Birds and wave & tidal stream energy: an ecological review

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Executive summary

The UK government has a target for sourcing 15% of energy from renewable sources by 2020. A significant component of this is likely to be produced by wave and tidal stream energy convertors. At present a total of over 30 such projects in UK waters are under operation, testing or development, and large scale investment is being made into the development of suitable technology. Once the technology is developed there will be an influx of applications for the installation and operation of arrays of wave and tidal stream devices, but these will have as yet undetermined impacts on the marine environment. An important component of this environment is seabirds and the UK hosts a seabird assemblage of outstanding international importance. This review is a response to the lack of knowledge on how these emerging technologies will impact on this assemblage, as well as some other potentially affected species, and it aims to use an ecological approach to understand the potential nature of these impacts. Currently, there is very limited experience of operational wave and tidal stream devices at sea, and hence very little information about their impacts on marine birds. It is therefore necessary to only make inferences about *potential* impacts from a theoretical background, based on review of current technological and ecological knowledge.

Marine birds can be potentially affected by wave and tidal stream developments in a number of ways. These may be direct or indirect, adverse or beneficial, temporary or long term. In the majority of cases, little or nothing is known about the likelihood of occurrence or the scale of such an impact. Impacts are likely at three distinct stages in the life of a development, installation, operation and decommissioning, and in this review installation and decommissioning are considered together. During installation and decommissioning, the threats to seabirds will be from collision, disturbance, habitat exclusion and displacement, changes to sedimentary processes, and pollution. These threats will also apply during operation, in addition to potential habitat creation and a possible increase in predation.

While the risks to seabirds from wave and tidal steam devices are largely undefined, this review takes the approach of examining the component parts of such devices and to drawing structural parallels with existing human activities. Such component parts are vessels, sea bed structures, mooring equipment, surface structures, turbines, traps and attractants, either lights or fish aggregating devices. In addition ecological aspects of the receptors, marine birds, are also examined. These are physiology, that is visual and aural sensitivity; geography, breeding, wintering, foraging, rafting and moulting areas, including protected areas; demography, potentially affected birds in the context of their biogeographical population; and foraging ecology, mode and rhythm.

Existing wave and tidal stream devices are described, in generic terms, to reflect the fact that the technology is evolving rapidly, and detailed descriptions of individual devices are likely to be superseded. However, an appendix lists those devices that are currently operational or in development. The review then details the suite of UK marine bird species that will potentially be affected and describes the ecological characteristics of each, in terms of conservation status, distribution, ecology and vulnerability. This section of the review also contains coastal waders, raptors and chough that could be potentially affected, notably by disturbance.

For any development, ornithological surveys will be required, and these surveys will then be used to determine potential receptors and impacts. These surveys should not just be of the immediate development area, but should also provide ecological context, and so the methods used for survey must be carefully considered. As seabird distribution is stochastic, densities and behaviours are highly variable and therefore need to be surveyed with a high spatial and temporal resolution. Understanding the mechanisms of this natural variability is vital for any assessment of whether a development has caused change in bird behaviour or distribution. Therefore, distribution

patterns need to be described in the context of a variety of biotic and abiotic factors and coverage must include as broad a variety of conditions as logistically and safely possible. Surveys may include components of desk study, boat survey, aerial survey and remote sensing.

In this review we have noted that there is a paucity of applicable data on the impacts of wave and tidal devices on birds. This lack of data has implications for understanding the overall impacts of these novel technologies, and for impact assessment of individual schemes. In the final section these knowledge gaps and approaches to filling them are discussed. The key information that is lacking can be summarised as spatial and behavioural. We identify the practical issues for data collection: a need for standardisation throughout the industry, the use and development of remote sensing, further refinement of modelling techniques; refining sensitivity indices, defining the scale of impacts, and cumulative impact assessment.

Introduction

As a signatory to the EU Renewable Energy Directive, the UK government has a target for sourcing 15% of energy from renewable sources by 2020 (EU Renewable Energy Directive 2008). The Carbon Trust has estimated that around one sixth of this target could be provided by marine renewables, that is, wave and tidal stream devices (Carbon Trust 2006). In order to accelerate the progression of the technology needed to achieve this aim; in 2004 the Department for Trade and Industry (DTI) announced a £50 million Marine Deployment Fund to enable full scale performance testing and deployment of the first small arrays of devices. At the same time, the European Marine Energy Centre (EMEC) in Orkney was opened and the Carbon Trust launched its Marine Energy Challenge. The UK and devolved governments have all published Strategic Environmental Assessments (SEA, Directive 2001/42/EC) in preparation for offshore developments. In December 2008, the Scottish Government launched the £10 million Saltire Prize for marine renewable energy innovation. In March 2010, the Crown Estate announced the first commercial wave and tidal stream leasing round, for 1200MW installed capacity, from ten projects in the Pentland Firth and Orkney Waters of Scotland, by 2020 (http://www.thecrownestate.co.uk/our_portfolio/marine/wave-tidal/pentland-firth-orkney-waters.htm). Most recently, the Crown Estate announced a further eight new offshore sites for wave and tidal developments. The majority of these are in Scottish waters and range from small technology test schemes, for short-term installation, to commercial projects each with up to 30 MW potential generating capacity. This brings the total to over 30 projects in UK waters.

Clearly, once the technology is developed there will be an influx of applications for the installation and operation of arrays of wave and tidal stream devices, which will not only be novel in design, but will have as yet undetermined impacts on the marine environment. An important component of this environment is seabirds and the UK hosts a seabird assemblage of outstanding international importance. This review is a response to the lack of knowledge on how these emerging technologies will impact on this assemblage, and some other potentially affected species, and it uses an ecological approach to understand the potential nature of these impacts.

The review is structured as follows:

There are five sections; a theoretical background, an evaluation of device types, ornithological species accounts, a description of survey methods and the identification of information gaps and research requirements. The first describes the effects of marine energy developments in functional terms, rather than specific terms, detailing the effects, the sources of these effects and the receptors (ie birds) of the effects. The effects and the sources of these effects are described in terms of ecological impact, rather than mechanical category. The receptors are described in terms of the interaction of physiology, geography, demography and ecology, with the effects of the energy device and infrastructure.

The second section reviews wave and tidal stream marine energy devices. As this industry is evolving and changing rapidly, these devices are described generically, rather than as specific models.

The third section presents species accounts for those birds most likely to be affected by wave and tidal stream devices, either directly or indirectly, with reference to the theoretical background described in section one. As well as UK seabirds, other species – several coastal waders, cliff nesting raptors and chough - are included here because of the potential for disturbance from construction and maintenance vehicles and personnel on the shore. Best practice measures including timing, screening and containing onshore activity will be sufficient to mitigate for disturbance effects in most cases. Bird species nomenclature is given as the English vernacular, with the scientific name given in the species account heading (vernacular names are from 2010 BOU update see http://thebritishlist.blogspot.com/2009/01/british-list-1-jan-2009.html). The fourth section reviews and evaluates current survey methods for Environmental Impact Assessment (EIA), and the fifth section identifies knowledge gaps and makes recommendations for further research.

There are four summary tables in the appendix. The first of these summarises the vulnerability of each species to the threats generated by marine renewable devices based on the ecological information presented in sections one and two. The second table summarises how different functional elements of the devices may generate the threats detailed in the first table and in the text. The purpose of these tables is to summarise the text; it must be stressed that relevant text also should be read, as much that is summarised is, by necessity, subject to caveats and assumptions which are presented in the text. The third table lists devices that currently are operational or under development, with web links to further information. The final table provides guidance on information requirements and suitable methodologies for EIA, and is organised in response to a series of questions to which the EIA should provide answers.

1. Theoretical background

Currently, there is very limited experience of operational wave and tidal stream devices at sea, and hence very little information about their impacts on marine birds. Instead of such direct information, this section makes inferences about *potential* impacts from a theoretical background of the type of effects likely, the probable sources of these effects and likely key receptors of these effects, namely birds, (although marine mammals and fish will also be receptors, they are not included in this review). These inferences will be derived from our existing knowledge of marine processes, engineering and bird ecology and behaviour. More detail on specific devices and species is presented in Sections 2 and 3.

Effects

Marine birds can be potentially affected in a number of ways. These may be direct (eg from the device itself) or indirect (eg reducing visibility by increasing turbidity), adverse (eg collision mortality) or beneficial (eg creation of foraging habitat). Additionally, the impacts may be temporary or long-term and last the lifetime of the device. In most cases, little or nothing is known about the likelihood of occurrence or scale of impact. Furthermore, an understanding of the cumulative effects is crucial. Generally, it is assumed that the direct effects of decommissioning a site will be similar to those associated with construction (Gill, 2005), so they are considered together here.

Installation/Decommissioning

The greatest impacts likely during construction and decommissioning are through direct habitat change or destruction, noise and vibration, and altered sedimentary processes (Inger *et al.*, 2009).

