes various recommendations on data acquisition and assessment of cumulative effects on birds, principally in relation to assessment at a local or regional scale.

Displacement and barrier effects on birds could theoretically be cumulative with disturbance effects resulting from other activities, or even synergistic (most probably through nutritional or energetic mechanisms). The potential incremental effect resulting from the presence of marine renewables on birds is unlikely to be significant, primarily due to the likely demonstrator scale of potential projects. However, projects may be located in areas of importance for diving birds and marine mammals and therefore potential displacement and barrier effects should be an important consideration at the project level. A CCW project to map a tidal stream device vulnerability index for diving birds and marine mammals in Welsh waters is currently underway (see RPS 2010); the outputs of these will assist with location of such technologies, particularly if the methodology can be extended to other UK waters.

**Incremental** Small increment from oil and gas, $CO_2$ and gas storage and marine renewables to existing exclusion zones and obstructions, visual intrusion and disturbance; potentially significant increment from offshore wind farms. Displacement, barrier effects and collision risk to birds potentially significant at a local or regional level; considered unlikely to be significant to bird populations at a strategic level.

**Cumulative** Exclusion and snagging risks are cumulative to those resulting from natural obstructions, shipwrecks and other debris. Extent of cumulative effect associated with oil and gas, $CO_2$ and gas storage licensing round is negligible. Potential cumulative displacement, barrier effects on birds.

**Synergistic** No conclusive data

**Secondary** No conclusive data

## 5.16.7 Landscape/seascape

In coming years offshore wind is likely to be placed further offshore partly due to the location of the Round 3 leasing zones and as turbine foundations develop so that deeper waters can be exploited. A significant number of offshore wind farms and development zones are now in place in UK territorial and offshore waters. It is difficult to resolve the local implications on seascape from such developments at a strategic level, though in the areas of the East Irish Sea, Thames and Wash, the concentration of farms and their proximity to the coast may lead to the seascapes of these areas being dominated by this use of the sea (Section 5.8). This is already being reflected in a number of offshore wind Environmental Statements (e.g. Walney, Sheringham Shoal) for developments in these areas, which outline that other offshore wind developments are a potential source of at least moderate cumulative impacts. Resources for wave, tidal and wind technologies tend not to overlap and therefore it is unlikely that different renewable technologies will compete for space, or generate a scenario where there are cumulative effects from different types of renewable technologies. Where this might occur is in views down certain estuaries should tidal stream or range devices interrupt open sea views which are then overlain with, for instance, offshore wind turbines.

Other activities which may result from the draft plan/programme which could lead to cumulative visual impacts include gas and carbon dioxide storage, and any ancillary development of any element of the plan, though this would need to be assessed at the local level. It is unlikely that any significant new oil and gas infrastructure will be commissioned within the currency of OESEA2, and in the foreseeable future as UKCS reserves decline.

**Incremental** In certain Round 1 and 2 leasing areas, incremental effects are characterised by successive developments of offshore wind farms which are intervisible with the coast and one another. Though Round 3 leasing areas are typically further from the coast and therefore have less potential for visual impacts at the coast, further intervisibility with future wind sites and existing sites could lead to significant incremental effects.

**Cumulative** The location of wind, wave and tidal energy resources are such that there is unlikely to be any significant cumulative effects between these technologies. With regard to gas storage and CCS, any new surface infrastructure, particularly in the East Irish Sea Basin may generate cumulative visual effects.

**Synergistic** No conclusive data

**Secondary** No conclusive data

### 5.16.8 Marine discharges

Total produced water discharge from UKCS oil production was 198 million $m^3$ in 2008, with an average oil in water content of 15.99mg/l (DECC website). In comparison with this, the potential discharge from new developments following the proposed round will be negligible since it is expected that the bulk of produced water will be reinjected rather than discharged. Through OSPAR, the UK is committed to a presumption against discharge from new developments.

Environmental effects of produced water discharges are limited primarily by dispersion, to below No Observed Effect Concentrations (NOECs). Synergistic interactions are possible between individual components, particularly PAHs, specific process chemicals (especially those which are surface-active, including demulsifiers), and other organic components. However, given the anticipation that the bulk of produced water from new field developments will be reinjected rather than discharged, and that such discharges as are made will be treated to required quality standards, the scope for incremental, cumulative or synergistic effects is remote.

Previous discharges of WBM cuttings in the UKCS have been shown to disperse rapidly and to have minimal ecological effects. Dispersion of further discharges of mud and cuttings could lead to localised accumulation in areas where reduced current allows the particles to settle on the seabed. However, in view of the scale of the SEA area, the water depths and currents, and probability of reinjection drill cuttings from any major field development, this is considered unlikely to be detectable and to have negligible incremental or cumulative ecological effect.

OWF developments have essentially no planned discharges, although there is a potential incidental release of copper and carbon dust from abrasion of the slip-rings of the turbines; this is considered to have negligible environmental effect

**Incremental** Produced water – incremental contribution of produced water is dependent on the extent of reinjection but noting the presumption against new produced water discharges, the scale of discharge and effects will be negligible. WBM drilling discharges generally disperse widely and significant accumulations do not occur. It is therefore possible that discharge footprints will overlap, although the ecological effects will be undetectable. Potential "sinks" may occur in areas of sediment accumulation although this is considered unlikely to be detectable.

**Cumulative** Principal cumulative sources of major contaminants, including hydrocarbons and metals, are shipping (including wrecks) and atmospheric inputs. Cumulative sources of particulate contaminants include aeolian dust and sediment disturbance from trawling, although these are negligible in the context of natural suspended particulate loads.

**Synergistic** Synergistic effects of chemical contaminants in produced water and drilling discharges are conceivable, although substantive data is almost entirely lacking and it is considered unlikely that significant synergistic effects would result from chemicals used in exploration and production operations.

**Secondary** None known

## 5.16.9 Wastes to land

In view of the relatively small number of wells predicted, and recent establishment of a licensing mechanism to allow interfield cuttings reinjection, it is considered unlikely that major incremental or cumulative landfill requirement will result from proposed licensing/leasing.

**Incremental** Incremental return of general oilfield wastes insignificant; incremental return of drilling wastes also unlikely to represent a significant contribution to onshore waste disposal requirements.

**Cumulative** Not quantified

**Synergistic** None known

**Secondary** None known

## 5.16.10 Atmospheric emissions

Atmospheric emissions from offshore oil and gas exploration and production activities may contribute to reduction of local air quality (Section 5.11). Greenhouse and acid gas emissions effectively contribute to a mixed regional or global "pool" and can therefore be considered cumulative (Section 5.12).

The implications of the ultimate use of oil and gas production from UKCS for greenhouse gas emissions and on UK commitments under the Kyoto Protocol, were not considered here since these are subjects for different high level policies, fora and initiatives including UK energy policy, security of supply considerations, emissions trading etc.

Flaring from existing UKCS facilities has been substantially reduced relative to past levels, largely through continuing development of export infrastructure and markets, together with gas cycling and reinjection technologies. In addition, offshore oil industry emissions are subject to an Emissions Trading Scheme. New developments will generally flare in substantial quantities only for emergency pressure relief, with "zero routine flaring" now considered a realistic design target for new developments. Other than start-up flaring, subsea tie-back developments will generally have little effect on host installation flaring.

Atmospheric emissions associated with offshore renewables are largely from their manufacture and deployment, with maintenance involving less intensive boat-based visits. Cumulative effects from an increase in port capacity or the increased utilisation of ports with existing capacity could lead to local air quality effects if unabated. The increased deployment of offshore renewables towards 2020 and beyond will, in association with $CO_2$ storage and other energy efficiency measures, cumulatively make a positive contribution to both greenhouse gas abatement and air quality improvement.

Operational air quality effects of $CO_2$ storage are unlikely to be significant and should not pose any cumulative effects.

**Incremental** Incremental emissions resulting from internal combustion for power generation by installations, terminals, vessels and aircraft, flaring for pressure relief and gas disposal, and fugitive emissions during tanker loading.

**Cumulative** Greenhouse and acid gas emissions effectively contribute to a mixed regional or global "pool" and are therefore considered to be cumulative. On a global scale, cumulative contributions of emissions resulting from predicted activities and developments will be negligible in comparison to the influence of onshore sources.

**Synergistic** None known

## 5.16.11 Accidental events

Accidental events (with environmental consequences) that could potentially occur on offshore E&P, and gas storage facilities, and associated support vessels, include oil and chemical spills and gas releases, although large volume oil spills are only possible from oil exploration, production or export facilities (Section 5.13). Marine renewable energy developments generally have a negligible inventory of oils and chemicals, and spill risks are accordingly mostly associated with construction and operational maintenance; or with navigational safety risks to other (not OWF-related) vessel traffic.

Although the consequences of a major oil spill could be severe, in both ecological and economic terms, the incremental risk associated with the predicted level of activity over that considered in the OESEA is moderate or low. In a study of accidental oil spills and maritime casualties carried out on behalf of the MCA to inform the placement of emergency towing vessels, Safetec (2000) ranked pollution risk[41] as high or very high to the north of Shetland, in the Fair Isle Channel, through the Pentland Firth, down much of the east coasts of Scotland and England, through the Dover Strait and along much of the Channel coast, around Land's End, in the Approaches to Milford Haven, through the North Channel, around St Kilda and the Flannans, on the west coast of Lewis and around the Butt of Lewis. The increasing numbers of offshore installations in UK waters, and in particular the number and spatial footprint of large wind farms, will affect the relative risk of vessel collision. This risk is expected to be mitigated (*inter alia*) by siting of developments so that they do not impinge on major commercial navigation routes or significantly increase collision risk. With this caveat, the predicted scale of activity that could follow adoption of the draft plan/programme would not have a significant influence on the cumulative risk.

Regulatory mechanisms already in place require developers and facility operators to develop effective oil spill mitigation measures, covering organisational aspects and the provision of physical and human resources which will minimise incremental risks. Times to beach, under worst case trajectory modelling conditions, are relatively short in some areas and effective contingency planning and local resources are therefore necessary to allow the deployment of response measures where appropriate.

In terms of cumulative risk, there is little doubt that due to scale and consequence, the major risk of significant oil spills is associated with tanker transport of crude oil and refined products. While some control and response measures have been implemented, for example following the Donaldson inquiry into the *Braer* incident, the residual risk remains relatively

[41] The risk assessment methodology considered frequency, but not sensitivity or consequence

high (in comparison to other oil spill sources). A major well blowout can also result in significant release to sea of oil; however, the probability of such events occurring, and thus influencing cumulative risk, is extremely low.

Other cumulative sources of anthropogenic hydrocarbon input to the UKCS (including those from outside the area) include rivers and land run-off, coastal sewage discharges, dredge spoil, operational shipping discharges and atmospheric deposition. Although cumulative hydrocarbon inputs are often summed for comparative purposes, it is important to note that the environmental effects and fate of individual oil types and sources may be very different. Simple comparison of cumulative inputs may therefore be misleading in terms of effects assessment. In size and frequency terms, the majority of oil spills most likely to result from E&P operations will make an insignificant contribution to overall regional inputs.

As context, it may be noted that overall, although the acute effects of oil spills can be severe at a local scale, the cumulative effects of around a century of oil spills from shipping – and over forty years of oil and gas development – do not appear to have resulted in wide-scale or chronic ecological effects. It is therefore concluded that the limited incremental effects of predicted activity, assuming that effective risk management practices continue to be implemented, will be minimal.

The scale of $CO_2$ storage activity likely to take place within the currency of OESEA2 may be reasonably expected to consist of either a single coal or gas fired power plant under the UK Government-funded demonstration programme, or potentially a demonstrator scale commercial project. Considering the scale of likely development, even a large $CO_2$ leak, when regionally integrated, is likely to be insignificant when compared with that from continued non-mitigated atmospheric $CO_2$ emissions and the subsequent acidification of the marine system. Consequently, significant cumulative effects from accidental events associated with $CO_2$ storage are not expected.

**Incremental** Hydrocarbons from oil spills will be incremental to (minor) offshore exploration and operational discharges; however, it is considered very unlikely that oil spill footprints will overlap given the spill frequency associated with predicted activities.

**Cumulative** There are a range of cumulative sources of hydrocarbons to the area. Depending on magnitude, accidental spills represent a minor to major contribution to overall regional inputs of oil.

**Synergistic** None known

## 5.16.12 Potential for transboundary effects

The OESEA2 includes all UK waters, therefore transboundary effects are possible with all neighbouring states whose waters abut the UK. These are France, Belgium, the Netherlands, Germany, Denmark, Norway, the Faroes and the Republic of Ireland. Since activities from this draft plan/programme may occur in UK waters and including adjacent to the majority of median lines, the sources of potentially significant environmental effects with the additional potential for transboundary effects include:

- Underwater noise
- Marine discharges
- Atmospheric emissions
- Impact mortality on migrating birds and bats
- Accidental events – oil spills

All of the five aspects above may be able to be detected physically or chemically in the waters of neighbouring states.

The scale and consequences of environmental effects in adjacent state territories due to activities resulting from adoption of the draft plan/programme will be less than those in UK waters and are considered unlikely to be significant.

## 5.17 Consideration of alternatives

### 5.17.1 Introduction

The plan/programme alternatives were described in Section 2.3 and include:

1. Not to offer any areas for leasing/licensing
2. To proceed with a leasing and licensing programme
3. To restrict the areas offered for leasing and licensing temporally or spatially

The assessment of alternatives below is presented by SEA topic and consists of a two stage process which includes:

- Consideration of sources of potentially significant effect (as described in Section 5.2)
- Consideration of OESEA2 objectives and guide phrases (as described in Section 3)

Based on the preceding consideration of effects (Sections 5.3-5.16), the potential effects of the plan/programme alternatives in relation to the SEA topics is summarised below.