Collision

During installation and decommissioning, the primary collision risk will be with vessels, such as boats and helicopters. These are likely to be stationary or moving slowly in comparison with other commercial vehicles. While collisions with installation vessels appear no more likely than with other marine vessels no empirical data exist to evaluate this (Wilson *et al.*, 2006), and the numbers of vessels and frequency of traffic during installation will increase the level of risk. Collision could occur in two situations; either the bird flies or dives into the vessel, or the vessel collides with for example, rafting birds. Given that data are sparse, relating to any types of collisions with these species, the most appropriate analogue may be wind turbines, albeit they protrude above the water surface to a far greater extent. The most applicable data comes from the Danish offshore wind energy industry. For example, radar studies carried out as part of EIA, show that birds (predominantly eiders) entering offshore wind farms tend to re-orientate to fly down between turbine rows, minimizing their risk of collision (Petersen et al, 2006). This study also showed that many birds, particularly migratory waterbirds, avoid the wind farm entirely often at considerable distance. Data gathered from an offshore wind farm in Dutch waters also suggests that at least some species of birds may largely avoid wind turbines (Stewart *et al.*, 2007; Lindeboom *et al.*, 2011). In the context of collision with vessels, or indeed the wave and tidal stream devices themselves, with a lower profile on the sea surface, such avoidance is likely to be at closer range. In the case of collision with vessels, we are constrained by the lack of data, although it can be assumed that rafting species, particularly, those that do so at night, are at risk of being collided with by installation vessels (Daunt, 2006). Similarly, since the danger of collision is potentially greater at night or during periods of poor visibility, it is likely to increase for species that spend a higher proportion of time flying at night. Conversely, the experience at some onshore wind farms, where collisions for some species occur in fine weather when wind speeds are very low, (Barrios and Rodriguez, 2004) suggests that poor visibility does not encompass all collisions, and that manoeuvrability and local environmental factors (topography and wind profile in this onshore wind farm research example) influence risk. In the marine environment, these local environmental factors could be transposed to currents and water turbulence. Birds that feed on discards are known to be actively attracted to boats, which may increase their risk of collision or entanglement.

Disturbance/habitat exclusion/displacement

While there are data demonstrating that construction noise will have effects on other taxa such as mammals and fish, which can detect pile driving noise over considerable distances, there are very few data on birds. Levels of marine noise are likely to be considerably greater during device installation, especially from pile driving, than during operation. There are however mitigation measures to attenuate noise levels from pile driving which are estimated to reduce the distance at which it could affect marine mammals by at least 66% (Nehls *et al.*, 2007), and so presumably to reduce the effect on birds. The most likely response of birds to noise disturbance is avoidance; for example underwater noise has been used to prevent waterfowl from foraging (Ross *et al.*, 2001). Noise also may have an impact on fish prey species. The ability to detect higher frequency noise in fish is strongly linked to the presence of a swim bladder and whether it has a connection with the ear (Wahlberg and Westerberg, 2005); those with both, such as clupeids have the greatest ability, those with neither such as flatfish have a low ability, and those with an unconnected swimbladder, such as gadoids (eg cod) have a moderate ability. It is however, unclear what the effect may be, whether restricted to masking communication and orientation signals or causing physiological damage or avoidance reactions. In turn, the implications of any impact on the seabird populations are unclear.

Physical disturbance is likely to be a temporary impact, albeit effects may continue for several years, representing a physical or visual intrusion. The most probable response will be avoidance. While this will not have a direct impact on mortality, there may be implications for foraging success, hence for individual survival and breeding success, for instance because of reduced provisioning rates. The magnitude of impacts will be determined in part by the extent and suitability of alternative habitat, and so the cumulative impact of multiple developments is an extremely important consideration.

There are increasing, although still scant, data on the response of certain species to disturbance; for example common scoter are sensitive to disturbance caused by moving vessels at a distance of up to 2km from the vessel (Kaiser *et al.*, 2002; Kaiser *et al.*, 2006) and seem to show no habituation to these vessels (Schwemmer *et al.*, 2011). In recognition of the lack of data, an approach was developed to quantify disturbance by ship and helicopter traffic, allocating subjective scores to different bird species' escape and avoidance behaviour, based on the experience of marine bird surveyors (both ship and low-flying airplane based), subsequently modulated by a team of experts, to produce a sensitivity index (Garthe and Hüppop, 2004). This approach suggested that species differed greatly in their sensitivity index; black-throated and red-throated divers were considered most sensitive and the least sensitive were black-legged kittiwake, black-headed gull and northern fulmar. Since the disturbance from installation (and decommissioning) is not prolonged in the case of individual devices or small arrays, there is unlikely to be habituation, although this may, or may not, be the case with larger arrays. The installation of submerged fixed structures such as support piles and anchor plinths and associated underwater substations and power cables are likely to cause considerable disturbance to the seabed, although this will depend to a large extent on the method of installation, for example trenching for cables can cause disturbance stretching from the device itself to the shore. Sediments mobilized during installation may smother neighbouring habitats (Gill, 2005), and negative effects could extend beyond the development area. Resuspension of organically rich sediments is likely to reduce available oxygen, at least temporarily, and there also exists the potential for disturbance of pollutants such as heavy metals. The disturbance may be similar to that from fishing and dredging, which have been shown to alter the local biota, both in terms of diversity and density (Blyth *et al.*, 2004). After disturbance, recolonisation can take from a few months to many years, depending largely on the stability of the substrata, the installation methods used and whether any mitigation measures have been applied.

Sedimentary processes and pollution

Pollution can occur through the disturbance of contaminated sediments, discussed below, and through oil and hydraulic fluids leaking or leaching from the construction vessels and associated plant. Such pollution can have the effect both of feather oiling and negative changes to water quality.

Fine-grained benthic sediments tend to accumulate contaminants, reducing the toxicity to aquatic organisms. The physical disturbance of these sediments can lead to changes in the chemical properties of that sediment, and can in turn stimulate the mobilisation of contaminants within it (Eggleton and Thomas, 2004). This mobilisation and subsequent exposure to a different chemical environment can result in the transformation of contaminants into more bioavailable or toxic chemical forms (Sturm *et al.* 2002). While the processes are poorly understood, any increase in toxic contaminants will have potential lethal or sub-lethal effects on seabirds, and changes in the availability of nutrients could affect benthic communities and thereby have an indirect impact on seabirds.

Disturbance of the seabed during construction will result in an increase in suspended sediment levels and consequent increase in turbidity. Risks of collision with installation machinery may be increased under such conditions, although the response to other non-visual cues, such as vibration and noise, may compensate for the lack of visibility. However, the use of non-visual cues would require response recognition and learning, by which time collision already may have occurred. Furthermore the reduced visibility caused by increased turbidity could have adverse effects on foraging success; marine birds are thought to have a high sensitivity to reductions in visibility (Strod *et al.*, 2008).

Operation

Collision

This is considered the key potential effect during operation. There have been several studies of collision risk with both onshore and offshore wind turbines (Stewart *et al.*, 2007; Drewitt and Langston, 2008; Petersen and Fox, 2008; Langston, 2010) although wave and tidal stream devices will have a much smaller collision window than wind turbines (Grecian *et al.*, 2010). The risk is a novel one, and therefore it is impossible to accurately quantify based on our current knowledge. Collision may occur above or below the water surface.

The above water profile of wave and tidal stream devices is considerably lower than that of wind turbines. The capacity to avoid devices and the risk of collision with them will be a function of species, behaviour, flight height and size of bird (Grecian *et al.*, 2010) and it has been argued that nocturnal and crepuscular species will be more affected (Daunt, 2006). Conversely, such species often have enhanced visual capability, and this may make them quicker to respond to the presence of devices. However, many birds will modify their behaviour in response to perceived threats, for example in some situations eider forage nocturnally as an anti-predator strategy (Merkel and Mosbech, 2008), and may not be as physiologically adapted for new behaviour. Other ecological factors may also influence collision risk, such as age and reproductive stage (Henderson *et al.*, 1996).

There is within the literature widespread consensus that a paucity of information exists regarding collision risk of animals with underwater structures (Wilson *et al.*, 2006; Inger *et al.*, 2009; Grecian *et al.*, 2010), and that such collisions are more poorly understood for birds than other species groups (Wilson *et al.*, 2006). This lack of knowledge has meant that few mitigation measures have been developed. However, it is possible to make some generalisations. The response of birds will depend on their detection of a device and any associated structures, eg anchorage; whether it is detected above or below the water surface and how close it is before detection. When below surface devices are visible above the surface it is likely that they will be avoided. As such, devices closer to the surface are more likely to be detected and therefore avoided. Devices that are not detected until the bird itself is below water will be avoided to some extent, dependent on when detection occurs, in turn influenced by the nature of the environment and foraging behaviour, eg pursuit hunters or divers may be have less time to react, but be more agile. The risk of collision may be increased if the devices alter the characteristics of the current, especially if such changes create new foraging opportunities, since this may impact on the manoeuvrability and underwater swimming agility of birds. The burst speed of birds, while considerably slower than the speed of the tidal turbine blade tip (Fraenkel 2006), is thought to be fast enough to enable escape from the path of the blades in many situations (Wilson *et al.* 2007). However, this does assume that birds detect the presence of the device in sufficient time, likely to depend on the bird's behaviour and visual perception of objects around them (Martin, 2010; Martin and Shaw, 2010).

Fixed structures are less likely to be risky than mobile structures, such as energy converters, anchor chains and cabling. The risks will be greater when the birds are diving for prey, therefore the highest risk is when devices are located within the foraging range of a species. Since the greatest risk is when the device is within the dive profile of a species, the risk to the largest number of species will occur when a device is located within the dive depth range. Conversely a device with a surface presence is likely to be detected before a dive commences, unlike one below surface, which may not be detected in time for avoidance behaviour to be initiated.

A number of structural elements of offshore energy devices, particularly turbine housing, articulations and mooring equipment, may entrap and kill seabirds. In studies of the impact of fisheries on seabirds, pursuit diving species, particularly alcids, are most at risk of entrapment in gill nets and other fixed gear (Tasker *et al.*, 2000). Experience in the USA indicates that fisheries bycatch in gill nets is a significant cause of mortality in divers along the Atlantic seaboard (eg Warden 2010).

Disturbance/habitat exclusion/displacement

Unlike tidal barrages, which can cause significant habitat losses (Clark, 2006; Fraenkel, 2006), other offshore renewable devices are thought to only cause such losses when inappropriately sited in relation to certain taxa, such as seaduck (Inger *et al.*, 2009). These will vary depending on the type and size of installation, location and whether they are situated in degraded or pristine habitat.

However, although they may directly remove minimal habitat they may exclude birds by creating a physical or perceptual barrier, for example through producing noise, resulting in avoidance, and consequent exclusion from food resources. There is now evidence from operational offshore wind farms that they cause a proportion of individuals and species to avoid the local area where the scheme is placed (Garthe & Hüppop 2004; Desholm & Kahlert 2005; Lindeboom *et al.* 2011). In particular, divers and seaduck have been displaced by 2-4 km from wind farm areas. Experimental studies at Tunø Knob (Denmark) offshore wind farm and the area up to 600m beyond the wind turbines, indicate that wintering common eiders reacted to the visual presence of the wind turbines (Larsen and Guillemette, 2007). Common eiders were observed to reduce both the frequency of flights and landings on the sea surface at a distance of about 200m away from the turbines, even in the presence of a decoy flock situated both within and outwith the turbine envelope. However, there is evidence that, at least for common scoter, birds displaced during the first few years post-construction have now resumed occurrence within the wind farm area at similar densities to those surrounding the wind farm; it is unclear to what extent food availability may have affected use of the wind farm area (Petersen & Fox 2007). By contrast, post-construction monitoring at Kentish Flats, Thames (Percival, 2009; Percival, 2010), Horns Rev I, Denmark (Petersen *et al.*, 2006), and Gunfleet

Sands, Thames (Percival, 2010) indicate that red-throated divers are either absent or occur at substantially reduced density within the wind farm footprint and a buffer of at least 1km, by comparison with the situation prior to wind farm installation. This wider displacement is thought to be due to perception of the turbines or disturbance due to maintenance vessels. It is possible that the same would be the case with tidal and wave schemes, in particular because they are likely to overlap with favoured foraging areas of many species of marine bird (Daunt *et al.* 2006). The arrays will potentially cause a net loss of foraging area and potentially removal of prey resource (depending on the method of device attachment to the seabed). Habitat exclusion may cause increased competition for prey species in adjacent areas and could therefore have knock-on effects on adjacent populations of birds. There may be immediate impacts on individual foraging, or more far reaching consequences for bird populations.

Operational noise is likely to be considerably less than installation noise; however, this will depend on device type and environmental conditions. For example measurements of background underwater noise at the Strangford Narrows region of Strangford Lough, Northern Ireland, found high levels of high frequency noise, probably due to the fast tidal flow (Nedwell and Brooker, 2008). Above the surface of the water there is some evidence that noise may assist in avoidance (Inger *et al.*, 2009). There is evidence of the disturbance of breeding seabirds by human recreational activity (Beale and Monaghan, 2004) although it is unclear to what extent this is due to noise or visual cues. Underwater noise has been used to prevent waterfowl from foraging, in order to reduce commercial losses of farmed molluscs (Ross, Lien & Furness 2001). Very little is known about the importance of hearing underwater to birds and whether noise can disorientate them or adversely affect their foraging success. Marine noise and more especially vibration will potentially have a greater impact on fish, and could thus alter the distribution of fish prey around device arrays. Studies have found that noise, such as from shipping activity, can cause an avoidance or attraction in fish (Thomsen *et al.*, 2006). While it has been suggested that such impacts are likely to be limited to the immediate vicinity of the devices (Faber Maunsell & Metoc 2007), the sensitivity of fish to noise is unknown for most species, particularly those of importance to seabirds, such as sandeel *Ammodytes marinus*, and for those with a swim bladder, such as clupeids.

Sedimentary processes and pollution

The area around any moving parts of energy devices will be characterized by an increase in turbidity, associated with alterations of sedimentation patterns (Langhamer *et al.*, 2010). Marine birds are likely to be affected by a reduction in visibility caused by increased turbidity around the devices, and therefore potentially an increased collision risk. However, given that the devices are likely to be placed in high-energy environments where any disturbed sediment is likely to be dispersed rapidly, and this impact is likely to be limited to the immediate vicinity of the devices, an increase in turbidity is considered to be of negligible significance (Faber Maunsell & Metoc 2007). An increase in turbidity can cause changes in foraging strategy, for example an increase in communal foraging has been described in cormorants in conditions of higher turbidity (Vaneerden and Voslamber, 1995), however this is unlikely to occur in response to the scale of turbidity changes associated with individual devices.

There is a potential risk of toxic compounds being leached from antifouling paints, hydraulic, or lubricating fluids. Sacrificial anodes, where a metallic electrode is allowed to corrode in sea water to protect other metal components from corrosion, also release potentially toxic materials. However, although a small number of both wave and tidal devices are likely to use antifouling paints, the quantities and toxicities associated with sacrificial anodes and antifouling coatings are generally expected to be extremely small (Faber Maunsell & Metoc 2007).

Marine birds are particularly sensitive to contamination by oil-based compounds, which cause the plumage of birds to lose its waterproofing properties (Wernham *et al.*, 1997) and when ingested can cause considerable physiological damage. Such oil-based pollutants may be included in hydraulic fluids. Those species that spend a large proportion of time on the sea surface relative to time spent flying and on land (eg divers and auks) will be at greater risk.

Industry guidelines (Carbon Trust 2005) exist to encourage developers to minimise the risks of hydraulic fluid leakage. The design of most devices is such that at least two seal or containment failures are required for the leaking fluid to reach the sea. Many devices avoid having mechanical components in contact with the sea, although this is not possible for devices such as rotors, which have to be in contact with the sea to operate. In such devices, leakage rates are likely to be small, as part of the approach to creating low maintenance devices will include the design of devices that do not require frequent oil replacement or grease injection into bearings. Where a design will result in some unavoidable seepage to the sea, the selection of biodegradable options for both hydraulic and lubricating oils and greases is a legal requirement.

Habitat creation

Man made objects in the marine environment are not necessarily negative in their effects; they also create new habitats, the effects of which can be positive as well as negative. However, it is extremely unlikely that their situation in undegraded habitats could produce ecological benefits. Above the surface they are frequently used as roosting points, below the water they act as artificial reefs. Effectively they both increase the amount of hard substrate and the three dimensional heterogeneity, both acting as attractants to marine organisms, and potentially increasing foraging opportunities for birds. However, such positive effects can be counterbalanced by the fact that any attraction will increase the probability of a negative interaction, such as collision. Also the species composition of these artificial reefs may not be the same as natural reefs and their presence may influence the species' diversity of adjacent habitats, promoting the establishment of non-native and/or harmful species (Langhamer *et al.,* 2009).

There is now preliminary evidence for the foundations of marine energy devices acting as artificial reefs, within which the suite of species was dominated by resident species whose diversity increased with time (Langhamer *et al.*, 2009). For the piscine species, it remains unclear whether this was a genuine increase, rather than redistribution because of the refuge from fishing activity which, while still a valid positive effect, is less significant.

Predation

Predation by mink of ground nesting birds, such as those in seabird colonies, has had considerable impact on the local populations of some species, for example terns in the Scottish Western Isles (Ratcliffe *et al.*, 2008). Arrays of devices with surface structures could provide a substitute for islet chains and have the potential to increase the risk of mink accessing offshore islands that were previously too far (>2 km) from shore. While there is no documented evidence currently to indicate that mink would use man-made structures as stepping stones in order to colonise offshore islands (Faber-Maunsell and Metoc, 2007), it remains a possibility. Another indirect impact might be the concentration of fishing effort in other sea areas – potentially reducing prey availability either through removal or increased damage to seabed habitats.

Sources (Wave and Tidal Stream Devices)

The definition of the sources of threats by mechanical or engineering type is unlikely to provide ecological insight and therefore to facilitate the assessment of any risks they pose to birds. The nature of the devices is also likely to change during their development. Rather, following Wilson et al 2007, it is more useful to identify risks from the standpoint of installation and maintenance vessels and machinery, and component parts, drawing structural parallels with existing human activities. The generating device will usually combine several of these components (Appendix II).

Vessels

Vessels and other mobile machinery will be a source of risk both during installation and decommissioning and during maintenance and repair of the devices during the operational phase. There is an important distinction between maintenance and repair, in that maintenance can be scheduled around predictable ecological events, such as migration or chick provisioning, whereas the timetable of repair cannot be predictably scheduled, and can therefore have a greater impact during sensitive periods. The risk during operation is likely to be least, since the intensity of use will be restricted to maintenance and repair only, although repairs will have to be carried out promptly and there will therefore be less scope for any moderation of impact through scheduling. The risks from such vessels have been described in other sections.

Seabed structures

These will be used in a variety of generators, most commonly as vertical support piles. Fixed structures are less likely to create collision risk than mobile structures. Collision risks are most likely to pose the greatest risk in areas of strong water movement, such as areas of strong tidal flow or wave motion (Wilson *et al.*, 2006). While larger structures may create a larger surface area for collision, conversely the greater change in flow characteristics, and greater visibility, of larger structures is likely to mean they will be easier to detect and avoid. Oil platforms are known to alter the three dimensional structure of the seabed and create artificial reefs and augment local levels of benthic fauna and flora, zooplankton and fish (Wiese *et al.*, 2001), and fixed submerged structures for marine renewable devices are likely to behave similarly.