The consideration of sources of potentially significant effect uses the key below:

| | |
|---|---|
| (dark green) | Potential positive impact on topic |
| (light green) | Potential minor positive impact on topic |
| (blue) | Neutral impact on topic |
| (yellow) | Potential minor negative impact on topic |
| (orange) | Potential negative impact on topic |

### 5.17.2 Biodiversity, habitats, flora and fauna

**Consideration of sources of potentially significant effect**

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Physical damage to habitats from infrastructure construction, vessel/rig anchoring etc | | | | 'Footprint' effects associated with OWF, wet renewables, oil & gas and $CO_2$ storage in saline reservoirs; negligible incremental effect from gas and $CO_2$ storage in developed reservoirs. |
| Potential behavioural and physiological effects on marine mammals, birds and fish from seismic surveys | | | | Geophysical surveys principally associated with oil & gas exploration and development; some seismic potentially required for gas and $CO_2$ storage. |
| Potential behavioural and physiological effects on marine mammals, birds and fish associated with piling and construction noise | | | | Potential effects associated with pile driving primarily from OWF and to a lesser extent wave, tidal stream and oil & gas; may generate high source levels with significant potential for propagation; negligible incremental effect from gas and $CO_2$ storage in depleted reservoirs. Construction of tidal range schemes likely to result in significant noise both above and below water. |
| Potential behavioural and physiological effects on marine mammals, birds and fish associated with operational noise | | | | Negligible operational noise from OWF; source levels from oil & gas production, and gas and $CO_2$ storage (e.g. gas compression) relatively low therefore local effects only. Potential for noise associated with operation of wave and tidal stream devices although limited information. |
| Potential behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise | | | | As with OWF, noise emissions associated with decommissioning of wave and tidal developments of a similar nature to those generated during construction and installation, with the exception of an absence of extensive pile-driving noise. |
| Potential for non-native species introductions in ballast water discharges or spread through "stepping stone" effect | | | | Possibility of effects mitigated by adherence to recent ballast water guidance. Presence of OWF and wet renewable foundations may result in localised increases in species diversity but given the widespread natural presence of hard substrates such as glacial dropstones, unlikely that foundations will facilitate the spread non-native species. |

| **Sources of potentially significant effect** | **Alternatives** | | | **Narrative** |
|---|---|---|---|---|
| | **1** | **2** | **3** | |
| Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities | | | | Potential effects associated with OWF, wet renewables and oil & gas; negligible incremental effect from gas and $CO_2$ storage in depleted reservoirs |
| Collision risks to birds | | | | Principally associated with OWF; mortality rate variable depending on location but unlikely to be significant at a strategic level with locational mitigation. Collision risk to diving birds from wet renewable devices not well understood. |
| Collision risk to marine mammals, fish and large water column animals | | | | Principally associated with wet renewable devices although as yet not fully understood. Unlikely to be significant at a strategic level with locational mitigation. |
| Barriers to movement of birds (e.g. foraging, migration) | | | | Principally associated with OWF; significance of effect variable depending on location but unlikely to be significant at a strategic level. |
| | | | | Loss of intertidal areas as a result of tidal range development may have a significant impact on foraging areas for waterbirds causing displacement of birds. |
| Barriers to movement of fish and marine mammals | | | | Principally associated with wet renewables; significance of effect variable depending on location but unlikely to be significant at a strategic level with locational mitigation with the potential exception of large tidal range schemes. |
| | | | | Tidal range schemes may represent a significant barrier to the movement of migratory and estuarine fish. |
| Changes/loss of habitats from major alteration of hydrography or sedimentation | | | | May be associated with OWF and wet renewables although locational mitigation should minimise impacts. |
| | | | | Tidal range schemes may cause significant changes/loss of habitats as a result of altering hydrography or sedimentation patterns. |
| Potential for effects on flora and fauna of produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | | | | Associated principally with oil & gas exploration and development; gas and $CO_2$ storage, and OWF foundations. Produced water discharges unlikely for new developments; drilling discharges limited to WBM. Effect of saline discharges unlikely to be significant if appropriate mitigation followed. |

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| EMF effects on fish | | | | Principally associated with OWF; current evidence does not indicate significant effects and unlikely to be significant at a strategic level |
| The nature and use of antifouling materials | | | | Unlikely to be significant at a strategic level. |
| Accidental events - major oil or chemical spill | | | | Low risk of occurrence of major spills, predominantly related to oil exploration and production. Very low risk of spills related to navigation for OWF, wave and tidal, with a slightly higher risk associated with $CO_2$ and gas transport by vessel and from associated fixed installations. |
| Accidental events - major release of $CO_2$ | | | | Potential effects associated with $CO_2$ storage activities. The risk of loss of containment is considered likely to be low, although there is a very limited basis of experience and quantitative risk assessment on which to base this judgement. |

## Consideration of OESEA2 objectives and guide phrases

### Biodiversity, habitats, flora and fauna objectives

- Contributes to conservation of the biodiversity and ecosystems of the United Kingdom
- Avoids significant impact to conservation sites, including draft, possible, candidate and designated Natura 2000 sites, along with consideration of future Marine Conservation Zones and Marine Protected Areas
- Avoids significant impact to, or disturbance of, protected species

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities do not lead to the loss of biological diversity, the degradation in the quality and occurrence of habitats, and the distribution and abundance of species* | Neutral effect – no plan activities take place. | With appropriate regulatory control and the implementation of best practice, plan activities are unlikely to lead to significant loss of biological diversity. Appropriate Assessments/screenings at both strategic and project-level will consider the potential of proposed leasing/licensing and subsequent activities to affect the site integrity of Natura 2000 sites. | Restricting the plan spatially or temporally may allow a precautionary approach to be taken. For example, some areas with relevant interests may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field. |
| *Plan activities do not lead to the introduction of non-native species at levels which adversely alter marine ecosystems* | Neutral effect – no plan activities take place. | The draft plan will not lead to the introduction of non-native species at levels which adversely alter marine ecosystems. Ballast water from shipping/rigs likely to represent the main potential source of non-native species although guidance should minimise risk. Increased local species diversity may be associated with hard foundations although this is unlikely to cause significant ecosystem effects. | Restrictions on areas licensed are unlikely to reduce potential for introduction and spread of non-native species (as described in Alternative 2). However, it is considered that the draft plan will not lead to the introduction of non-native species at levels which adversely alter marine ecosystems. |
| *The plan recognises the ecosystem importance of land-sea coupling, for instance its role in species migration* | Neutral effect – no plan activities take place. | Tidal range aspects of the plan (although at present no projects have been identified) may represent the most significant threat to fish migration. OWF developments may displace birds from migratory routes but this is unlikely to be significant. | Restricting the areas offered spatially or temporarily may facilitate protection of important migratory routes (e.g. for diadromous fish returning to rivers and for birds on seasonal migrations). |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *The plan promotes the achievement of good ecological status for water bodies as outlined at a European Level.* | Neutral effect – no plan activities take place. | The objectives of the WFD (coastal and estuarine waters) and the MFSD (marine) to promote the achievement of good status for water bodies are an integral part of the environmental management context within which the draft plan is set (see Section 2.2). | The objectives of the WFD (coastal and estuarine waters) and the MFSD (marine) to promote the achievement of good status for water bodies are an integral part of the marine management context within which the draft plan is set (see Section 2.2). |
| **Conclusion** | Neutral effect – no plan activities take place. | The draft plan is unlikely to have an adverse impact on the objectives for biodiversity, habitats, flora and fauna. Appropriate Assessments/ screenings and environmental management at the project-level will ensure that the objectives with respect to protected sites, habitats and species are met. | Restricting the plan spatially or temporally will facilitate attainment of the objectives as will allow a precautionary approach to be taken. Relevant areas may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field. Given the paucity of information on infield effects of some aspects of the draft plan, a precautionary approach is recommended. |

## 5.17.3 Geology and sediments

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Physical effects of anchoring and infrastructure construction (including pipelines and cables) on seabed sediments and geomorphological features (including scour) | | | | ‘Footprint’ effects associated with OWF, wave, tidal and oil & gas and cable / pipeline installation. Negligible effect from $CO_2$ and gas storage in existing hydrocarbon reservoirs, more substantial in alternative non-hydrocarbon reservoirs. |
| | | | | Tidal barrage will have a very large spatial ‘footprint’. |

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment | | | | Predominantly associated with oil & gas exploration and development. Some drilling required for $CO_2$ and gas storage in non-hydrocarbon reservoirs and the foundations of OWF, wave and tidal stream devices. Limited extra drilling for $CO_2$ and gas storage in existing hydrocarbon reservoirs. |
| | | | | Significant effects associated with the construction of tidal barrages, which have very long (multiple years) construction periods. |
| Effects of reinjection of produced water and/or cuttings | | | | Associated principally with oil & gas exploration, gas and $CO_2$ storage. |
| Onshore disposal of returned wastes – requirement for landfill | | | | Associated principally with oil & gas exploration and development and gas storage. OWF, wave, tidal and $CO_2$ storage have limited waste production other than decommissioning. |
| Post-decommissioning (legacy) effects – cuttings piles, footings, foundations etc | | | | Some structures/foundations below seabed level may be left after decommissioning, with potential for future exposure by sediment processes within the area. |
| | | | | Tidal barrages are unlikely to be removed. |
| Accidental events - risk of sediment contamination from oil or chemical spills | | | | Low risk of occurrence of major spills, predominantly related to oil exploration and production. Very low risk of spills related to navigation for OWF, wave and tidal, with a slightly higher risk associated with $CO_2$ and gas transport by vessel and from associated fixed installations. |
| Accidental events – blow out impacts on seabed | | | | Low risk of a blow out associated with oil & gas exploration and gas storage. |
| Changes to sedimentation regime and associated physical effects | | | | Significant localised effects associated with changes to hydrography of the area expected for wave and tidal stream, but potentially negligible at distance although information base is limited. |
| | | | | Tidal barrage will permanently alter physical conditions, with effects potentially detectable over the whole continental shelf. |

## Consideration of OESEA2 objectives and guide phrases

### Geology and sediments objectives

- Protects the quality of the seabed, coast and associated sediments and avoids significant effects on their morphology and sediment transport
- Avoids significant damage to geological conservation sites and protects important geological/geomorphological features

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Activities arising from the plan do not adversely affect the quality and character of the geology and geomorphology of seabed or coastal sediments.* | Neutral effect – no plan activities take place. | Without appropriate planning measures or mitigation there is the potential for cumulative impacts of device 'footprints', especially relating to scour effects, cabling and pipeline laying, although this is still on a significantly smaller scale than the effects of demersal fishing. Some significant local scale sediment effects are expected for wave and tidal stream devices although these are potentially negligible at larger distances, with the scale of effect dependant on location, setting and physical conditions. Tidal range causes permanent large scale changes to the geomorphology of the area. | The large extent of physical effects resulting from tidal barrage construction, and their permanency, mean that very careful site consideration is required at a project specific level. Caution is also required in the planning of scaled up arrays of wave and tidal stream devices until the extent of the spatial effects of energy removal on physical processes and how they affect differing environments are better understood. |
| *Plan activities avoid adverse effects on designated geological and geomorphological sites of international and national importance.* | Neutral effect – no plan activities take place. | Certain aspects of the plan (predominantly tidal range) have the potential to significantly affect sites of geological and geomorphological importance and as such detailed site specific surveys should be conducted to assess the likely impact. | As above. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| **Conclusion** | Neutral effect – no plan activities take place. | OWF, wind, tidal stream, oil & gas and $CO_2$ and gas storage in existing hydrocarbon reservoirs will have only small scale impacts on the geology and sediments of an area. However without mitigation the potential cumulative effects of cabling, pipeline laying and scour in regions of high density usage may become a significant issue. Tidal range schemes (barrages) have very extensive, very significant, permanent effects that even with mitigation are unlikely to lower the impact. | Initial evidence suggests potential variance in physical effects on sediments and geology of wave and tidal stream devices with differing locations and possibilities of significant array scale cumulative effects. There may be a case for restricting their localities but until a greater understanding of these effects and potential impacts of arrays are reached, no specific restrictions can be suggested. |

## 5.17.4 Landscape/seascape

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Potential visual impacts and seascape effects of development including change to character | | | | There will be visual effects associated with all offshore developments arising from the draft/plan programme. The significance of seascape impacts is largely dependent upon the sensitivity/capacity of individual seascapes, the specific nature of a given development, and the potential for cumulative or incremental effects between plan activities, and other existing and proposed marine activities. |

## Consideration of OESEA2 objectives and guide phrases

### Landscape/seascape objective

- To accord with, and contribute to the delivery of the aims and articles of the European Landscape Convention and minimise significant adverse impact on seascape/landscape including designated and non-designated areas