Mooring equipment

Any generator not directly fixed to the substrate will require mooring equipment, particularly surface floating devices. Static anchor blocks and plinths are unlikely to pose any great risk, although considerable disturbance is probable during installation. However, cables and chains extending up from the anchors will create an obstacle to diving birds and a consequent collision risk. In contrast to the larger structures described above while the collision window will be smaller, the detectability will be lower. The experience from the avian bycatch of trawl fisheries suggest it is long winged species that forage aggressively with their wings outstretched, such as larger petrels, that are most at risk of collision with cables.

Surface structures

Surface, and subsurface structures will be either fixed to the seabed via support piles or anchored via mooring equipment, and may be individual units or multiple articulated components. It is likely they will be used, to some extent, as landing or roosting sites; such refuges are rare in marine habitats and therefore seabirds will congregate on them. As such, if there are exposed moving parts or articulations there is a risk of injury to roosting birds, although this will be no more so than with existing marine structures, and is likely to be only a minor problem, dependent on the scale of arrays as deployment increases. Such structures also have the potential to act as Fish Aggregating Devices (Inger *et al.*, 2009), see below.

Turbines

Wave and tidal stream devices with rotating turbines are likely to pose a greater threat to birds than those without such blades. While in many ways analogous to both wind turbines and the propellers of ships and boats, the turbines of wave and tidal devices spin at considerably slower speeds, at or below 12 ms^{-1}, than such analogues, and therefore are less likely to cause injury. The majority of devices have fairly narrow turbine blades, which will also reduce the risk of collision injury. However, the experience of bird collisions with onshore turbines has sometimes been counterintuitive; some raptors are more likely to have fatal collisions with turbine blades in conditions of low wind and good visibility (Barrios and Rodriguez, 2004). Although this situation may be specific to soaring raptors, it illuminates the unpredictable nature of the impacts from novel technologies. Key to the impact will be whether the blades are semi-shielded or fully shielded within a larger device or open, the latter particularly associated with tidal stream devices.

Traps

Several structures in combination can create traps, restricting options of movement thereby leading to a higher risk of collision. Birds could potentially dive into these structures and with movement restriction be unable to avoid collision. Examples of traps include ducts, venturi devices (see section 3) and combinations of turbines and surface corrals, and there is particular concern about venturi devices and turbines mounted in ducts.

Attractants

Some seabirds are attracted to large offshore structures (Wiese *et al.*, 2001), and there is a well-recorded phenomenon of higher concentrations of seabirds around platforms. The most important reasons may be the creation of a roosting refuge at sea and increased food availability around the structures.

Fish Aggregating Devices (FADs)

There is a well established body of literature detailing the tendency for a large number of fish species to aggregate around and beneath floating objects (Castro *et al.*, 2001). It is extremely likely that energy generating devices attached to the seabed but free to float on the surface will act as such FADs. It is unclear whether the effects of this on seabirds will be positive or negative.

Since the greatest possibility of underwater collision is when devices are located within foraging areas there exists a potential problem in the creation of good foraging areas around devices, as FADs would do; in other words attracting fish to a device would increase the risk of collision or other terminal effect. However, there is some evidence that FADs do not attract larger numbers of piscivorous seabirds (Jaquemet *et al.*, 2004), although this evidence is not as well established as the link between floating objects and fish. FADs act to concentrate, rather than increase recruitment to fish stocks so may not be directly beneficial to the fish population and consequently seabirds. However it has been argued (Inger *et al.*, 2009; Blyth-Skyrme, 2010; Grecian *et al.*, 2010) that because such indirect FADs will attract fish away from commercial fisheries to areas where, as a consequence of the presence of energy generating devices, commercial fish harvesting will be excluded, that there will be an overall ecological benefit. However, this would only be a benefit to birds if these fish were prey species, had not been attracted from, and thereby reduced, elsewhere, and the birds were not displaced by the FADs.

Lights

Lights and flares are known to attract birds, for example storm petrels often fly directly into lights (Wiese *et al.*, 2001; Rodríguez and Rodríguez, 2009). Weir (1976) pointed out that “nocturnal kills are virtually certain whenever a lit obstacle extends into air space.” The characteristics of the light source can be manipulated to reduce mortality (Jones and Francis, 2003), and this has potential to become an important mitigation tool, subject to the requirements for navigation safety at sea. The low profile above water of wave and tidal devices is likely to reduce the extent of light attraction and hence risk of collision. Avoidance of beaming light upwards also will serve to reduce the possibility of attraction.

Receptors (Birds)

Physiology

Visual sensitivity

Nearly all marine birds use sight to obtain prey, and have adaptations for amphibious foraging (Martin, 1998; Martin, 1999; Martin, 2007; Martin *et al.*, 2008). Most species are predators of fast-moving prey, and have binocular vision, with the exception of most seaducks that typically forage on more sessile prey such as bivalve molluscs. Very little empirical data exist on the importance of visibility, but it is likely to depend on the type of prey and the extent to which birds can switch to tactile foraging. Given that all marine birds use sight to some extent to obtain prey and that birds' vision can be affected by small levels of turbidity (Strod *et al.* 2004), collision risk can be expected to be greater in conditions of reduced visibility. Thus, diving species will be more at risk in turbid waters than surface feeding species.

Physiologically, birds that take food items directly in the bill under visual guidance have frontal visual fields with narrow and vertically long binocular fields (Martin and Shaw, 2010). There are also blind areas which project above and below the binocular fields, although the extent of these blind areas will vary from species to species. The importance of these blind areas is that when in flight or swimming, a bird actively looking for prey may be effectively blind in the direction of travel. While it is unclear how much this will be relevant for seabirds (in particular its relevance to birds underwater), it may have important implications in determining the risk of collision with subsurface structures.

Aural sensitivity

Very little is known about the importance of hearing underwater to birds and whether noise can disorientate them or adversely affect their foraging success. In general, there is less variation in hearing sensitivity among birds than among members of other vertebrate groups (Dooling, 2002) and compared to most mammals birds do not hear well at either high or low frequencies. Any adverse impact of additional noise from wave or tidal energy devices would be more likely to affect diving than surface-feeding species, in particular those feeding at night (Daunt 2006), since they cannot rely wholly on sight.

Marine noise and more especially vibration will potentially have a greater impact on fish, even leading to loss of spawn and affecting in particular species with a swim bladder, and could thus alter the distribution of fish prey around device arrays. Studies have found that noise, such as from shipping activity, can cause an avoidance or attraction in fish (Thomsen *et al.* 2006). It is suggested that such impacts are likely to be limited to the immediate vicinity of the devices (Faber Maunsell & Metoc 2007), however the suggestion is made without empirical evidence or indeed definition of what is the extent of the immediate vicinity. Other modelling studies indicate variable avoidance responses ranging from several hundreds of metres to several kilometres depending on species (Thomsen, 2010).

Geography

Knowledge on the distribution and relative abundance of birds in UK waters is limited, in particular offshore. The European Seabirds At Sea (ESAS) dataset is the most comprehensive available (Stone *et al.* 1995), but suffers from patchy coverage, low spatial and temporal resolution and age (most is more than 10-20 years old) (Pollock and Barton, 2006). However, there has been some limited resurvey of offshore areas as part of the UK Offshore Energy Strategic Environmental Assessment (Langston 2010). There has been better coverage of inshore waters, especially in winter, due to a recent programme of visual aerial surveys by JNCC (Scotland) and WWT (England and Wales), much of it co-ordinated by or on behalf of DECC (UK Government Department of Energy and Climate

Change, and its predecessors). In addition there are surveys of the Round 3 offshore wind farm development zones commissioned by the Crown Estate and zone developers. The winter surveys have targeted inshore areas known to be important for seaduck, divers and grebes. However, some species are poorly covered by aerial survey, such as scaup, great crested grebe, red-necked grebe and Slavonian grebe, for which boat-based or land-based surveys may be more suitable monitoring methods (Lewis *et al.* 2008). The evolution of digital aerial surveys will increase the coverage resolution of aerial survey (Burt *et al.*, 2010).

Land-based surveys, mainly comprising the Wetland Bird Survey (WeBS) or local *ad hoc* seawatching surveys and data from bird observatories, extend only a short distance offshore into coastal waters, mostly ranging from 500m to 2km, depending on weather conditions (eg Musgrove *et al.* 2003; Austin *et al.* 2008a). These data provide an indication of species present in coastal waters and potentially of distributions further offshore, and may be particularly applicable in relation to wave and tidal stream devices in coastal waters.

Data on the distribution and abundance of wintering waders on UK coasts is collected systematically through two separate count schemes. WeBS covers mainly estuarine and enclosed coastal habitats (as well as inland wetlands) and counts are undertaken throughout each year (Holt *et al.*, 2011). The recording of gulls is optional for this survey and therefore not comprehensive. The Non-Estuarine Waterbird Survey (NEWS; previously Winter Shorebird Count) covers open coastal habitats considered suitable for waders and is undertaken at roughly 10-year intervals, with the most recent repeat in 2006/07 (Austin *et al.* 2008b). Survey coverage, although extensive, is not comprehensive and a random sampling design was used in 2006-07 to minimise bias in site coverage.

As these data on bird distributions develop, it is important that knowledge is also gained of how the birds move between areas, notably the origins of birds using sea areas proposed for deployment of wave and tidal stream devices. Knowledge of birds' origins, eg breeding colony, is an important factor in determining which population is relevant for assessment purposes. Such information will increasingly be derived from remote sensing technology, such as radiotelemetry, GPS data loggers and satellite tracking eg (Hamer *et al.*, 2000; Hamer *et al.*, 2001; Perrow *et al.*, 2006; Guilford *et al.*, 2008; Hamer *et al.*, 2009; Perrow *et al.*, 2010), as such technologies develop. The potential for satellite tracking to follow birds over potentially huge distances and over extended time periods is increasingly important, but the technology, in particular the size and cost of devices has still to improve; ie smaller tags to enable tracking of smaller seabirds. Visual tracking remains useful in the context of wave & tidal stream in coastal waters eg Perrow *et al* 2010, or land/boat-based observations.

Designated areas

The UK Government set a target of 2012 to establish a coherent network of marine protected areas for UK waters. These will consist of European Marine Sites (Marine Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) designated under European legislation), and marine protected areas designated under national legislation. Marine protected areas have been defined as "any area of the intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher 1999). While seabirds are often well-protected at their breeding colonies on land, this protection rarely extends into the marine environment upon which they depend for food and where they spend most of their time. The RSPB is concerned that the MPA designation process, at the time of writing, will fail to deliver an adequate network of marine SPAs to protect internationally important seabird populations in UK waters.

The UK Marine and Coastal Access Act 2009 introduced a new marine protected area designation, the Marine Conservation Zone (MCZ). The Act allows for MCZs to be designated in inshore waters around England and Wales, and offshore waters around the whole of the UK. Currently, there is considerable debate about the inclusion of mobile species in English MCZs and, consequently, few of the MCZs identified in English waters include seabirds as interest features. The UK Government has 'executively devolved' the power to designate protected areas in the offshore waters around Scotland to the Scottish Government. These sites will be called Marine Protected Areas (MPAs). In addition, the Marine (Scotland) Act 2010 introduces a corresponding designation for nationally important areas in Scottish inshore waters, which will also be called Marine Protected Areas (MPAs).

With the exception of black guillemot, all UK seabirds are either listed on Annex I of the Birds Directive or qualify as ‘regularly occurring migratory’ species, and therefore confer a greater responsibility on the part of the UK Government for their conservation. Furthermore, the UK is host to several million breeding seabirds each year, representing a high proportion of the biogeographical populations of several species, most notably Manx shearwater, northern gannet, great skua and lesser black-backed gull (Reid in Mitchell *et al.* 2004).

For safety reasons, there will be no commercial fishing in the vicinity of wave and tidal stream devices. Therefore it has been argued (Inger *et al.*, 2009; Blyth-Skyrme, 2010; Grecian *et al.*, 2010) that sites where devices are located will act as *de facto* marine protected areas, although the habitat within them is unlikely to have the same ecological character as that within qualifying/designated MPAs. Curtailment of fishery activity through the requirements of health and safety legislation would not be simply an automatic consequence of installation; such restrictions would require enforcement. However, even outwith high quality habitats, any reduction in the pressure from trawled fisheries is likely to be of ecological benefit (Kaiser *et al.*, 2006), although this may not necessarily benefit seabirds. Any ecological benefit to birds will only apply if the birds and the fish coincide within the same space.

Breeding areas

An important factor in risk assessment will be the breeding status of birds. During the breeding season, seabirds are central-place foragers, tied to returning to the colony whilst actively breeding. Provisioning growing chicks is a particularly demanding stage of the breeding season and different species have different adaptations to dealing with these pressures. For example, terns generally make many short foraging flights to provide multiple deliveries of food, whereas shearwaters may be away on a single foraging trip of more than 24 hours when they are feeding chicks. For terns, this leads to elevated flight activity between the breeding colony and proximate feeding areas, although the locations of the latter may change as prey availability changes. In a bad year, they may have to make longer flights to find food for their chicks, and chick survival is likely to be lower (Langston, 2010).

The location of any potential marine energy device in relation to breeding area will be crucial. Human activity close to breeding areas is known to be disruptive to breeding (Beale & Monaghan 2004), but the physical relationship between the breeding area, foraging area and location of devices is also crucial. Any disruption of a bird’s ability to provision chicks, and any device that increases the risk of foraging in order to provision chicks, for example through collision, will have an adverse effect.

Wintering areas

The locations of wintering seabirds are less known and less predictable than those of breeding birds. They tend to be further offshore, and are subject to dramatic change in response to climate and fluctuations in prey availability (Vaitkus, 1999). Outside the breeding season, seabirds are no longer constrained by central-place foraging. In general, many aspects of the winter distribution and ecology of seabirds remain unknown (Cherel *et al.*, 2006) although our knowledge of the distribution of inshore wintering birds has improved recently through the aerial surveys, in particular those coordinated by DECC, see above. Developing our knowledge of the distribution and behaviour of wintering seabirds is crucial in assessing offshore energy schemes, and remote sensing technology, including tracking of individual birds, radar etc., will be important in obtaining this knowledge.

Foraging areas

Marine birds are at risk of collision because their foraging areas are likely to overlap considerably with areas suitable for wave and tidal energy schemes. This overlap is potentially much higher for tidal stream devices, since marine birds preferentially forage in areas of high tidal activity (Daunt, 2006). Since the risks of collision with underwater structures is greatest when birds are diving for prey (Grecian *et al.*, 2010) developments with the greatest effect will be within foraging areas. Birds tend to congregate in areas where their feeding efficiency is greatest.

A wide range of seabird species has been recorded at increased densities at tidal mixing fronts, notably northern fulmar, Manx shearwater, European storm petrel, northern gannet and auks. Various fish species concentrate to feed on plankton blooms associated with these seasonal fronts. Species such as northern fulmar, European storm petrel and Leach's petrel often forage at the edge of the continental shelf. Shallow waters around sandbanks attract foraging seabirds that feed on sandeel, eg terns, divers, shags, auks, northern gannets, black-legged kittiwakes (various authors cited in Ratcliffe *et al.* 2000). Currently, there is fairly limited, but increasing, understanding of the complex relationships between marine features and seabird foraging behaviour. Such understanding will be essential for identifying feeding aggregations for offshore SPAs and for risk assessment of wave and tidal energy schemes.

Rafting and moulting areas

Many seabirds, notably the seaduck, form rafts, particularly when overwintering at sea, gatherings of non-breeding birds away from breeding areas, or aggregations of breeding birds prior to returning to their nests, eg Manx shearwaters. There is potential for displacement from these areas, as this is often when the birds, for example common scoter (Kaiser *et al.*, 2002), are most reactive to vessels. This susceptibility to disturbance may be related to vulnerability, for example when flightless whilst moulting flight feathers.

Demography

As stated above, the UK is of outstanding international importance for its breeding seabirds. Of the 25 species of seabird that breed in the UK, 13 species have more than 10% of their biogeographical population breeding in the UK, six of which have more than 30% of their biogeographical population breeding in the UK. Moreover, the UK supports more than 1% of the global breeding populations of at least 21 species (Reid, in Mitchell *et al.* 2004).

Any assessment of a development must consider not only the numbers of birds likely to be affected but this number in relation to a species' conservation status and its biogeographical population size (Garthe and Hüppop, 2004), that is the local population as a proportion of global population.

Ecology

Foraging behaviour

Mode

The mode of foraging will influence the magnitude of risk for a bird; in terms of underwater collision (Daunt, 2006). Plunge divers such as gannets will be subject to the greatest risk, then pursuit divers, such as guillemots, then surface feeders, such as shearwaters and ambush predators, such as cormorants (Martin *et al.*, 2008). Risk is greatest when the devices are at a depth coinciding with the dive profile.

Sensitivity to risk will vary as a function of avoidance ability, generally surface divers are slow and controlled whereas plunge divers have lower margins for avoidance (Grecian *et al.*, 2010). Species that dive underwater to feed are likely to be at greater risk of collision with sub-surface rotating turbines and mooring cables than those that feed at the surface. Considerable data exist on the foraging depths of a range of UK breeding seabirds. In general, these show that the distribution of a species through the water column depends on the maximum foraging depth. Shallow divers spend most time near the sea surface and progressively less time at depth, whereas deep divers (eg guillemots), which are principally benthic feeders, spend peaks of time at deep depths and at the surface but less time at intermediate depths. However, it is important to note that many of these studies are based on small numbers of individuals, often from a single colony, and the available means of study, such as Time Depth Recorders and individually mounted video cameras, have only recently become available. Therefore, it is not known to what extent such data are representative across a species' range, especially for species showing geographical variation in diet (eg guillemots breeding on the east and west coasts of Scotland).

Rhythm

Seasonal

The reproductive stage of a bird, including courtship, incubation and provisioning, will greatly influence the impact of a development. For example (Henderson *et al.*, 1996) found that the increased foraging demands on parent common terns during the breeding season caused a significant increase in their vulnerability to collision with power cables. This study also highlighted that the flight behaviour of juveniles was more risky than that of adults, as they flew consistently closer to the wires.

Diurnal

Collision risk has been considered to increase in those species which forage at night or are crepuscular (Daunt, 2006). However such species often have enhanced visual capability and this may make them quicker to respond to the presence of devices except where turbulence is a feature.

Tidal

Those species whose behaviour is governed entirely or in part by tidal rhythms may be more at risk when the point in the tidal cycle at which they forage preferentially coincides with poor or low light.

Time budgets

Time budgets, in particular the proportion of time spent foraging, flying (Garthe and Hüppop, 2004), rafting, or roosting, will have an influence on the impact of wave and tidal energy devices. Such budgets cannot be viewed in isolation, as they will be influenced by external factors such as prey availability (Monaghan *et al.*, 1994).