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Activities do not adversely affect the character of the landscape/ seascape.* | Neutral effect – no plan activities take place. | In the absence of appropriate marine spatial planning and project level mitigation there is the potential for incremental, cumulative effects between existing and future offshore wind zones, and in-combination effects with other elements of the draft plan/programme, particularly in areas identified as having a high number of existing users. | The spatial and temporal restriction of plan activities in relation to seascape concerns would have to be addressed at the project level through SVIA incorporating cumulative impact assessment. |
| *The plan helps to conserve the physical and cultural visual resource associated with the land and sea.* | Neutral effect – no plan activities take place. | Plan activities have the potential to generate negative impacts on the physical and cultural resource, as they introduce an industrial element, the character and scale of which will not be compatible with certain areas. Current controls, draft marine policy and accordance with present and forthcoming assessment guidance should provide a suitable level of mitigation. | The spatial restriction of certain plan activities may reduce the potential visual impact at the coast and at sea in certain locations. In addition, current controls, draft marine policy and accordance with present and forthcoming assessment guidance should provide a suitable level of mitigation. |

| **Guide phrases** | **Consideration of Alternatives** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| **Conclusion** | Neutral effect – no plan activities take place. | Some plan activities (oil & gas, gas storage, $CO_2$ storage, some R3 wind) will take place at sufficient distance offshore that seascape impacts at the coast will be confined to ancillary developments. In the absence of mitigation at the project level, those activities which necessarily take place within close proximity to the coast (tidal range and stream) could generate significant effects. | Consideration is required at the project specific level as to the capacity of a particular seascape to 'absorb' a development, both in isolation and in combination with existing and potential future developments. Existing controls, including the requirement to undertake a SVIA, should provide a suitable level of mitigation provided that cumulative impacts considerations are made and the latest available guidance followed. |

## 5.17.5 Water environment

### Consideration of sources of potentially significant effect

| **Sources of potentially significant effect** | **Alternatives** | | | **Narrative** |
|---|---|---|---|---|
| | **1** | **2** | **3** | |
| Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction | | | | Associated principally with oil & gas exploration and development; gas and $CO_2$ storage, and OWF foundations. Produced water discharges unlikely for new developments; drilling discharges limited to WBM. Effect of saline discharges unlikely to be significant if appropriate mitigation followed. |
| Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment | | | | Principally associated with gas and $CO_2$ storage, and tidal range. Consented discharges of aquifer water etc unlikely to have a significant impact although accidental release events may be significant (see below). Tidal range schemes have the potential to significantly change seawater properties through impoundment although at present no projects identified. |

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Energy removal downstream of wet renewable devices | | | | Unlikely to be significant for wave and tidal stream given the likely demonstrator scale of potential projects although location specific. Tidal range schemes have the potential for significant energy removal downstream with wide ranging effects on currents, turbidity etc. |
| Accidental events – contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases | | | | Low risk of occurrence of major accidents. $CO_2$ and gas storage developments are not considered to represent a significant source of accidental spills where navigational safety risks have been fully considered and where there is knowledge of the reservoir properties. Overall risk associated with oil exploration and development considered low. |

## Consideration of OESEA2 objectives and guide phrases

### Water environment objective

- Protects estuarine and marine surface waters, and potable and other aquifer resources

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities do not result in concentrations of contaminants at levels giving rise to pollution effects.* | Neutral effect – no plan activities take place. | With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan should not give rise to pollution effects. Accidental events (e.g. oil/chemical spill), whilst unlikely could lead to pollution effects. | Restricting the areas offered spatially or temporarily may protect areas at particular risk from accidental pollution events. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities do not result in permanent alteration of hydrographical conditions which adversely affect coastal and marine ecosystems.* | Neutral effect – no plan activities take place. | Tidal range schemes could permanently alter hydrographical conditions although at present there are no proposed projects. Given the demonstrator scale of likely wave and tidal stream projects these are unlikely to significantly affect ecosystems although this will be location- and technology-specific and therefore perhaps better assessed at a project level. | Restricting the areas offered for tidal range devices may limit the potential for alteration of hydrographical conditions although at present there are no proposed projects. Given the demonstrator scale of likely wave and tidal stream projects, these are unlikely to significantly affect ecosystems, although this will be location- and technology-specific, and therefore perhaps better assessed at a project level rather than imposing strategic restrictions. |
| *Plan activities do not result in adverse effects on saline and potable aquifer resources.* | Neutral effect – no plan activities take place. | With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan should not give rise to adverse effects on aquifers. | Restricting the areas offered spatially or temporarily may protect aquifers at particular risk from accidental pollution events. However, given the localised nature of some aquifers, restrictions may be more effectively imposed at the project level. |
| **Conclusion** | Neutral effect – no plan activities take place. | With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan should not adversely affect estuarine and marine surface waters, and potable and other aquifer resources. | Restricting the areas offered spatially or temporally may increase protection of particular areas at risk from pollution events. |

## 5.17.6 Air quality

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Local air quality effects resulting from exhaust emissions, flaring and venting | | | | Combustion emissions arise from power generation associated with primarily oil & gas and gas storage (including $CO_2$ storage). Vessel emissions are associated will all elements of the draft plan. |
| Air quality effects of a major gas release or volatile oil spill | | | | Low risk of occurrence of major spills. Offshore renewables and gas storage (including $CO_2$) are not considered to represent a significant source of accidental spills where navigational risks and geological characterisation have been fully considered. Overall risk associated with oil exploration and development considered low. |

### Consideration of OESEA2 objectives and guide phrases

#### Air quality objectives

- Avoids degradation of regional air quality from plan related activities

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *The plan contributes to the achievement of air quality targets for those emissions outlined in the UK Air Quality Strategy.* | Neutral effect – no plan activities take place. | Combustion emissions from power generation (e.g. for compression) are unlikely to represent a major contribution to industry or national totals. An increase in port facilities or uptake of existing port capacity could lead to an increase in emissions which can contribute to the perpetuation, or creation, of Local Air Quality Management Areas. | As for alternative 2, though with reduced potential air quality and any associated health or environmental effects from plan activities. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Emissions from plan activities do not contribute to, or result in, air quality issues which adversely affect human health or the wider environment.* | Neutral effect – no plan activities take place. | Emissions from oil & gas and gas storage (including $CO_2$ storage) are not expected to directly contribute to emissions which may lead to detrimental air quality and resultant health effects at a local level. The ongoing reporting of offshore oil & gas emissions through the EEMS process and the reduction of sulphur in shipping fuel through MARPOL represent just a few programmes which will help to reduce the impact of plan activities. The expansion of port activities (as above) has the greatest potential to produce effects at the local level. | As for alternative 2, though with reduced potential air quality and any associated health or environmental effects from plan activities. |
| **Conclusion** | Neutral effect – no plan activities take place. | Emissions could lead to local air quality effects around those ports from which operations associated with plan activities are concentrated. Emissions offshore are unlikely to significantly contribute to national totals, or to human health or wider environmental effects, and are otherwise controlled through appropriate regulation. | Emissions could lead to local air quality effects around those ports from which operations associated with plan activities are concentrated. Emissions offshore are unlikely to significantly contribute to national totals, or to human health or wider environmental effects, and are otherwise controlled through appropriate regulation. |

## 5.17.7 Climatic factors

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Contributions to net greenhouse gas emissions | | | | It is not expected that offshore oil and gas activities will result in significant incremental or increased emissions. |
| Reduction in net greenhouse gas emissions | | | | The deployment of a wider range of renewable energy technologies will contribute to a significant reduction in emissions. Carbon dioxide transport and storage will not in itself contribute to emissions reductions, but as part of the wider CCS process will help in the transition to low carbon energy sources. |

### Consideration of OESEA2 objectives and guide phrases

Climatic factors objective

- Minimises greenhouse gas emissions

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *The plan contributes to the achievement of targets relating to greenhouse gases at a national and international level.* | The expansion of offshore renewables is significantly reduced and the ability to meet targets relating to GHG emissions and renewable energy generation is reduced accordingly. | The wider deployment of offshore renewables and the storage of $CO_2$ would offset UK energy generation emissions and make a significant contribution to GHG targets. | A coordinated approach to deployment of new technologies is required in order to both help attain the relevant GHG reduction targets and mitigate climate change while not compromising other existing marine resources and activities. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities contribute to mitigating climate change.* | Emissions potentially avoided through a larger offshore renewables sector and through the storage of $CO_2$ offshore are instead released to the atmosphere. | In combination with international efforts, it is predicted that a reduction in emissions from the UK can still contribute to the avoidance of the worst effects of climate change. Renewable energy has the potential to provide a long-term solution to reduced fossil fuel dependence. As this transition occurs, the maximisation of domestic fossil fuel reserves, and the storage of $CO_2$ represent solutions for low carbon energy production. | As above. |
| **Conclusion** | In the absence of the plan/programme, climate change mitigation and reduced reliance on fossil fuel energy would become increasingly harder to achieve. | Plan/programme activities will make a significant contribution towards reducing UK GHG emissions. Though oil and gas activities do not confer any climate change mitigation, emissions from these activities are increasingly controlled (e.g. through emissions trading and reduced flaring), and it is not expected that emissions from the sector will appreciably change in the lifetime of this SEA. | The spatial restriction of certain activities could reduce the overall potential of the draft plan/programme to contribute towards reduced net UK GHG emissions, though the expansion of offshore renewables in the lifetime of this SEA is expected to be such that restrictions will have little to no impact on the expansion of installed capacity. |

## 5.17.8 Population and human health

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Positive socio-economic effects of potential activities, in terms of security of supply, employment, expenditure and tax revenue (outline assessment) | | | | Positive effects are associated with all proposed activities, though large-scale OWF and associated developments would have a major benefit. |
| Potential for effects on human health associated with effects on local air quality resulting from atmospheric emissions | | | | Negligible negative effects at a strategic level. The contribution of renewable energy should result in a net positive effect. |
| Potential for effects on human health associated with effects of discharges of naturally occurring radioactive material in produced water | | | | Negligible negative effects at a strategic level. |
| Accidental events – potential food chain or other effects of major oil or chemical spills or gas release | | | | Negligible negative effects at a strategic level. |

### Consideration of OESEA2 objectives and guide phrases

Population and human health objectives

- Has no adverse impact on human health

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities do not result in, or contribute to the contamination of fish and other seafood for human consumption at levels which exceed those established by Community legislation or other relevant standards.* | Neutral effect – no plan activities take place. | Discharges from plan activities are subject to regulatory controls at the project level, and are not expected to contribute to the contamination of fish or seafood for human consumption. | As for alternative 2, though discharges may be reduced in line with a potentially smaller number of developments, subject to any spatial restrictions. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities avoid adverse effects on physical and mental health.* | Neutral effect – no plan activities take place. | Plan activities will be subject to Health and Safety requirements and other regulatory controls at the project specific level. | As for alternative 2, though spatial and temporal restriction will reduce the number of people potentially affected by plan activities. |
| **Conclusion** | Neutral effect – no plan activities take place. | Plan activities should not contribute to wider adverse effects on physical and mental health, subject to project level assessment. | Plan activities should not contribute to wider adverse effects on physical and mental health, subject to project level assessment. |

## 5.17.9 Other users and material assets

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Positive socio-economic effects of reducing climate change (outline assessment only) | | | | The economic consequences of climate change outweigh the cost of early abatement through GHG reduction. |
| Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, "sanctuary effects") | | | | Potential significant effects (at strategic level) arise from marine renewable developments due to spatial scale (primarily OWF); location-specific. |
| Other interactions with shipping, military, potential other offshore renewables and other human uses of the offshore environment | | | | Potential significant effects (at strategic level) arise from marine renewable developments due to spatial scale (primarily OWF); location-specific. |
| Accidental events – socio-economic consequences of oil or chemical spills and gas releases | | | | Associated principally with oil & gas exploration and development, gas storage (including $CO_2$); low risk of significant event. |

## Consideration of OESEA2 objectives and guide phrases

### Other users and material assets objectives

- Balances other United Kingdom resources and activities of economic, safety, security and amenity value including defence, shipping, fishing, aviation, aggregate extraction, dredging, tourism and recreation against the need to develop offshore energy resources
- Safety of Navigation
- Reduces waste

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities integrate with the range of other existing uses of the marine environment.* | Neutral effect – no plan activities take place. | Mitigation between plan activities and existing users is already controlled through a range of licensing and leasing conditions, and regulatory controls. The co-location of activities could take place where it is deemed appropriate. | The spatial restriction of certain plan activities would reduce the potential for interactions with other users of the sea. |
| *Plan activities do not result in adverse effects on marine assets and resources.* | Neutral effect – no plan activities take place. | Plan activities should not sterilise areas of potential future use (e.g. potential hydrocarbon resources) or compromise those presently in use (e.g. aggregate extraction areas) through inappropriate siting. | As for alternative 2, though further spatial restrictions based on environmental and socio-economic considerations would lead to a reduced likelihood of adverse effects on marine assets and resources. |

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Plan activities avoid adverse effects on, and contribute to the maintenance of, navigation, including recognised shipping routes, traffic separation and existing and proposed port operations.* | Neutral effect – no plan activities take place. | Potentially significant effects could arise (at strategic level) from OWF and other marine renewables due to spatial scale and the location-specific nature of certain resources, though activities would not take place in specified IMO routeing areas. Existing leasing/licensing measures and regulatory controls (e.g. consent to locate) provide a suitable level of control with regard to the location of activities. | As for alternative 2. The SEA has highlighted, in addition to IMO routeing, a range of indicative navigation routes – suitable shipping traffic surveys would need to be undertaken at the project level to assess the risk to shipping. Spatial restrictions may reduce the overall impact on navigation from plan activities. |
| *Properties and quantities of waste and litter resulting from plan activities do not cause harm to the coastal and marine environment.* | Neutral effect – no plan activities take place. | Through existing regulatory controls, offshore waste is returned to shore and disposed of appropriately. | Through existing regulatory controls, offshore waste is returned to shore and disposed of appropriately. |
| **Conclusion** | Neutral effect – no plan activities take place. | Plan activities have the potential to negatively impact existing users of the sea. There is the potential for co-location of activities where it is appropriate. Activities will not generate waste related impacts at sea or at the coast, nor will they impact upon present or potential marine resources. | Plan activities have the potential to negatively impact existing users of the sea. There is the potential for co-location of activities where it is appropriate. Activities will not generate waste related impacts at sea or at the coast, nor will they impact upon present or potential marine resources. |