2. Wave and Tidal Stream Devices

Wave and tidal stream resources are of quite different natures, hence so too are the devices designed to capture energy from them (Appendix III). Waves are generated by wind passing over the water surface, which causes water particles to move in circular motions and carry kinetic energy, but it does not undergo a net movement itself. The quantity of wave energy is determined by wind speed and duration, the length of sea over which it blows (the 'fetch'), water depth, sea bed interactions and interactions with the tides. In principle, it is possible to extract almost all of the energy in a sea wave. By contrast, tidal energy occurs due to large movements of water in the sea, involving the entire water body from the surface to the seabed. Tidal energy may be extracted by conversion of potential energy of the tidal range (the rise and fall in water levels near the coast) by a tidal barrage (not considered further in this report), or kinetic energy of the tidal flow itself by marine turbines. The energy content of tidal streams is a function of current velocity, which is defined as the speed of water particles moving in the tidal stream in the mean flow direction.

One of the main advantages of wave and tidal energy is their predictability. Tidal power is highly predictable compared to other renewable energy resources (solar, wind, wave), while wave power is available up to 90% of the time, compared to 20-30% for solar and wind (Pelc and Fujita, 2002). A distinct advantage of tidal stream energy over most other renewable sources is its perceived invulnerability to climate change. Whereas wind, solar, wave and traditional hydro are susceptible to unpredictable changes in renewable energy fluxes brought about by shifts of climate regimes, tidal currents are thought to be immune to such disruptions (Pearce, 2005).

The UK's exploitable wave resource has been estimated at 50 TWh/yr, equivalent to *c.* 14% of UK electricity demand (Callaghan and Boud, 2006). The UK total tidal stream energy resource is estimated at *c.* 110 TWh/yr, of which the technically extractable resource is 18 TWh/yr, while the extractable resource for the rest of Europe was estimated at 17 TWh/yr (Black and Veatch, 2005). This assumed that only the most promising and economically viable schemes are developed and represents *c.* 5% of UK electricity demand.

The Atlas of UK Marine Renewable Energy Resources (ABPmer *et al.*, 2008) maps modelled wave and tidal resource around the UK. As such, it gives a good overview of the potential resource available and the areas of interest for wave and tidal stream development. However, it does not necessarily identify all areas of potential interest, particularly for the tidal resource close to land (< 1km), due to the size of the grid cell used for modelling. Assessments of the UK's resource have identified *c.*60 sites (Black and Veatch, 2005).

Wave energy shows clear seasonal trends, being greater in winter than summer. Almost half the wave power available annually around the UK occurs during December, January and February. Areas of high energy potential are generally west facing and with deep water, with the greatest wave energy occurring off the northwest and southwest coasts. Since wave energy is dissipated by seabed friction, the most attractive sites are those with deep water close to shore. However, there are few deep shoreline sites and consequently the inshore resource potential is small compared to that offshore (Thorpe, 1992).

The tidal stream resource is site-specific and is enhanced at 'pinch points' where the underwater topography causes currents to accelerate, such as channels between islands or between islands and mainland, and shallows around headlands. The narrower and shallower the channel relative to the surrounding water depth, the greater the amplification effect. Tidal energy is dominated by two superimposed cycles. The semi-diurnal cycle is unique to particular sites, and sites may be out of phase with each other. By contrast, the spring/neap cycle occurs at all sites simultaneously. Unlike wave energy, tidal stream energy exhibits no significant seasonal trends.

The Pentland Firth is by far the largest tidal stream resource, followed by the Channel Islands, and together they account for over 70% of the UK's available resource. Other important sites in terms of energy resource include Rathlin Island (Northern Ireland), Mull of Galloway, Carmel Head (Anglesey), Isle of Wight, Islay, Portland Bill, Bristol Channel, Yell Sound (Shetland), Papa Westray and Westray Firth (both Orkney).

Wave energy

Attenuators

An attenuator is a device which sits high in the water column, or floats on the surface, and works perpendicular to the wave direction. Wave movements are transported down the length of the device. Often the device is articulated, with hydraulic rams positioned between the articulations, the compression of which drives an electrical generator to produce electricity. Power from all the joints is fed down a single cable to a junction on the seabed.

The best known example of an attenuator is the Pelamis, originally trialled at Leith in Scotland, then three trial versions of which were installed at Aguçadoura in Portugal in 2008, although technical and financial problems meant its recall. E.ON and Scottish Power Renewables have placed orders for second generation Pelamis in The Crown Estates' Round 1 wave and tidal development area west of Orkney.

Other attenuators include the C-wave, a deepwater floating system, the Dexawave, two pontoons hinged together, which is being tested in Danish waters, the Edinburgh Duck, although there has been no development of this recently, and the Wello Penguin, which is due to be tested at EMEC in 2011.

Point absorbers

A point absorber is a floating structure which absorbs energy in all directions through its movements at/near the water surface. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors, from moored buoys to articulated units that absorb energy along the line of travel of the wave, some that react against an external weight or mooring, and others that internally self-react.

An example of a point absorber is the EGWaP (Electrical Generating Wave Pipe), a vertical pipe stretching from the ocean floor to the highest wave peak. An internal float and counterweight move with the waves, the action of which drives an electrical generator. Seatricity is currently testing a point absorber at EMEC. Others include the Brandl Generator, the DelBuoy, the Horizon and the Manchester Bobber.

Overtopping devices

This type of device relies on physical capture of water from waves that break over the device. The water is then held in a reservoir above sea level, before being returned to the sea through conventional low-head turbines, generating power. An overtopping device may use collectors to concentrate the wave energy.

An example which is currently connected to the grid in Denmark, and proposed for construction in Wales, is the Wave Dragon, which uses overtopping waves to collect water in a reservoir above sea level, and subsequently releases it through turbines. It is a floating and stationary device, situated in relatively deep water.

Submerged pressure differentials

Submerged pressure differential devices are similar to point absorbers but are fully submerged. Typically located nearshore they are attached to the seabed. The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device. The alternating pressure can then pump fluid through a system to generate electricity. An example of this is the AWS-III device, developed from the Archimedes Wave Swing and currently being tested (in miniature) in Loch Ness.

Oscillating wave surge converters

These devices extract the energy caused by wave surges with an articulated arm. The arm oscillates like a pendulum and is mounted on a pivoted joint. For example, the Oyster, which is being tested at EMEC in Orkney, is a hinged flap attached to the nearshore seabed at around 10m depth. Movement of the flap drives hydraulic pistons, which push water onshore, driving turbines. Testing of the larger Oyster 2 is due to begin in 2011 and installation is planned for Brough Head in Orkney.

A number of similar devices are in development, such as the Wave Roller, the bioWave, the Langlec and the Neptune Triton.

Oscillating water column devices

An oscillating water column is a partially submerged, hollow structure. It is open to the sea below the water line, and encapsulates a column of air in a chamber on top of a column of water. Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column. This trapped air is allowed to flow to and from the atmosphere via a turbine, which usually has the ability to rotate regardless of the direction of the airflow (the most common type being the 'Wells turbine'). The rotation of the turbine is used to generate electricity.

An example is the Limpet which has been installed and operational on the coast of Islay since 2000. This was the first commercial wave power generator, and is situated on the shoreline.

Tidal Stream energy

Horizontal axis turbine

This type of device extracts energy from moving water in much the same way as wind turbines extract energy from moving air. Water is nearly 800 times denser than air, so a much smaller diameter of rotor is required compared to a wind turbine for the same power output. Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure differential. Turbines are bi-directional to function on both the ebb and flood tides. The most developed devices include: Seagen, which has been installed in Strangford Lough, Northern Ireland; the Blue or E-Tide concept; the Rotech Tidal Turbine; and OpenHydro which has been installed in the Bay of Fundy, Canada, and is also being tested at EMEC in Orkney for proposed installation at Cantick Head, Orkney.

Vertical axis turbine / tidal fence

This extracts energy from moving water in a similar fashion to the horizontal axis turbine, however the turbine is mounted on a vertical axis. The number of blades and configuration of the blades vary between vertical axis devices. Since the rotor is vertically oriented, transmission of the rotational force is direct to the surface generator. This design also permits the harnessing of the tidal flow from any direction, allowing it to extract energy from the full tidal ellipse. Vertical axis turbines are typically founded on gravity bases (heavy concrete foundations). Current examples include the Kobold Turbine, Davis Hydro Turbine, and the Gorlov Helical Turbine.

Vertical axis turbines can also be linked to form a tidal fence that extends across a channel. They can be deployed in unconfined basins, eg in channels between small islands or in straits between the mainland and offshore islands. In constructing a tidal fence, the cross-section of the channel with free-flowing water is reduced and therefore increases the current velocity through the turbines. As with the individual vertical axis turbines, the electrical equipment (generators and transformers) can be kept above the water.

Oscillating hydrofoil

This is a hydrofoil attached to an oscillating arm and the motion is caused by the tidal current flowing either side of a wing, which results in lift. This motion can then drive fluid in a hydraulic system to be converted into electricity.

An example of this is the Stingray, which was developed by the University of Strathclyde, although the project is currently suspended.

Venturi effect systems

The venturi effect is defined as the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe. For tidal energy converting technology, this means that by housing the device in a duct, the flow past the turbine is concentrated. A funnel-like collecting device sits submerged in the tidal current. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine installed on land. These systems are still developing technology.