## 5.17.10 Cultural heritage

### Consideration of sources of potentially significant effect

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |

| Sources of potentially significant effect | Alternatives | | | Narrative |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access. | | | | The risk of damage associated with the footprint of oil and gas, gas storage (including $CO_2$), OWF and other marine renewables anchoring is mitigated through preparatory survey work. Such survey work has the potential to make positive contributions to identification and interpretation of archaeological remains. |

## Consideration of OESEA2 objectives and guide phrases

### Cultural heritage objective

- Protects the historic environment and cultural heritage of the United Kingdom, including its setting

| Guide phrases | Consideration of Alternatives | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *Activities avoid adverse effects on the character, quality and integrity of the historic and/or cultural landscape, including those sites which are designated or registered, and areas of potential importance.* | Neutral effect – no plan activities take place. | The impact of plan activities on the archaeological resource is largely mitigated through statutory controls and project level assessment, though in the absence of the same level of protection offshore as afforded onshore, site specific surveys would be required to prevent any loss to the marine archaeological resource. | The outcome is the same as for alternative 2, though certain areas would be avoided though primarily for environmental or socio-economic reasons, though these may confer indirect protection to certain areas of interest, for instance intertidal areas. |
| *Plan activities contribute to the archaeological and cultural knowledge of the marine and coastal environment.* | No plan activities and associated surveys take place. | Site surveys associated with plan activities may identify new archaeological material and further knowledge in this area. | Site surveys associated with plan activities may identify new archaeological material and further knowledge in this area, albeit on a more restricted basis than for alternative 2. |
| **Conclusions** | Neutral effect, though the potential for industry led research from plan activities is reduced. | Preparatory survey work will both help to minimise potential damage to marine archaeological sites, and further knowledge in the area. | Preparatory survey work will both help to minimise potential damage to marine archaeological sites, and further knowledge in the area. |

# 6 RECOMMENDATIONS AND MONITORING

## 6.1 Recommendations

The SEA considered the alternatives to the draft plan/programme and the potential environmental implications of the resultant activities in the context of the objectives of the draft plan/programme, the SEA objectives, the existing regulatory and other control mechanisms, the wider policy and environmental protection objectives, the current state of the environment and its likely evolution over time, and existing environmental problems. The conclusion of the SEA is that alternative 3 to the draft plan/programme is the preferred option, with the area offered restricted spatially through the exclusion of certain areas together with a number of mitigation measures to prevent, reduce and offset significant adverse impacts on the environment and other users of the sea.

Substantial progress has been made in implementing the recommendations from previous UK Offshore Energy SEAs (see listing on SEA website[42]) which, together with a wide range of other initiatives have served to improve understanding of receptors and effects.

The following recommendations are made from the OESEA2 process, for amplification and detail see the assessments in Section 5. Many recommendations apply to all the different elements of the draft plan/programme since there is a large degree of commonality in the potential sources of effect from the different industrial activities. The recommendations are listed below under the five categories of: spatial considerations, managing environmental risk, improving the information base, best practice/mitigation and clarification of statutory process. No implied priority is given to the ordering of the recommendations. These recommendations recognise the previous DECC SEA recommendations (SEAs 1-7 and the OESEA, the latter as elaborated in the Post Consultation Report).

The intensity of existing and projected usage of some areas of UK waters is reaching levels that dictate a coordinated approach to spatial matters and activity consenting, in particular where the installation of structures is required. In the southern North Sea for example, existing gas production and storage infrastructure will be augmented by the massive scale of offshore wind farm development projected by Round 3 leasing as well as potential developments for gas production, hydrocarbon and carbon dioxide gas storage, and renewable energy generation included in the current draft plan/programme.

### Spatial considerations

1. As part of the Natura 2000 initiative, further offshore SACs and extensions to SPAs are being identified. Although existing and future Natura 2000 sites are not intended or treated as strict no-go areas for other activities, competent authorities have a responsibility to ensure that favourable conservation status is maintained or restored. It is recommended that developers are made aware at the licensing/leasing stage that SAC/SPA designation may, subject to the conclusions of any Habitats Regulations Assessment, preclude development or necessitate suitable mitigation measures so as to avoid adverse effects on a designated site or species.

2. Efforts are underway to identify offshore Marine Conservation Zones/Marine Protected Areas under the Marine Strategy Framework Directive, OSPAR and the *Marine and Coastal Access Act* (and the Marine Act in Scotland and similar Bill in Northern Ireland).

[42] DECC offshore SEA website - SEA recommendations compilation http://www.offshore-sea.org.uk/downloads/DECC_SEA_Recommendations_Compilation.pdf

Where marine renewable energy and other large footprint developments are proposed that do not conflict with the conservation objectives of an MCZ, opportunities for collocation should be explored which could mitigate potential spatial conflicts with existing users.

3. It is recommended that leasing/licensing and any subsequent consenting of activities must ensure the minimisation of disruption, economic loss and safety risks to other users of the sea and the UK as a whole. In particular, developments, individually or cumulatively, should aim to avoid:

   a) impingement on major commercial navigation routes, significantly increase collision risk or cause appreciably longer transit times (see also recommendation 20 i) below);
   b) causing alteration to the ease and safety of navigation in port approaches or reduce the commercial attractiveness of the ports e.g. through increases in vessel insurance premiums;
   c) occupying recognised important fishing grounds in coastal or offshore areas (where this would prevent or significantly impede sustainable fisheries);
   d) interference with civilian aviation operations necessary to ensure aviation safety, efficiency and capacity, including radar systems, unless the impacts can be mitigated, deemed acceptable, are temporary or can be reversed;
   e) jeopardising national security for example through interference with radar systems or unacceptable impact on training areas unless the impacts can be appropriately mitigated or are deemed acceptable;
   f) causing significant detriment to tourism, recreation, amenity and quality of life as a consequence of deterioration in valued attributes such as landscape, tranquillity, biodiversity and hydrographic features.

4. Reflecting the previous OESEA and the relative sensitivity of multiple receptors in coastal waters, it is recommended that the bulk of new offshore wind farm generation capacity should be sited away from the coast, generally outside 12 nautical miles (some 22km). The environmental sensitivity of coastal areas is not uniform, and in certain cases new offshore wind farm projects may be acceptable closer to the coast. Conversely, siting beyond 12nm may be justified for some areas/developments. As with other developments, detailed site-specific information gathering and stakeholder consultation is required before the acceptability of further wind farm projects close to the coast can be assessed.

5. In areas of prospective interest to multiple energy technologies (including renewable energies, hydrocarbon production, and hydrocarbon and carbon dioxide gas storage) DECC and The Crown Estate should coordinate licensing and leasing decisions, to facilitate and promote the coexistence of uses where practicable, to minimise potential conflicts and industrial land take of the sea, and the inadvertent “sterilisation” of areas.

6. The potential for any further capacity extensions to existing Round 1 and 2 wind farm leases requires careful site-specific evaluation since significant new information on sensitivities and uses of these areas is now available (see also recommendation 4 above) and there is increasing potential for cumulative impacts. Similar considerations apply to other new marine wind farm sites proposed near the coast.

7. For the area to the west of the Hebrides (covered in SEA 7) it is recommended that blocks west of 14 degrees west should continue to be withheld from oil and gas licensing for the present. This recommendation also applies to the deepest parts of the Southwest Approaches. This is in view of the paucity of information on many potentially vulnerable

components of the marine environment, and other considerations. Once further information becomes available, the possible licensing in these areas can be revisited.

## Managing environmental risk

8. The offshore wind and marine renewable industry remains relatively young, with appreciable technological development expected in for example, turbine size, rotation speed, foundation structure, spacing and potentially rotational axis. A firm base of information is required to inform risk assessments and adaptive management, and consequently in respect of ecological receptors a precautionary approach to facility siting in areas known to be of key importance to bird and marine mammal populations is recommended unless evidence indicates otherwise (see also recommendation 20 below).

9. For areas which contain habitats/species listed in the Habitats Directive Annexes, developers should be made aware that a precautionary approach will be taken and some areas may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field.

10. Regarding the effects of noise on marine mammals particularly from piling and seismic survey, previous SEAs have recommended consideration of the establishment of criteria for determining limits of acceptable cumulative impact; and for subsequent regulation of cumulative impact. The SEA is cognisant of the ongoing MSFD Task Group 11 work to determine criteria for an indicator relating to high amplitude, low and mid-frequency impulsive anthropogenic sounds including those from pile driving, seismic surveys and some sonar systems. It is recommended that the findings of this Task Group are reviewed closely with respect to consenting of relevant activities which may result from the draft plan/programme, as well as other activities which generate noise in the marine environment. The establishment of noise criteria and the consenting of activities will require a coordinated approach across different industries and activities, possibly through the future marine planning system.

11. The increasing footprint of offshore renewables (and potential future expansion of gas storage facilities) could result in significant incremental and cumulative visual effects from the shore and at sea. A characterisation and sensitivity study for England's seascapes would complement those completed for Wales and Scotland in relation to offshore renewables, and aid the assessment of possible impacts at a strategic level, particularly cumulative impacts. It is recommended that such a study be undertaken in order to inform subsequent offshore SEAs, future Marine Plans, and other programmes which require a high level consideration of seascape.

12. The nature and uses of the range of estuaries and embayments in which tidal range developments have been and may be proposed vary widely; similarly there is a wide diversity in the type and location of installations to exploit tidal range. Consequently it is recommended that site specific assessments are undertaken before decisions can be taken on potential leasing and the desirability and acceptability of individual projects.

13. A study for the MCA in 2000 assessed incident frequencies and the likelihood of different types of accidental events in causing coastal pollution to guide the placement of tugs (Emergency Towing Vessels) in different locations around the UK coastline. The tugs provide important mitigation of the risk of vessel collision and coastal pollution and the UK arrangements for their provision are due to change from September 2011. Offshore wind farm and other developments over the last decade, and those projected in the near future have, and will, alter the collision and spill risk profile around the UK.

Consequently, it is recommended that periodic reviews of the availability of tugs should be undertaken to ensure that adequate response capability is maintained. Specifically, the location of tugs must continue to be based on periodic strategic assessments of risk.

14. There is wide scale existing use of $CO_2$ for industrial and other applications. However, it is likely that transport of $CO_2$ to offshore storage facilities will be as dense phase or supercritical fluid. The HSE note the limited operating experience in the handling of supercritical $CO_2$ offshore (in comparison to hydrocarbon processing), the current lack of internationally recognised standards and codes of practice specific to dense phase or supercritical $CO_2$ plant and equipment, substantial operational experience, understanding and validated models of the behaviour of $CO_2$ when released from dense phase. Similarly, the environmental implications of subsea accidental releases of dense phase or supercritical $CO_2$ are poorly understood. A range of research is underway (under various auspices) on these issues and it is recommended that the results of these studies are periodically synthesised to provide guidance for consideration of development applications and to allow gap identification.

## Improving the marine management information base

15. Although there has recently been significant survey effort in coastal waters, there is a general lack of modern data on waterbirds in offshore areas. Adequate data on waterbird distribution and abundance is a prerequisite to effective environmental management of activities, for example, in timing of operations to avoid periods of particular sensitivity. A study has been initiated to compare the results of data collected in 3 representative areas of the North Sea with older data; this will inform decisions on the adequacy of the existing information base on waterbirds offshore.

16. The Offshore Vulnerability Index (OVI) to surface pollutants developed by the JNCC should be reviewed in the light of results from recent aerial and boat based bird survey data, and updated if necessary. The potential application of a Species Sensitivity Index (SSI) for wind farms (Garthe & Hüppop 2004) is noted; and it is recommended that consideration is given to the practicality and utility of the development of UK-specific individual SSI and their mapping in UK waters. The recent aerial bird survey data should be incorporated in the distributional database used to map the SSI and an updated version of the OVI to surface pollutants. The existing initiatives to develop Population Viability Analysis for sensitive species should also be progressed, including, if necessary, research to improve the accuracy of inputs to the models.

17. The information collected by offshore renewables and oil industry site surveys and studies is valuable in increasing the understanding of UK waters. The initiatives such as the UKDEAL, Cowrie and UKBenthos databases to ensure that such information is archived for potential future use should be continued and actively promoted during the consenting processes. Similarly, there should be encouragement for the analysis of this information to a credible standard and its wider dissemination.

18. There is little empirical data on the impacts of wave and tidal stream technologies in particular on the array scale effects of energy removal on the physical environment and biotopes; further research is needed into the effects and cumulative impacts of arrays of these devices.

19. There is little information available on the interaction of birds, marine mammals and fish with surface and submerged wave and tidal devices. It is recommended that for the deployment of single devices and small arrays, appropriately focussed surveys of animal activity and behaviour should be undertaken to inform commercial scale deployment risk

assessments and consenting. A strategic and coordinated approach to such research is recommended since the results will be of wider application; research results should be made publicly available where ever possible.