3. Ornithology

When not directly cited, information has been derived from the sensitivity indices contained in Garthe and Hüppop (2004) and King *et al.* (2009). SPA and population details are from JNCC, otherwise from Birdlife International (Birdlife Seabird Wikispace: http://seabird.wikispaces.com/ on 30/10/2011 and BirdLife International (2010) IUCN Red List for birds, downloaded from http://www.birdlife.org on 10/10/2011), Mitchell *et al.* (2004), Kober *et al.* (2009), Birds of Conservation Concern 3 (BoCC3 – Eaton *et al.*, 2009), and Langston (2010). The SPA data include SPAs for which the listed species' local population exceeds the one percentage threshold, or where it is part of the qualifying assemblage. A new SPA review is in progress, which may update the situation, combined with preparatory work for identifying marine SPAs.

Seaducks

Greater scaup *Aythya marila*

Conservation status

There are five SPAs for which greater scaup (hereafter scaup) is a qualifying species, all for wintering birds. Three of these are in England, one in Scotland and one, the Solway marshes, overlaps both. Scaup are red listed in *BoCC3* (Eaton *et al.*, 2009), although not listed in Annex 1 of the EU Birds Directive. There are some 7560 individuals (Baker *et al.*, 2006) wintering in UK waters, and up to five pairs breed every year.

Distribution

Wintering scaup are found around the coasts of Britain, concentrating in estuaries on the east coast, the south west of Scotland and the north west of England, and can be found on fresh water lakes too. However distribution data are limited (Daunt, 2006).

Ecology

The winter diet of scaup consists primarily of bivalve molluscs, in particular mussels, as well as other invertebrates, small fish and aquatic plants (Winfield and Winfield, 1994; Ross *et al.*, 2005). These food items are obtained from on or close to the seabed. Foraging is in relatively shallow water, less than 10m deep, although the majority of dives will be in shallower water (Jones and Drobney, 1986; Winfield and Winfield, 1994). Feeding is in bursts of short dives followed by long surface pauses (De Leeuw, 1999). These long digestive pauses and a limited capacity to store food in the gut imply that a large fraction of the time budget must be spent on the feeding grounds.

They roost in sheltered waters often, though not always, during the day, in which case they forage at night (Dirksen *et al.*, 1998). Flights between foraging and roosting sites will take place predominantly during dusk and dawn (*Ibid.*).

Vulnerability

Scaup fly relatively close to the water surface, though usually not within the first 5m (King *et al.* 2009), so they are at some risk of above surface collisions. A number of studies have shown that they are less displaced from marine wind farms than other seaducks (see review in Dierschke & Garthe 2006) and are therefore less likely to be susceptible to disturbance. Scaup forage in benthic habitats, so devices anywhere in the water column will coincide with their dive profile at some point. Presumably they rely on sight underwater, and so collision risk will be increased by turbidity. This would not be the case if the bird obtains food by tactile foraging. Mussel growth will occur on the structures associated with offshore renewable devices (Langhamer *et al.*, 2009) and there is therefore a danger, particularly if there are exposed turbines or a risk of entrapment, in such growth attracting scaup to a device, thereby increasing risk of collision.

Since scaup spend the majority of their time on the water surface, they will be susceptible to contamination by floating pollutants.

Common eider *Somateria mollissima*

Conservation status

There are three SPAs for which the common eider is a qualifying species, two in Scotland and one in England, all of which are for wintering birds. Eider is included in the *BoCC3* amber list, and not listed on Annex I of the EU Birds Directive. There are 31000 pairs in summer in the UK and 73000 individuals in winter (Baker *et al.*, 2006).

Distribution

They are almost entirely marine and most often found within 10km of the shore, although they can occur as far as 40km from the coast. During the breeding season, they are found around the coast of Scotland, particularly the west coast, and Northumberland, and generally nest in colonies. They remain in the adjoining coastal waters in winter in large flocks and also can be found on the Yorkshire coast, around the east and south coast of England, in Belfast Lough and along the Welsh coast.

Ecology

Eiders show a high degree of variability in their foraging behaviour and habitats. Their main prey are benthic invertebrates particularly bivalve molluscs, which they obtain usually by diving from the surface, but also, in shallower water by up-ending, head-dipping and trampling. In the majority of studies, though not all (see review in http://seabird.wikispaces.com/Common+Eider accessed 10/10/2011) they have been found to prefer mussels, preferring smaller individuals, as found in shallower water. However a study of wintering birds in Greenland (Merkel *et al.*, 2007) identified 39 different prey items, including polychaetes and crustaceans and so there is considerable variability in diet, in relation to availability of prey items, season and location. Although considered to be diurnal, nocturnal feeding does occur (Merkel and Mosbech, 2008) associated with greater levels of disturbance and the presence of predators. There is also large variation in dive behaviour, in part related to physiological state (Guillemette *et al.*, 2004), but also to foraging habitat and prey (Guillemette *et al.*, 1992). Similarly there is variation in choice of foraging sites, including soft and rocky substrates and the distance travelled from roost sites to foraging sites. Although they can dive to 42m, they usually prefer to dive where prey is most abundant, often in shallow reefs and the largest flocks will congregate over these (Guillemette *et al.*, 1993). In winter birds can show a high level of site fidelity, roosting close to (mean 1.7km) foraging areas (Merkel *et al.*, 2006). Other studies, elsewhere, have shown birds flying 50-100km from wintering roost locations in open oceanic currents to coastal foraging sites (Goudie, R.I., Robertson, G.J. and Reed, A., 2000, cited in http://seabird.wikispaces.com/Common+Eider). Generally foraging takes place close to both the coast and the breeding location, although this will be subject to location and individual variation. Females of the subspecies Northern eider have been known to make foraging trips of over 80km from nest sites, although not during incubation (Cooch, 1965).

Vulnerability

Behavioural modification by eiders in the presence of turbines has been described in studies at offshore wind farms. At Tunø Knob wind farm, the eiders showed strong avoidance of the turbines, seemingly in response to visual cues as they were unaffected by either turbine noise or movement (Larsen and Guillemette, 2007). This raised concern over their collision risk in poor visibility, as eiders are known to fly at night (Merkel and Mosbech, 2008). At Nysted wind farm, in Denmark, migratory eiders also showed strong avoidance of turbines, and this occurred both during the day and at night, although flight avoidance was initiated at greater distance from the turbines in daylight, indicating visual cues (Desholm & Kahlert 2005). Those birds that entered the wind farm appeared to maintain maximum distance from turbines when they flew between the turbines. This may indicate that eiders have good night-vision. We have no evidence for what avoidance would occur in poor visibility caused by fog rather than darkness. Above surface structures associated with wave and tidal stream devices will have a lower profile above the water surface than turbines, so collision risk is expected to be reduced. Conversely, detectability is also lower and so collision risk cannot be completely eliminated. Eiders are low flying and have relatively poor manoeuvrability, (Garthe and Hüppop, 2004) and so must be considered to be of at least some risk of above surface collision, particularly in conditions of poor visibility.

Beneath the surface it is harder to predict collision risk. Eiders forage in benthic habitats, so a device anywhere in the water column will coincide with their dive profile at some point. If they rely on sight underwater, collision risk will be increased by turbidity. It has been demonstrated that there will be mussel growth on the structures associated with offshore renewable devices (Langhamer *et al.*, 2009) and there is therefore a danger, particularly if there are exposed turbines or a risk of entrapment, in attracting eiders to a device. This risk is increased by eiders' responsiveness to changes in habitats.

Since eiders spend much of their time on the surface, they will be susceptible to contamination by floating pollutants. They are fairly sensitive to disturbance (Garthe and Hüppop, 2004), and will modify their behaviour in response to human disturbance (Merkel and Mosbech, 2008). However their flexibility in exploiting habitat and food resources will reduce the effect of displacement from such disturbance.

Long-tailed duck *Clangula hyemalis*

Conservation status

There are three UK SPAs where long-tailed duck is a qualifying species; two in Scotland and one in England, all for wintering birds. The species is green listed in *BoCC3* and is not listed in Annex1 of the EU Birds Directive. The British wintering population is 16000 individuals (Baker *et al.*, 2006)

Distribution

The main wintering areas in Britain have been identified as the Moray Firth and around Orkney, with smaller concentrations in the Firth of Forth and Outer Hebrides (Stone *et al.*, 1995; Lewis *et al.*, 2008). Although considered a coastal species, aerial surveys have recorded long-tailed ducks 65km offshore, where there are shallow banks suitable for foraging (White *et al.*, 2009).

Ecology

The diet of long-tailed ducks consists largely of benthic and pelagic invertebrates, although fish, especially sand eels and fish eggs, as well as some plant matter, are also consumed (Jamieson *et al.*, 2001; Zydelis and Ruskyte, 2005; White *et al.*, 2009). Prey is obtained by surface dives. They exhibit a degree of plasticity in their foraging habits and will change prey dependent on availability and benthic substrate; one study (Zydelis and Ruskyte, 2005) identified prey in hard bottom substrates as mussels, and in soft bottomed substrates, crustaceans including pelagic amphipods (White *et al.*, 2009). Consequently, since they are not solely benthic feeders, they will feed in moderately deep water, of at least 20m.

The available information suggests that they roost at night and commuting flights are made during daylight (Dierschke and Garthe, 2006; White *et al.*, 2009). Flights are low, typically less than five metres above the surface of the water (King *et al.*, 2009).

Vulnerability

Surveys to determine the ecological effects of marine wind farms at Nysted and Utgrunden (Sweden) wind farms (Dierschke and Garthe, 2006) have shown long-tailed ducks are displaced by construction activities and by service boats. Numbers were also lower at both sites during operation; at Utgrunden, displacements appeared to be caused by service boats rather than by the turbines themselves. Long-tailed ducks are clearly susceptible to disturbance (Garthe and Hüppop, 2004; DONG *et al.*, 2006) and there is no evidence that they become habituated to it, therefore disturbance arising from installation and subsequent traffic associated with maintenance and repair are likely to effectively exclude them from foraging and rafting habitats.