20. Although the information base continues to improve, there remain a number of subject areas for which information is limited and should be enhanced to support future marine spatial planning as well as project-specific consenting. These information gaps include aspects of the natural world and human uses, with regional context and long-term trend data notably lacking. These gaps include:

    a) Seabed topography and texture. For some areas there is excellent data for example from multibeam mapping undertaken variously including by the MCA, BGS and the SEA programme. The NERC Marine Environmental Mapping Programme (MAREMAP) is noted. Significant gaps in coverage remain, and continued effort should be focussed on developing comprehensive coverage of the UKCS, prioritising areas of industrial and conservation interest.
    b) Recent information on the distribution of fish eggs and larvae, and variability in space and time
    c) Detail of bird migration patterns, and variability in space and time including flight heights in different weather conditions
    d) Further understanding of the marine areas routinely used by breeding birds for foraging, in particular those adjacent to SPAs
    e) Better understanding of the ecology of most marine mammal species and in particular important areas for breeding, foraging and resting
    f) Understanding of variations in ambient noise, and other anthropogenic noise sources, must be improved to assess likely effects of additional noise from geophysical survey and construction or operation of marine installations
    g) Data are required on the spatial scale at which marine mammals and their prey respond to well characterised noise sources, and whether this varies according to individual characteristics, behavioural state or other environmental variables
    h) Finer scale distribution of fishing effort, gears and catches for smaller vessels (<15m). A study of fishing effort in Round 3 wind farm zones funded by The Crown Estate and DECC may partially address this.
    i) Precision on the offshore distribution of navigation to allow the identification and maintenance of priority navigation routes (good quality AIS data coverage typically only extends 50km from shore); it is recommended that the identified priority navigation routes are treated as "Clearways" in the siting and consenting of marine developments. These "Clearways" require agreement for all UK waters as well as international coordination for transboundary routes since there are wind farm and other development proposals in the waters of adjacent states
    j) Effects (both short and longer term) on fishing activity in and immediately adjacent to constructed wind farms
    k) The ecological significance of field responses of fish to electromagnetic fields associated with cables; it is recommended that the research needs identified by Gill *et al*. (2009), and Bochert & Zettler (2006) are considered in the context of the Defra review of Round 1 and 2 wind farm monitoring. Similarly, research is needed on the behavioural response of seals to electromagnetic fields (extrapolating from the unexpected results of Forrest *et al*. 2009), to understand if there is a potential for exclusion from the footprints of developments with a network of electric cables such as large marine renewable energy arrays.

## Best practice/mitigation

21. To minimise permanent habitat change and to ensure areas developed as a result of the current draft plan/programme are left fit for previous or other uses after decommissioning, the volumes of rock used in cable armouring, foundation scour protection and pipeline protection must be minimised and there should be active promotion of alternative protection methods through the consenting process.

22. Siting and consenting processes for marine renewable energy developments must remain flexible to allow for technological innovation, including in mitigation measures.

23. To assist developers and the achievement of conservation objectives, DECC and others in Government should encourage the adoption of consistent guidance across the UK on the implementation of Habitats Directive requirements, for example disturbance of European Protected Species (Annex IV species).

24. In areas with vulnerable habitats and species such as cold water coral reefs mitigation may be required for physically damaging activities such as rig/vessel anchoring and discharges of drilling wastes (from hydrocarbon, gas storage or renewable energy related activities). Prior to decisions on activity consenting in such areas, developers should provide a detailed assessment and seabed information so that appropriate site specific mitigation can be defined, for example no anchoring and zero discharge.

25. Depending on the outcome of further investigations of seal injuries currently attributed to ducted propeller nozzles or thrusters, mitigation measures may be required in important areas for seals for longer term vessel operations e.g. facilities installation

26. DECC should seek and give consideration when consenting new oil and gas developments to $CO_2$ emission reduction proposals in relation to disposal of pre-combustion $CO_2$ from gas treatment offshore.

## Clarification of statutory process

27. Carbon dioxide storage in saline aquifers may result in the production and discharge of aquifer water. The *Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005* apply to discharges containing reservoir hydrocarbons and although they have been amended to apply to carbon storage, it is not yet clear whether they will apply to aquifer discharges. The quality of water between aquifers is variable and the concentrations of elements and compounds of potential environmental concern are poorly characterised; a permitting mechanism is needed to ensure that such discharges can be controlled.

# 6.2 Monitoring

The SEA Regulations require the responsible authority for the draft plan/programme to:

> *"….monitor the significant environmental effects of the implementation of each plan or programme with the purpose of identifying unforeseen adverse effects at an early stage and being able to undertake appropriate remedial action."*

In so doing, the Regulations allow for the responsible authority's monitoring arrangements to comprise or include arrangements established otherwise than for the express purpose of complying with the Regulations e.g. monitoring conducted for other regulatory purposes.

The types of relevant monitoring already undertaken or proposed for this SEA fall into three types:

- Emissions monitoring
- Effects monitoring
- SEA objectives monitoring

Each of these is summarised below.

## Emissions monitoring

As required by the various environmental permits and other environmental legislative requirements (see Appendix 5), developers must monitor and report the quantities of solid, liquid and atmospheric emissions, discharges and wastes generated. For the marine renewable energy industry the former FEPA and CPA licensing regime will be replaced from 1st April 2011 with a combined marine licence; for the oil industry, including gas storage this is via the Environmental Emissions Monitoring Scheme and all oil or chemical spills via Petroleum Operations Notice Number 1 (PON 1). As well as monitoring compliance with individual permit conditions the data provides a benchmark which allows performance trends to be monitored over time, and projected increases from a new DECC draft plan/programme to be placed into context. The DECC Offshore Environmental Inspectorate enforce statutory instruments which regulate, using permits with conditions. In support of this, all offshore installations are inspected and operators are encouraged to use Best Environmental Practice (BEP) in all activities. It is anticipated this will also be the case for carbon dioxide storage facilities, except those in Scottish Territorial Waters where other arrangements may apply.

## Effects monitoring

There has been extensive monitoring of the effects of UK offshore oil and gas activities dating back to 1975, and several regional surveys have been undertaken in recent years under the auspices of DECC/OGUK Monitoring Committee, FRS (now Marine Scotland), CEFAS and the National Marine Monitoring Programme. Similarly, there are extensive monitoring programmes undertaken in connection with UK offshore wind farm development and operation, through FEPA (currently) and other permit conditions. There is also a large body of monitoring work on the effects of oil industry operations and a rapidly growing one for offshore wind farms, from other North Sea states and beyond. Studies include operational effects monitoring at field or regional scales, themed research projects and academic studies. This existing monitoring activity is reviewed as part of the DECC SEA process and to date has been found adequate to understand the evolution of baseline conditions in respect of sediment contamination and biological effects across the SEA areas. For other marine renewable energy generation types, monitoring of effects is in its infancy although the body of information is expected to grow through monitoring required by FEPA and other permit conditions. The effects of carbon dioxide transport and storage developments are anticipated to be largely similar to those of offshore hydrocarbon exploration, production and storage. Research studies, and developer initiated and permit required monitoring is expected to provide the basis for effects monitoring of demonstrator and commercial scale developments.

## SEA objectives monitoring

The draft Offshore Energy SEA objectives and indicators were considered during scoping and at the assessment workshop and the stakeholder meetings (see Appendix 2). The agreed objectives and indicators are given in Section 3.5. The SEA indicators will be monitored by the DECC and the SEA team to track SEA performance over time.

Where unforeseen adverse effects are identified the DECC will seek to establish the cause in consultation with the Consultation Bodies/Authorities and other stakeholders. Remedial action will be developed and agreed with relevant parties and implemented as appropriate.

Information on the overall status of the UK seas and trends over time are variously collated for national, European and international initiatives. For example the UK Charting Progress 2 Report was published in 2010 (following the Charting Progress of 2005). Similarly the latest OSPAR Quality Status Report was published in 2010, a decade after the previous QSR. Data from the monitoring of the effects of the implementation of this draft plan/programme would be included in future such reports as well as those reporting on the achievement of good environmental status as required by the Marine Strategy Framework Directive. The conservation status of UK Natura 2000 sites is monitored by the statutory nature conservation agencies and progress with Habitats & Birds Directives implementation, including marine Natura 2000 sites is reported to the European Commission by Defra.

In respect of atmospheric emissions, the Committee on Climate Change was set up under the *Climate Change Act 2008* to support the strategic aims of DECC and the devolved administrations and to independently assess how the UK can optimally achieve its emissions reductions goals for 2020 and 2050. The Committee will advise Government on the level of carbon budgets and will submit annual reports to Parliament on the UK's progress towards targets and budgets to which the Government must respond.

# 7 NEXT STEPS

The OESEA2 Environmental Report and supporting documents are available for review and public comment for a period of 12 weeks from the date of publication. The documents are being made available from the SEA website (www.offshore-sea.org.uk). Comments[43] and feedback should be marked "OESEA2 Consultation" and may be made via the website or by letter or e-mail addressed to:

OESEA2 Consultation
The Department of Energy and Climate Change
4th Floor Atholl House
86-88 Guild Street
Aberdeen AB11 6AR
Fax: 01224 254019
E-mail: oesea2011@decc.gsi.gov.uk

On completion of the public consultation phase a Post Consultation Report will be prepared and placed on the offshore SEA website collating the comments, DECC responses to them and any technical clarifications required.

The Department will consider comments received from the public consultation in their decision making regarding the draft plan/programme.

On adoption of the plan/programme a Statement will be published detailing:

a) how environmental considerations have been integrated into the plan/programme
b) how the Environmental Report has been taken into account
c) how opinions expressed by the consultation bodies and public consultees on the relevant documents have been taken into account
d) how the results of any consultations entered into with other Member States have been taken into account (if required)
e) the reasons for choosing the plan/programme as adopted, in the light of the other reasonable alternatives dealt with; and
f) the measures that are to be taken to monitor for potential significant environmental effects of the implementation of the plan/programme.

[43] **Confidentiality:** Your comments may be made public by DECC in relation to this consultation exercise. If you do not want your name or all or part of your response made public, please state this clearly in the response. Any confidentiality disclaimer that may be generated by your organisation's IT system or included as a general statement in your fax cover sheet will be taken to apply only to information in your response for which confidentiality has been requested. However, please also note that DECC may disclose information it holds pursuant to a statutory, legal or parliamentary obligation, including without limitation, requirements for disclosure under the Freedom of Information Act 2000 and/or the Environmental Information Regulations 2004. In considering any request for disclosure of such information under the Freedom of Information Act 2000 or the Environmental Information Regulations 2004, DECC will consider and make use of relevant exemptions or exceptions where they properly apply and, where relevant, will consider whether the public interest in withholding the information outweighs the public interest in disclosing the information. It is DECC's normal practice to consult and consider the views of third parties where necessary although decisions on disclosure are ultimately taken by DECC. However, any decision by DECC against the release of information can be appealed to the Information Commissioner and ultimately the Information Tribunal. We will handle any personal data you provide appropriately in accordance with the Data Protection Act 1998 and the Freedom of Information Act 2000.

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# GLOSSARY AND ABBREVIATIONS

| Term | Definition |
|---|---|
| 4D seismic | A series of 3D seismic surveys acquired at the same place at different times |
| μg | Microgram(s) |
| μPa | Micropascal(s) (unit of pressure) |
| AA | Appropriate Assessment |
| Abiotic | Refers to nonliving objects, substances or processes e.g. climate |
| Abyssal | Relating to the great depths of the ocean, typically in water depths of 2000-6000m |
| AC | Alternating current where the movement of electric charge periodically reverses direction |
| Acceptable EE% | For tidal stream devices, the limit of percentage energy extraction before any significant environmental effects occur. |
| Accretion | An increase resulting from depositional processes |
| Actiniaria | Sea anemones |
| Aeolian | Wind-borne source |
| AFEN | Atlantic Frontier Environmental Network |
| AGLV | Areas of Great Landscape Value |
| AIS | Automatic identification system (related to navigation) |
| AIS | Air insulated switchgear (related to cables) |
| ALARP | As low as is reasonably practical |
| AMD | Acoustic mitigation device |
| Amnesic Shellfish Poisoning | An illness caused by consumption of shellfish (principally bivalves such as clams, mussels, oysters, snails and scallops) contaminated by poisonous concentrations of toxins produced by dinoflagellate algae. See also Paralytic Shellfish Poisoning and Diarrhetic Shellfish Poisoning |
| Amphipods | Small crustaceans e.g. “sandhoppers” |
| Anadromous | Migrating from marine environments to freshwater rivers to breed |
| Annex I | Under the Habitats Directive, a list of habitats considered to be most in need of conservation at a European level |
| Annex II | Under the Habitats Directive, a list of species considered to be most in need of conservation at a European level (excluding birds) |
| Annex IV | Under the Habitats Directive, a list of ‘animal and plant species of Community interest in need of strict protection’, of which the deliberate capture, killing or disturbance of such species is banned, as is their keeping, sale or exchange |
| Anthropogenic | Relating to/caused by humans |
| AOB | Apparently Occupied Burrows (birds) |
| AON | Apparently Occupied Nests (birds) |
| AONB | Area of Outstanding Natural Beauty |
| AOS | Apparently Occupied Sites (birds) |
| AoSP | Area of Special Protection |
| AOT | Apparently Occupied Territories (birds) |
| AQMA | Air Quality Management Areas |
| Aquaculture | The cultivation of aquatic plants and animals for food or other purposes |
| Array | A collation or series of items |
| Archipelago | A group of many islands in a large body of water |
| ARU | Automated recording unit |
| Ascidians | “Sea squirts”, sedentary marine invertebrates having a saclike body with siphons through which water is drawn and expelled |

| Term | Definition |
|---|---|
| ASCOBANS | Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (United Nations). Now (as of 2008) the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas |
| ASP | See Amnesic Shellfish Poisoning |
| ASSI | Area of Special Scientific Interest |
| ATBA | Areas to be avoided |
| Auks | Diving seabirds of the family Alcidae, characterised by a chunky body, short wings and webbed feet e.g. razorbills, guillemots, puffins |
| Autotrophic | An organism capable of synthesizing its own food from inorganic substances, using light or chemical energy e.g. green plants, algae, certain bacteria |
| B field | Magnetic field component of a cable |
| Bacterioplankton | The bacterial component of plankton |
| Ballast water/sediments | Water (and suspended sediments) put into a vessel to enhance stability |
| BAP | Biodiversity Action Plans |
| Barchan dunes | Type of sand dune found in areas of limited sediment supply with peak currents in excess of $0.4ms^{-1}$ |
| Barrage | An artificial obstruction, such as a dam, built in a watercourse to increase its depth or to divert its flow |
| BAT | Best available techniques |
| Bathymetry | The measurement of the depth of bodies of water |
| Beam trawling | A bottom trawl that is kept open laterally by a rigid beam |
| BECPELAG | ICES study "Biological Effects of Contaminants in Pelagic Ecosystems" |
| Bedform | Seabed features (e.g. sandwaves, ripples) resulting from the movement of sediment, from seabed erosion or deposition |
| Benthic | Relating to organisms living in or on the seabed |
| Benthos | Organisms living in or on the seabed |
| BEP | Best Environmental Practice |
| Bioaccumulation | The accumulation of a substance, such as a toxic chemical, in various tissues of a living organism |
| Biodiversity | The variety of life in all its forms, levels and combinations. Includes ecosystem diversity, species diversity, and genetic diversity |
| Biogenetic Reserve | An area of conservation which includes species for the purposes of genetic preservation |
| Biogenic | Produced by the action of living organisms |
| Biogeographic | Relating to the geographical area characterised by distinctive flora and fauna |
| Biomass | Living material; e.g. the total mass of a species or of all living organisms present in a habitat; usually excluding shell mass |
| Biosphere reserve | Non-statutory protected area representing significant examples of biomes protected for their conservation purposes (UNESCO) |
| Biota | The total flora and fauna of a given area |
| Biotopes | The smallest unit of habitat where all environmental conditions and all types of organisms found within it are the same throughout |
| Bioturbation | Physical disturbance of sediment or soil by organisms, especially by burrowing or boring |
| Birds Directive | Council Directive 79/409/EEC on the conservation of wild birds |
| Bivalves | Marine or freshwater molluscs having a soft body with plate-like gills enclosed within two shells hinged together |
| Block | See *Licence Block* |
| Bloom | Rapid increase in concentration of phytoplankton, often dominated by one species; may be seasonal (spring bloom); natural or anthropogenic |
| Blowout | An uncontrolled flow of fluids from rock into a well, sometimes catastrophically to the surface. May consist of salt water, oil, gas or a mixture of these |

| Term | Definition |
|---|---|
| BODC | British Oceanographic Data Centre |
| boe/day | Barrels of oil equivalent per day |
| Boreal | Relating to the north, particularly forest areas of the northern North Temperate Zone |
| BP | BP is years before present (the present being standardised to 1950) |
| Brachiopods | Marine invertebrates of the phylum Brachiopoda with bivalve dorsal and ventral shells, similar in appearance to bivalve molluscs e.g. lamp shells |
| Brackish | Slightly salty |
| Bryozoans | Small aquatic animals of the phylum Bryozoa that reproduce by budding and form moss-like or branching colonies permanently attached to stones or seaweed |
| BTO | British Trust for Ornithology |
| By-catch | Species caught which are not the targeted species of the fishery; may be retained or discarded |
| Byssus | A tough, thread-like structure by which mussels attach themselves to the substratum |
| CAA | The UK Civil Aviation Authority |
| Caisson | A watertight chamber open at the bottom and containing air under pressure |
| Candidate Special Area of Conservation | Conservation site submitted to the EC for designation by national government, but not yet formally adopted |
| Carboniferous | a major division of the geologic timescale extending from approximately 360-300Ma |
| Carse | A low flat, peat or marsh covered plain, normally estuarine |
| Catenary | An inextensible cord hanging freely from two fixed points with a curved shape |
| CCA | Climate change agreement |
| CCC | Committee on climate change |
| CCL | Climate change levy |
| CCS | Carbon capture and storage |
| CCTS | Scottish carbon capture, transport and storage development study |
| CCW | Countryside Council for Wales |
| CEFAS | Centre for Environment, Fisheries and Aquaculture Science |
| Cephalopods | Marine molluscs including squid, octopus and cuttlefish |
| Cetaceans | Aquatic mammals including whales, dolphins and porpoises |
| CFCs | Chlorofluorocarbons |
| Chemosynthetic | Synthesis of carbohydrate from carbon dioxide and water using energy obtained from the chemical oxidation of simple inorganic compounds |
| Chlorophyll | Photosynthetic pigment found in most plants, algae and cyanobacteria. Sea surface chlorophyll concentration is often used as an index of phytoplankton abundance/primary productivity |
| CHP | Combined heat and power plant |
| CIA | Cumulative impact assessment |
| CITES | Convention on International Trade in Endangered Species |
| Clupeids | Fish of the family Clupeidae including herring, sprat and anchovy |
| CMA | Centre for Maritime Archaeology |
| CMS | Convention on the Conservation of Migratory Species of Wild Animals (also known as the Bonn Convention - 1979) |
| Cnidaria | A diverse phylum of relatively simple aquatic organisms containing specialised stinging cells e.g. jellyfish, anemones, corals |
| $CO_2$ | Carbon dioxide |
| Coastal lagoon | Small, shallow basin which has very low (or negligible) freshwater input |
| Coccolithophorids | Exclusively marine phytoplankton characterised by calcium carbonate plates |

| Term | Definition |
|---|---|
| Coelenterates | Invertebrate animals of the phylum Cnidaria including the jellyfishes, sea anemones and corals |
| Community | A group of animals or plants living or growing together in the same area |
| Continuous Plankton Recorder | A plankton sampling instrument designed to be towed from merchant ships on their normal sailings, with plankton collected on a moving band of filter material (Continuous Plankton Recorder) |
| Contourite | A marine sediment deposited by fast flowing ocean-bottom currents along contours. |
| Copepods | Small crustaceans, usually planktonic |
| COWRIE | Collaborative offshore wind research into the environment |
| CPA | Coast Protection Act |
| CPR | See *Continuous Plankton Recorder* |
| CRC | Climate reduction commitment |
| Creels | Basket-like fish traps placed on the seabed, usually to target crustaceans |
| Cretaceous | A major divisions of the geologic timescale, extending from approximately 146-65.5Ma |
| Crinoid | Echinoderms of the class Crinoidea including feather stars and sea lilies |
| Crustaceans | Arthropods (mostly aquatic) usually having a segmented body and chitinous exoskeleton e.g. crabs, lobsters, copepods |
| cSAC | See *Candidate Special Area of Conservation* |
| Ctenophores | Any of various marine animals of the phylum Ctenophora, having transparent, gelatinous bodies bearing eight rows of comb-like cilia used for swimming |
| dB | Decibel(s) |
| DC | Direct current, where the flow of electric charge is only in one direction |
| DCS | Decompression sickness |
| Decalcified fixed dunes | Mature stages of sand dune succession |
| Decapods | Crustaceans characterised by ten legs, such as lobsters, crabs, shrimps and prawns |
| DECC | Department of Energy and Climate Change |
| Defra | Department for Environment, Food and Rural Affairs |
| Delphinids | Dolphins and porpoises |
| Demersal | Living at or near the bottom of the sea |
| DEPCON | Deposit Consent (included in Pipeline Works Authorisation) |
| Development well | Well drilled in order to produce hydrocarbons from a proven field |
| Diadromous | Migratory between fresh and salt waters (fish) |
| Diamicton | Thick unconsolidated muddy and gravelly unsorted sediments |
| Diarrhetic Shellfish Poisoning | An illness caused by consumption of shellfish (principally bivalves such as clams, mussels, oysters, snails and scallops) contaminated by poisonous concentrations of toxins produced by dinoflagellate algae. See also Paralytic Shellfish Poisoning and Amnesic Shellfish Poisoning |
| Diapir | An intrusion caused by buoyancy and pressure differentials, especially in non–igneous materials, examples being salt domes and mud diapirs |
| Diatoms | Microscopic algae, with cell walls of silica consisting of two interlocking symmetrical valves |
| Dinoflagellates | Minute single-celled organisms, primarily marine plankton, with one or more whip-like organelles (flagella) generally used for locomotion. Approximately half are photosynthetic, and some species may produce toxins |
| Draft Special Area of Conservation | Conservation site which has been formally advised to UK government as suitable for selection as a SAC, but has not been formally approved by government as sites for public consultation. |
| Drifters | Oceanographic instruments released into the water column to obtain information on currents |

| **Term** | **Definition** |
|---|---|
| Drill cuttings | Rock chips produced as a result of drilling |
| Drilling mud | Mixture of clays, water and chemicals used to cool and lubricate the drill bit, return rock cuttings to the surface and to exert hydrostatic pressure to maintain well control |
| dSAC | See *Draft Special Area of Conservation* |
| DSFB | District Salmon Fishery Boards |
| DSP | See Diarrhetic Shellfish Poisoning |
| DTI | Department of Trade and Industry |
| Duel operation mode | Power generation at tidal barrage occurs on both ebb and flood tides |
| Dune slacks | Low-lying areas within dune systems that are seasonally flooded and where nutrient levels are low |
| E&P | Exploration and Production |
| EAC | Ecotoxicological assessment criteria |
| Ebb Tide | The receding or outgoing tide |
| EC | European Community |
| Echinoderms | Radially symmetrical marine invertebrates e.g. starfish, sea urchins |
| Echiurans | Non-segmented worms, usually burrowing |
| Echolocation | Determining the location of something by measuring the time it takes for an echo to return from it |
| Ecosystem | An ecological community together with its environment, functioning as a unit |
| Eddy | A current of water or air, moving contrary to the direction of the main current, especially in a circular motion |
| EEMS | Environmental emissions monitoring system |
| EHS | Environment and Heritage Service (Northern Ireland) |
| EIA | See *Environmental Impact Assessment* |
| Elasmobranchs | Any of numerous fishes of the class Chondrichthyes, characterised by a cartilaginous skeleton and including the sharks, rays, and skates |
| EMEC | European Marine Energy Centre |
| EMF | Electromagnetic field |
| EN | English Nature now Natural England |
| ENAW | Eastern North Atlantic Water |
| Endocrine disruption | Disruption of the hormonal systems of organisms |
| ENSO | El Niño Southern Oscillation |
| Environmental Impact Assessment | Systematic assessment of the environmental effects a proposed project may have on its surrounding environment |
| Environmental Statement | Formal document presenting the findings of an EIA for a proposed project. Issued for public consultation in accordance with various UK EIA Regulations |
| EOR | Enhanced oil recovery |
| EPS | European protected species |
| Epifauna | Benthic organisms that live upon the surface of the seabed |
| EPT | Energy payback time |
| ES | See *Environmental Statement* |
| ESA | Environmentally Sensitive Area |
| ESAS | European Seabirds at Sea |
| ESCR | Earth Science Conservation Review |
| Espoo Convention | The Convention on Environmental Impact Assessment in a Transboundary Context (1991) |
| Estuarine | Of, relating to, or found in an estuary |
| Estuary | The wide part of a river where it nears the sea; normally where fresh and salt water mix |

| **Term** | **Definition** |
|---|---|
| ETV | Emergency towing vessel (tug) |
| Eulittoral | The intertidal band, in-between the low and high water line |
| EUNIS | European Nature Information System; includes data on species, habitats and sites; see http://eunis.eea.europa.eu/introduction.jsp |
| Euphausiids | Commonly known as krill, they are shrimp-like, small marine crustaceans forming an important component of zooplankton |
| Eustatic | A uniform worldwide change in sea level |
| Eutrophic | Rich in dissolved nutrients, photosynthetically productive and often deficient in oxygen during warm weather |
| Evaporites | Natural salt or mineral deposit formed from by evaporation of water |
| Exploration well | Well drilled to determine whether hydrocarbons are present in a particular area |
| Fault | A fracture in the continuity of a rock formation caused by a shifting or dislodging of the earth's crust, in which adjacent surfaces are displaced relative to one another and parallel to the plane of fracture |
| Faunal | The animals of a particular region or time period |
| FEPA | Food and Environment Protection Act |
| Fetch | The un-interrupted distance over which wind acts to produce waves |
| Fjard | Similar to a fjord but tend to be wider and narrower, often with larger numbers of low lying islands. |
| Fjord | A long, narrow, deep inlet of the sea between steep slopes |
| Flaring | The process of disposal by ignition of hydrocarbons during clean-up, emergency shut downs or disposal of small volume waste streams of mixed gasses that cannot easily or safely be separated. |
| Flood tide | The incoming tide |
| Fluvial | Produced by the action of a river or stream |
| Fog | When describing marine weather, visibility less than 1 mile |
| Formation | An assemblage of rocks or strata |
| FPSO | Floating production storage and offloading vessel. |
| Fronts | The interface between water masses of different characteristics, usually temperature and/or salinity |
| FRS | Fisheries Research Services (now Marine Scotland) |
| FSA | Formal safety assessment |
| Fugitive emissions | Very small chronic escape of gas and liquids from equipment and pipework |
| Ga | Billion years ago |
| Gadoid | Fish of the cod family |
| Gastropods | Univalve molluscs, usually with a coiled or spiralled shell e.g. snails, periwinkles, whelks |
| GCR | Geological Conservation Review site |
| Geomorphology | The study of the underlying form, and weathering processes, of rocks and land surfaces |
| GHG | Greenhouse gas |
| Gillnet | Nets that hang vertically in the water, either in a fixed position (e.g. surface or seabed) or drifting, that trap fish by their gill covers |
| GIS | Geographical Information System. A system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data |
| GIS | Gas insulated switchgear (related to cables) |
| Glacigenic | Relating to glacial activity |
| Gravity based foundation | Foundation type comprising a concrete slab stiffened with ribs or a cellular box-like structure, with a central cylindrical or tapered column. Once the structure is in position, sand or rock *ballast* is added to the cellular base and/or the central column in order to increase the total weight. |

| Term | Definition |
|---|---|
| Gravity survey | A survey technique used to measure the gravitational pull of the Earth over an area, to determine the density of the underlying rocks, helping to locate rock formations that might contain trapped oil |
| Grey dunes | Mature dunes, normally vegetated and inland |
| Grilse | A young Atlantic salmon on its first return from the sea to fresh or brackish waters |
| Gyre | A circulatory ocean current |
| Ha | Hectare(s) |
| HAB | Harmful algal bloom |
| Habitats Directive | Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, see *Habitats and Species Directive* |
| Haline / Halite | Salty or regarding salt content. Halite is also used geologically for rock salt |
| Heritage Coast | Sections of coast that are of exceptionally fine scenic quality, substantially undeveloped and containing features of special significance and interest |
| Heterogeneity | The quality of being diverse |
| Heterotrophic | Unable to synthesize food and is dependent on complex organic substances for nutrition |
| Hexactinellid sponges | Sponges with a skeleton made of four- and/or six-pointed silaceous spicules, often referred to as glass sponges |
| HMSO | Her Majesty's Stationery Office |
| Holocene | Geological period since latest glaciation; from about 10,000 years ago to present |
| Holoplankton | Planktonic organisms that spend all developmental stages within the plankton. |
| Holothurians | Sea cucumbers |
| HVDC | High voltage, direct current electric power transmission system. |
| Hydrocarbon | Compounds containing only the elements carbon and hydrogen, (such as oil and natural gas) |
| Hydrodynamic | Of, relating to, or operated by the force of liquid in motion |
| Hydrography | In this context, the study of sea water masses, currents and tides |
| Hydroid | Any of numerous characteristically colonial hydrozoan coelenterates having a polyp rather than a medusoid form as the dominant stage of the life cycle |
| Hypoxia | Deficiency in the amount of oxygen |
| Hz | Hertz (unit of frequency) |
| IACMST | Inter-Agency Committee on Marine Science and Technology |
| IBA | Important Bird Area |
| Iceberg ploughmarks | Ridge/trough features on the seabed created by icebergs |
| ICES | International Council for the Exploration of the Sea |
| ICZM | Integrated Coastal Zone Management |
| Igneous | Rocks formed when molten rock cools and solidifies |
| iE | Electrical field component of a cable |
| IFCA | International fisheries conservation authorities |
| IMO | International Maritime Organisation |
| Imposex | When male sex characteristics, such as the development of male sex organs i.e. penis and/or vas deferens, are stimulated to form on normal female gastropods |
| Infauna | Aquatic organisms (usually animals, but sometimes algae) living within sediments or soil |
| Interglacial | Geological interval of warmer global average temperature separating colder periods (glacials) |
| Internal waves | Within the sea, these are waves generated on the interface between two fluids of different densities |

| **Term** | **Definition** |
|---|---|
| INTERREG | European Commission community initiative that aims to stimulate interregional co-operation in the EU. |
| Intertidal | The coastal zone between high water mark and low water mark |
| Invasive species | A species that is non-native to the ecosystem and whose introduction causes or is likely to cause economic or environmental harm or harm to human health |
| Invertebrate | Animals without backbones |
| IOPP | International Oil Pollution Prevention |
| IPCC | International Panel on Climate Change |
| IPPC | Integrated Pollution Prevention and Control |
| Irish Sea Pilot | A pilot project set up in 2002 following the UK Government Review of Marine Nature Conservation to test the potential for an ecosystem approach to managing the marine environment at a regional sea scale |
| Isopod | Any of numerous crustaceans of the order Isopoda, characterised by a flattened body bearing seven pairs of legs and including the sow bugs and gribbles |
| IUCN | The World Conservation Union |
| Jacket foundation | A tubular steel lattice structure, typically with four legs. The legs are inclined at a shallow angle to the vertical and then braced with smaller diameter horizontal and diagonal members |
| JESS | Joint Energy Security of Supply Working Group |
| JMCs | Joint Maritime Courses |
| JNCC | Joint Nature Conservation Committee |
| Jurassic | A major unit of the geologic timescale, extending from approximately 200-146 Ma |
| Ka | Thousand years ago |
| Kelp | Any of often very large brown seaweeds of the order Laminariales |
| Km | Kilometre(s) |
| Lagoon | Stretch of salt water separated from the sea by for example, a low sandbank |
| Lamprey | Primitive elongated fishes characterised by a jawless sucking mouth with rasping teeth |
| LBAP | Local Biodiversity Action Plans |
| LCA | Life cycle assessment |
| Lewisian gneiss | Metamorphic rocks which have been modified by heat and pressure several times. Up to approximately 3,000 million years old |
| Licence block | Area of the sea which has been sub-divided and licensed to a company or group of companies for exploration and production of hydrocarbons. A Block is approximately 200-250 square kilometres |
| Licensing round | An allocation of licences made to oil companies |
| Limpet | Gastropods, usually marine, with low conical shells |
| LIMPET | Worlds first commercial wave power station located on the shoreline of Islay |
| Littoral | The edge of the sea, but particularly the intertidal zone |
| LNG | Liquefied Natural Gas |
| LNR | Local Nature Reserve |
| Loliginid | Squids of the family Loliginidae, mostly neritic and ranging in size from approximately 3-100cm mantle length |
| Long-crested wave | Ocean surface waves that are nearly two-dimensional, in that the crests appear very long in comparison with the wavelength, and the energy propagation is concentrated in a narrow band around the mean wave direction. |
| Lough | A lake, or bay/inlet of the sea (Ireland) |
| LNG | Liquefied natural gas |
| Ma | Million years ago |

| **Term** | **Definition** |
|---|---|
| Machair | A distinctive sand dune formation, comprising a fertile low-lying raised beach. Found only in western Ireland and the north and west of Scotland |
| Maerl beds | Calcified red seaweeds which grow as unattached nodules on the seabed, and can form extensive beds. Slow-growing, but over long periods its dead calcareous skeleton can accumulate into deep deposits |
| Marine Environment High Risk Area | Area of high environmental sensitivity at risk from shipping |
| Marine spatial planning | A means of bringing together separate sectoral policies with the aim of allocating and managing sea space to minimise conflicts between existing users and between users and the environment |
| MARPOL | The 1973/1978 International Convention for the prevention of pollution from ships |
| MASH | OSPAR working group on Marine Protected Areas and Species Habitats |
| MCA | Maritime and Coastguard Agency |
| MCA | Marine Consultation Area |
| MCS | Marine Conservation Society |
| MCZ | Marine Conservation Zone |
| MDAC | Methane derived authigenic carbonate |
| Medusae | A type of jellyfish |
| Megafauna | Large animals |
| Megaplankton | Very large zooplankton between 20 and 200cm in size e.g. large jellyfish |
| Megaturbidite | A thick, extensive deposit from an exceptionally large mass flow |
| MEHRA | see *Marine Environment High Risk Area* |
| Meiofauna | Small benthic animals |
| Meroplankton | Plankton that spend only part of their life cycle in the water column before settling to the bottom |
| MESH | Mapping European Seabed Habitats |
| Mesolithic | The middle Stone Age, marked by the appearance of small stone tools and weapons and by changes in the nature of settlements |
| Mesoscale | Of intermediate scale |
| Mesozoic | The era of geologic time that includes the Triassic, Jurassic, and Cretaceous periods |
| Meteorology | The study of the processes and phenomena of the atmosphere, especially as a means of forecasting the weather |
| Metocean | Relating to meteorology and oceanography |
| MSFD | Marine Strategy Framework Directive 2008/56/EC |
| Middens | A mound or deposit containing shells, animal bones, and other refuse that indicates the site of a human settlement |
| Miocene | epoch of geologic time extending from approximately 23.0-5.3Ma |
| MITS | Main interconnected transmission system |
| MMPA | US marine mammal protection act |
| MNCR | Marine Nature Conservation Review |
| MNR | Marine Nature Reserve |
| MOD | Ministry of Defence |
| Molluscs | Invertebrates (mainly marine) typically having a soft unsegmented body, a mantle, and a protective calcareous shell. They also include cephalopods e.g. squid, octopus, cuttlefish |
| Monopile foundation | A single, often cylindrical, steel pile driven vertically into the sea bed |
| Moraines | Rock debris transported by glaciers or ice sheets |
| Morphological | Concerned solely with shape |
| Moulting | The routine of shedding old feathers (birds) or hairs (mammals) |

| **Term** | **Definition** |
|---|---|
| MPA | Marine Protected Area |
| MSPP | Marine Spatial Planning Pilot |
| Mt | Million tonnes |
| MTTS | Masked temporary threshold shifts |
| Mudstones | Dark clay rock |
| Multibeam data | Multi beam is a type of sonar that produces multiple acoustic beams in a fan shape across the ocean floor, providing a detailed acoustic image of the sea floor, roughly equal to an underwater topographic map. |
| MW | Megawatt |
| NAC | See *North Atlantic Current* |
| NAEI | National Atmospheric Emissions Inventory |
| Nanoplankton | Planktonic organisms 2-20µm in diameter |
| NAO | See *North Atlantic Oscillation Index* |
| NAS Scotland | Nautical Archaeological Society Scotland |
| National Monuments Record | The national repository for archaeological and historic data |
| Natura 2000 Network | A network of sites, Special Areas of Conservation and Special Protection Areas, of conservation value designated under the EU Habitats and Birds Directives respectively |
| NCR | Nature Conservation Review sites |
| NEAFC | North East Atlantic Fisheries Commission |
| Necropsy | Examination of a body to determine or confirm the cause of death |
| Nematode | Roundworms (free-living or parasitic in plants and animals) |
| Nemertea | Soft unsegmented marine worms |
| Neolithic | A period in the development of human technology that is traditionally the last part of the Stone Age, characterised by the use of crops and domesticated animals |
| Nepheloid layers | Particle-rich layer above the ocean floor |
| *Nephrops* | Abbreviation of *Nephrops norvegicus*, commonly known as Norway lobster, Dublin Bay prawn or langoustine. A small orange-pink lobster found in the north-east Atlantic and Mediterranean Sea. The tail is frequently eaten, often under the name "scampi" |
| Neritic | Relating to the ocean waters between low tide and a depth of approximately 200m |
| NETS | National electricity transmission system |
| NGET | National grid electricity transmission plc |
| NGO | Non-Government Organisation |
| $NH_3$ | Ammonia |
| NI | Northern Ireland |
| NMFS | National marine fisheries service |
| NMMP | National Marine Monitoring Programme |
| NMR | See *National Monuments Record* |
| NNR | National Nature Reserve |
| $NO_x$ | Nitrogen oxide |
| NOEC | No observed effect concentrations |
| Non-statutory | Having no basis in statute or in law |
| NORM | Naturally Occurring Radioactive Material |
| North Atlantic Current | A powerful warm ocean current that continues the Gulf Stream north west before splitting in two west of Ireland. One branch (the Canary Current) goes south while the other continues north along the coast of north western Europe |

| **Term** | **Definition** |
|---|---|
| North Atlantic Oscillation Index | An index based on the pressure difference between the Azores high and the Icelandic low pressure areas |
| NPOA | National Plans for Action |
| NPPG | National Planning Policy Guidelines |
| NSA | National Scenic Area |
| Nursery | A subset of all habitats where juveniles of a species occur |
| Oceanography | The scientific study of the ocean and its phenomena |
| Octocoral | Corals with eight tentacles on each polyp. There are many different forms, which may be soft, leathery, or even those producing hard skeletons |
| Odontocetes | Toothed cetaceans |
| OESEA | Offshore Energy Strategic Environmental Assessment |
| Oligotrophic | Lacking in plant nutrients and having a large amount of dissolved oxygen throughout |
| Ommastrephid squid | Short-finned squid |
| OPEP | Oil Pollution Emergency Plan |
| OPF | Organic-Phase Drilling Fluids |
| Ophiuroids | Brittle stars, Echinoderms of the class Ophiuroidea |
| OPRC | The International Convention on Oil Pollution Preparedness, Response and Cooperation (1990) |
| OREI | Offshore renewable energy installations |
| OSPAR | Oslo and Paris Commission – for the protection of the marine environment of the North East Atlantic (1992) |
| Otter trawling | A demersal trawl that is held open laterally by otter boards or ‘doors’ |
| OVI | Offshore Vulnerability Index |
| OWF | Offshore wind farm |
| PAH | Polycyclic aromatic hydrocarbon |
| Palaeogene | Geologic period extending from approximately 65-23Ma |
| Palaeolithic | The ‘old’ Stone Age (being the period of the emergence of primitive man) about 2.5 million to 3 million years ago until about 12,000 B.C. |
| Paralytic Shellfish Poisoning | An illness caused by consumption of shellfish (principally bivalves such as clams, mussels, oysters, snails and scallops) contaminated by poisonous concentrations of toxins produced by algae (diatoms and dinoflagellates). See also Amnesic Shellfish Poisoning and Diarrhetic Shellfish Poisoning |
| Parasitic cones | Small satellite cones of igneous rock around a volcano where lava has been forced through lines of weakness at the side of a volcano |
| PCB | Polychlorinated biphenyl |
| PEC:PNEC | Predicted Effect Concentration: Predicted No-Effect Concentration |
| Pelagic | Relating to a distribution within (or above) the water column of the sea, generally away from the coast and seabed |
| Pennatulid | Sea pen: colonial marine cnidarians |
| Peri-glacial | Characteristic of a region adjoining a glacier or ice sheet |
| Permian | Geologic period extending from approximately 299-251Ma |
| Petrels | Tube-nosed, pelagic seabirds in the order Procellariiformes |
| Petrogenic | Derived from mineral hydrocarbons |
| PEXA | Practice and Exercise Area |
| Phalaropes | Any of several small wading birds of the family Phalaropodidae |
| Photic zone | The upper layers of bodies of water into which sunlight penetrates sufficiently to influence the growth of plants and animals |
| Physiographic | The study of the natural features of the earth's surface, especially in its current aspects, including land formation, climate, currents, and distribution of flora and fauna (also called physical geography) |

| Term | Definition |
|---|---|
| Phytodetritus | Detritus originating from photosynthetic organisms, typically phytoplankton, in the upper layers of the water column which then falls towards the seabed. Also known as 'marine snow' |
| Phytoplankton | Free floating microscopic plants (algae); including diatoms and dinoflagellates |
| Picoplankton | Tiny plankton between 0.2 and 2μm in size, mostly bacteria |
| PILOT programme | PILOT is the successor to the Oil and Gas Industry Task Force (OGITF) |
| Pingo | Dome-shaped mound found in permafrost areas |
| Pinnipeds | Marine mammals including seals, sea lions and walruses |
| Plankton | Free-floating microscopic organisms |
| Pleistocene | Epoch on the geologic timescale from approximately 1.81-0.01Ma |
| Pliocene | Epoch on the geologic timescale from approximately 5.3-1.8Ma |
| $PM_{10}$ | Particulate matter of less than 10 micrometres in diameter |
| $PM_{2.5}$ | Particulate matter of less than 2.5 micrometres in diameter |
| PMSU | Prime Minister's Strategy Unit |
| Pockmarks | Depressions or craters in the seabed, typically in 0.5-20m in depth and 1-1000m in diameter in the North Sea, generally believed to be formed by the expulsion of fluid (gas or water) through seabed sediments |
| Polychaetes | Annelid worms, chiefly marine |
| Polychlorinated biphenyls | Persistent, toxic organic compounds once widely used in industry |
| PON | Petroleum Operations Notice |
| Possible Special Area of Conservation | Conservation site which has been formally advised to UK Government, but not yet submitted to the EC. |
| Progradation | General term for a coastline which is advancing into the sea |
| Propagation | The process of spreading to a larger area or greater number. |
| Protozoan | Single-celled organisms with a nucleus |
| pSAC | See *Possible Special Area of Conservation* |
| PSP | See *Paralytic Shellfish Poisoning* |
| Pteropods | Small marine gastropod molluscs of the subclass Opisthobranchia with wing-like lobes on the feet |
| Purse seines | A deep curtain of netting that is shot in a circle to form an enclosing cylinder around shoals of pelagic fish |
| PVA | Population viability analysis |
| Pycnocline | Water column layer separating mixed surface and bottom layers during thermal stratification |
| Quadrant | Subdivision of sea area for purposes of awarding licences for hydrocarbon exploration and exploitation. A whole quadrant contains thirty blocks, and is approximately 7,500$km^2$ |
| Quaternary | Geologic time period extending from approximately 1.8Ma to the present |
| R3 | Round 3 offshore wind licensing round. |
| Radionuclide | Natural or artificial radioactive isotope |
| RAF | Royal Air Force |
| RAG | Research advisory group on marine renewable energy and the environment |
| Ramsar sites | Areas designated by the UK under the Ramsar Convention (Convention on Wetlands of International Importance especially as waterfowl habitat) |
| Raptors | Birds of prey, characterised by a hooked beak, sharp talons and good eyesight |
| RCAHMS | Royal Commission on the Ancient and Historical Monuments of Scotland. |
| Red Data Book | Documents the current status of globally threatened biodiversity |
| Refraction | The process by which a wave is bent or turned from its original direction |
| Richter local magnitude | A logarithmic scale which assigns a single number to quantify the size of an earthquake based on measurements of seismic waves |

| **Term** | **Definition** |
|---|---|
| Riverine | Relating to or resembling a river |
| RLD | Regional Landscape Designation |
| RMNC | Review of Marine Nature Conservation |
| RMS | Root mean squared is a measure of the average sound pressure over a given length of time |
| Roche moutonée | Small bare outcrop of rock shaped by glacial erosion |
| ROC | Renewables obligation certificate |
| ROI | Republic of Ireland |
| Ro-ro | Roll on-roll off |
| ROV | Remotely Operated Vehicle |
| ROW | Receiver of Wreck |
| RSPB | Royal Society for the Protection of Birds |
| RSPB | Royal Society for the Protection of Birds |
| SAC | See Special Area of Conservation |
| SAHFOS | Sir Alister Hardy Foundation for Ocean Science |
| *Salicornia* | Glassworts: salt-tolerant plants growing on beaches, saltmarshes or mangroves |
| Salmonids | Fishes of the family Salmonidae which includes salmon and trout |
| Salps | Any of various free-swimming tunicates |
| Salt Cavern | An artificial cavern constructed in a salt deposit by solution mining |
| Saltmarsh | Low coastal grassland normally overflowed by the tide |
| SAM | Static acoustic monitoring |
| Sarn | Relict glacial outwash features composed of ridges of boulder to pebble-size rocky material |
| SAR | Synthetic aperture radar. A form of radar whose defining characteristic is its use of relative motion between an antenna and its target region to provide distinctive long-term coherent-signal variations that are exploited to obtain finer spatial resolution than is possible with conventional beam-scanning means |
| SCANS | Small Cetacean Abundance in the North Sea |
| SCC | See *Scottish Coastal Current* |
| SCI | See *Site of Community Importance* |
| Scottish Coastal Current | A northward flowing current, derived from North Atlantic and Irish and Clyde Sea waters, running along the west coast of Scotland through the Minch and to the west of the Outer Hebrides |
| SCR | Seabird Colony Register |
| SEA | See *Strategic Environmental Assessment* |
| Sea urchin | Spiny, hard-shelled animal that lives on the rocky seafloor or burrows into soft sediments |
| Seamount | Permanently submerged mountains rising from the seafloor, typically formed from extinct volcanoes |
| SEC | See s*helf edge current* |
| SEERAD | Scottish Executive Environment and Rural Affairs Department |
| Seismic survey | Survey technique used to determine the structure of underlying rocks by passing acoustic shock waves into the strata and detecting and measuring the reflected signals. Depending on the spacing of survey lines, data processing method and temporal elements, the seismic is referred to as either 2-D, 3-D or 4-D |
| SEPA | Scottish Environment Protection Agency |
| Sessile | Permanently attached or fixed; not free-moving |
| SFG | Scope For Growth |

| Term | Definition |
|---|---|
| Shelf break | Region of bathymetric change between the gently inclined continental shelf to the much steeper depth gradient of the continental slope |
| Shelf edge current | A poleward flowing current following the shelf edge to the north west of Ireland and west of Scotland |
| Shellfish | General term for commercially fished Molluscs and Crustaceans |
| Shingle | Beach material which is intermediate in size between sand and cobbles |
| Shorebirds | Any of various birds, such as the sandpiper and plover, that frequent the shores of coastal or inland waters |
| Shoreline Management Plan | A document that sets out a strategy for coastal defence for a specified length of coast, taking account of natural coastal processes and human and environmental influences and needs |
| Short-crested wave | A wave that has a small extent in the direction perpendicular to the direction of propagation. Most waves in the ocean are short-crested. |
| Significant wave height | Average height (trough to crest) of the largest one third of waves for a given period of time |
| Silt | A sedimentary material consisting of very fine particles intermediate in size between sand and clay |
| SINTEF database | The SINTEF Offshore Blowout Database is a comprehensive event database for blowout risk assessment |
| Site of Community Importance | Conservation site that has been adopted by the EC but not yet formally designated by the government of a country |
| Sinusoid | A mathematical function that describes a smooth repetitive oscillation |
| Skerries | Small rocky islands, usually too small for habituation, and may be submerged at high tide |
| Slack tide | The period during which no appreciable tidal current flows in a body of water, It usually happens near high tide and low tide, when the direction of the tidal current reverses. |
| SLVIA | Seascape and landscape visibility impact assessment |
| Smolts | A young salmon at the stage intermediate between the parr and the grilse, when it becomes covered with silvery scales and first migrates from fresh water to the sea |
| SMRU | Sea Mammal Research Unit |
| SNH | Scottish Natural Heritage |
| $SO_2$ | Sulphur dioxide |
| SOMAP | Sound of Mull Archaeological Project |
| Sonar | A system using transmitted and reflected underwater sound waves to detect and locate submerged objects or measure the distance to the floor of a body of water |
| SOPEP | Shipboard Oil Pollution Emergency Plan |
| SOSREP | Secretary of State Representative |
| SOTEAG | Shetland Oil Terminal Environmental Advisory Group |
| SPA | See *Special Protection Area* |
| Spawning | The release of eggs of aquatic animals such as bivalve molluscs, fish and amphibians |
| Special Area of Conservation | Areas designated as European Sites (Natura 2000) under the Habitats and Species Directive |
| Special Protection Area | Areas designated as European Sites (Natura 2000) under the Birds Directive |
| Spicules | Calcareous or siliceous skeletal structures that occur in most sponges, providing structural support, as well as deterrence against predators |
| Sponges | Chiefly marine invertebrate animals of the phylum Porifera, characteristically having a porous skeleton and often forming irregularly shaped colonies attached to an underwater surface |
| SR | Scoping report |

| **Term** | **Definition** |
|---|---|
| SSI | Spatial sensitivity index. The combined assessment of spatial distribution of "priority" species with the assessment of sensitivity |
| SSSI | Site of Special Scientific interest |
| SST | Sea Surface Temperature |
| Stac | See Stack |
| Stack | A residual rock pinnacle which marks coastal cliff retreat and/or the landward advance of a rock platform |
| Statutory | Prescribed, authorised or punishable under a statute |
| Stochastic | A random variable |
| Storm surge | A positive or negative storm surge occurs respectively with a rise or fall of water against the shore, positive sometimes produced by strong winds blowing onshore, negative surge sometimes produced by strong winds blowing offshore. Currents produced can predominate over tidal streams and local wind-driven currents |
| Strand | General description of a wide intertidal area usually composed of sand |
| Strategic Environmental Assessment | An appraisal process through which environmental protection and sustainable development is considered in advance of decisions on policy, plans and programmes |
| Stratification | Development of a stable layered density structure in the water column; may be as a result of temperature gradients (thermal stratification) or salinity gradients; often seasonal |
| Sublittoral | Below intertidal, permanently submerged by seawater |
| SVIA | Seascape and visual impact assessment |
| Sweep | Addition of a batch of additive to a drilling fluid; typically of a viscous additive to clear the hole of cuttings |
| SWT | Scottish Wildlife Trust |
| TAC | Total allowable catch |
| Taxa | Taxonomic category or group |
| TBT | Tributyltin |
| Telemetry | The science and technology of automatic measurement and transmission of data by wire, radio, or other means from remote sources, to receiving stations for recording and analysis |
| Thermal stratification | Layering of the water column due to temperature gradients between different depths |
| Thermocline | Layer within the water column where temperature changes rapidly with depth |
| Tombolo | A sand or gravel bar connecting an island with another land mass |
| Topography | Surface features of an area |
| Trawling | Actively pulling a net through the water behind a vessel. Pelagic trawling does not make contact with the seabed; demersal trawling involves the use of a weighted line (footrope) which makes contact with the seabed |
| Triassic | Geologic period extending from approximately 251-200Ma |
| Tripod foundation | A simpler version of the *jacket foundation* with larger member sizes |
| Trophic | Relating to the nutrition/feeding habits of organisms |
| Trophic level | The position occupied by an organism in a food chain or a food web |
| TSS | Traffic separation scheme |
| TTS | Temporary threshold shift |
| Tubificids | A type of annelid worm |
| Tunicates | Chordate marine animals with a cylindrical or globular body enclosed in a tough outer covering e.g. sea squirts |
| Turbidity | Having sediment or foreign particles stirred up or suspended |
| UK | United Kingdom |
| UKCS | United Kingdom Continental Shelf |

| Term | Definition |
|---|---|
| UKOOA | United Kingdom Offshore Operators Association, now Oil and Gas UK |
| UKOPP | United Kingdom Oil Pollution Prevention |
| UNESCO | United Nations Organisation for Education, Science, Culture and Communications |
| Vitellogenesis | Formation of the yolk of an egg |
| VOC | Volatile organic compound |
| VSC | Voltage source converter |
| Waders | Any of many long-legged birds that wade in water in search of food (includes oystercatcher, whimbrel, snipe, avocets, stilts, plovers, sandpipers, godwits, curlews, snipe and phalarope) |
| Wake effect | The region of turbulence immediately to the rear of a solid body in motion relative to a fluid. Under certain conditions a series of vortices may form in the wake and extend downstream. |
| Waterbirds | Group of birds which include divers and grebes, bitterns and herons, rails, crakes and coots, wildfowl and waders |
| Waterfowl | Collective term for all swimming waterbirds including grebes, coots and all wildfowl |
| WBM | Water Based Mud |
| WCA | Wildlife and Countryside Act 1981 |
| WeBS | Wetland Bird Survey |
| WFD | Water Framework Directive (Directive 2000/60/EC) |
| Whelk | Predatory marine gastropod mollusc of the family Buccinidae. |
| White dunes | Embryonic small dunes on the upper beach |
| WHO | World Health Organisation |
| WHS | World Heritage Site |
| Wildfowl | Collective term for all ducks, shelducks, geese and swans |
| Winnowing | The separation of sediment by grain size |
| WNAW | Western North Atlantic Water |
| Wrasse | Fishes of the family Labridae |
| Xenophyophores | Large, single celled organisms of up to 10cm diameter, usually epifaunal benthic deposit feeders |
| Zoanthid | A soft coral |
| Zooplankton | Free floating animals (often microscopic) |
| ZTVI | Zone of theoretical visual influence |