Above water collision risk is increased by their low flight height, and while they often fly in daylight, some flights are made in darkness (King *et al.*, 2009), and the low profile of the devices may mean they are not easily seen. Below the surface they are generally, though not always, benthic feeders so devices and associated submerged structures will overlap their dive profile, except in deeper water (>20m). As foragers on benthic bivalves any increase in mussel growth associated with devices (Langhamer *et al.*, 2009) will act as attractants, and therefore increase the risks of collision, particularly with exposed turbines, and entrapment.

Long-tailed ducks spend a considerable proportion of their time on the water surface, and so are susceptible to both pollution and collision with vessels.

Common scoter *Melanitta nigra*

Conservation status

There are nine UK SPAs with common scoter as a qualifying species, four in Scotland, three in England, one in Wales, and one, Liverpool Bay, in both England and Wales. Seven of these are for wintering birds; two of the Scottish SPAs are for breeding birds and are freshwater areas. Common scoter is red listed in BoCC3, although not included in Annex 1 of the EU Birds Directive. There are around 95 breeding pairs , and some 50000 individuals overwintering, in UK waters (Baker *et al.*, 2006).

Distribution

In winter, common scoters occur in large numbers in Moray Firth and Liverpool Bay (Kaiser *et al.*, 2006; Lewis *et al.*, 2008), as well as in Carmarthen and Cardigan Bays in Wales, the Norfolk coast of England, and Dundrum Bay in Northern Ireland. They are primarily associated with shallow inshore waters and are usually associated with sandy coasts. The highest densities coincide with sites that have a high abundance and biomass of bivalve prey species, although they avoid areas with high anthropogenic activity (Kaiser *et al.*, 2006; Schwemmer *et al.*, 2011). The breeding population is primarily in the Flow Country of Caithness and Sutherland (Scotland), where scoters are associated with fresh water habitats. However throughout the year non-breeders and, from July onwards, males and moulting adults can be found in coastal areas.

Ecology

Scoters feed largely on or within the substratum mainly on bivalve molluscs, but also on a variety of invertebrates, plants and fish eggs (Kaiser *et al.*, 2002). During the breeding season they feed largely in freshwater areas, eating a greater variety of prey; when feeding in the sea, mussels are the predominant prey items. They locate prey by tactilely and all but the bulkiest prey is eaten underwater. They feed in patches, in flocks, and the location of these seems to be determined not only by prey availability but by information exchange. In other words, since the birds are unable to see benthic prey from the surface, they rely on cues from conspecifics to locate good feeding areas (Kaiser *et al.*, 2006). Their distribution is unaffected by areas of high turbidity, such as in Liverpool Bay, suggesting that they are unlikely to be visual feeders (Kaiser *et al.*, 2006). In a review of foraging depths (http://seabird.wikispaces.com/Black+Scoter accessed 10/10/2011), most authors agreed that wintering birds rarely foraged in waters deeper than 20m, while breeding birds remained in areas less than 3m deep.

During the winter they remain entirely at sea, often remaining faithful to the same feeding area (Mudge and Allen, 1980).

Vulnerability

Common scoter are sensitive to disturbance by moving vessels at a distance of up to 2km (Kaiser *et al.*, 2006), although they will eventually habituate to regular disturbance (Schwemmer *et al.*, 2011). They are therefore likely to be displaced from any development site during construction, and may continue to be displaced by service vessels, although this displacement will reduce the risk of collision with the vessels. This displacement is likely to be the greatest impact on common scoter, and its effects may be magnified by their reliance on visual cues from conspecifics to find new feeding grounds.

Other above surface collisions are of increased likelihood because of a low flight altitude (Garthe and Hüppop, 2004). Sub surface collisions also may occur, particularly in the context that scoters do not find their prey visually and therefore may dive in conditions of poor visibility. Conversely, they are unlikely to be affected by any increase in turbidity. As with all diving seaduck the development of mussel beds beneath the surface will act as an attractant, and increase the risk of entanglement and collision. During the winter scoters live entirely at sea, and are therefore at risk of contamination by oil-based pollutants.

Velvet scoter *Melanitta fusca*

Conservation status

Velvet scoter is a qualifying species for two UK SPAs, both of which are in Scotland, and both for wintering birds. The species is amber listed in BoCC3 and is not listed in Annex 1 of the EU Birds Directive. Around 3000 individuals overwinter in UK waters (Baker *et al.*, 2006).

Distribution

Largely associated with the east coast of Britain, key areas for the distribution of velvet scoter are the two SPAs in the Firths of Forth and Tay, although the Moray Firth is an important wintering area (Stone *et al* 1995). In general velvet scoters favour coastal estuaries, bays, and open coastline with shallow water over shellfish beds and hard, usually sand or gravel, bottoms.

Ecology

Velvet scoters frequently form mixed feeding flocks with common scoters and share a diet dominated by benthic bivalve molluscs. However, one study shows a tendency to take larger prey than common scoters (Bourne 1984), with more variation in the diet and a preference for gravel sediments, while another study suggested they feed closer to the coastline (Fox 2003). They dive from the water surface using both wings and feet to propel themselves (Richman and Lovvorn, 2008), which reduces the dive costs, and therefore the surface recovery time. Radiotelemetry studies in Canada (Lewis *et al.*, 2005) show that they forage almost entirely during the day, and go to deeper water during the night, suggesting that they are constrained by daylight. The daylight feeding areas are usually less than 20m deep.

Vulnerability

Similarly to common scoter, the greatest effect of a development on velvet scoter is likely to be displacement, since they show a similarly high degree of disturbance to construction and traffic. Since their foraging may be constrained by daylight, any disturbance that prevents them foraging, particularly during the winter may have dramatic effects on fitness and survival.

Above surface collisions are of increased likelihood because of a low flight altitude (Garthe and Hüppop, 2004). Sub surface collisions also may occur, potentially reduced by their tendency to feed during daylight, although it is unclear how important sight is during their diving behaviour. The development of mussel beds beneath the surface may act as an attractant, and increase the risk of entanglement and collision. During the winter velvet scoters are entirely marine, therefore at risk of contamination by oil-based pollutants.

Common goldeneye *Bucephala clangula*

Conservation status

There are 12 UK SPAs with goldeneye as a qualifying species, six in Scotland, four in England, one overlapping both, and one in Northern Ireland. All, except Loch Vaa in the Scottish Highlands, are designated for wintering birds. Goldeneye is *BoCC3* amber listed and is not included in Annex 1 of the EU Birds Directive. There are 200 pairs breeding in Britain, with 25000 individuals wintering (Baker *et al.*, 2006).

Distribution

In Britain, goldeneye breed in freshwater lochs in the Scottish Highlands, largely in Speyside. The wintering population is both freshwater and marine, and the marine population is restricted to sheltered inshore waters, although they are found throughout the British coast.

Ecology

The majority of ecological research on goldeneye has focused on breeding birds whose diet consists predominantly of aquatic invertebrates as well as amphibians, small fish and some plant material. In the winter, the diet is dominated by small crustaceans, in particular shore crabs, as well as some molluscs and small fish largely obtained on or just above the sea bed (Olney and Mills, 1963). The limited data available suggest that they prefer to feed at depths less than 2m (Jones and Drobney, 1986) although they can be found deeper in less favourable conditions (Winfield and Winfield, 1994).

In the winter, they roost communally on water, forming rafts in inshore waters.

Vulnerability

The flight altitude of goldeneye is within 5m of the water surface (King *et al.* 2009), and so they are at risk of above surface collision with any device components protruding above the water. Below the surface they are at risk of collision with any device or associated component, although they seem constrained to rather shallow water. As inshore birds spending the majority of their time on the water they are at risk of contamination by oil based pollutants, and this is probably the greatest risk posed to goldeneye, since their distribution will not greatly overlap with the anticipated locations of the devices.

Red-breasted merganser *Mergus serrator*

Conservation status

There are four UK SPAs where red-breasted merganser is a qualifying species, two in Scotland, two in England, and all for wintering populations. Merganser is are green listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive. There are 2150 breeding pairs in Britain and 9840 individuals wintering (Baker *et al.*, 2006).

Distribution
Uncommon in the sea during the breeding season, in winter red-breasted mergansers are common in coastal and estuarine habitats, generally in the north-west, with particular concentrations in the Solway Firth (Scotland), Duddon Estuary and Morecambe Bay (England), Traeth Lafan (Wales), north Norfolk coast and the Wash and Thames estuaries (England). They tend to be recorded within 10km of the shore, although surveys are biased toward inshore areas.

Ecology
Red-breasted mergansers are largely piscivorous, and their preference for salmonid prey has both brought them into conflict with man and dominated research themes. Their winter diet shows a preference for small shoaling fish, that they catch by diving from the surface and either pursuing prey or probing the substrate with their bill (Sjoberg, 1985). They are diurnal (Nilsson 1970).

Mergansers spend a relatively high proportion of time in flight (King *et al.*, 2009) and they are capable of very fast flight. They are also considered to have a moderate manoeuvrability, and a low flight height (*Ibid.*).

Vulnerability
The important vulnerability of red-breasted mergansers will be flight collisions with above surface structures, since they fly close to the water and can do so at considerable speed. As pursuit divers, they will have a moderate vulnerability to below surface collision, which may be increased by turbidity. The experience of marine wind farms has been that while service boats displace the mergansers temporarily, operating turbines do not cause major disturbance (Dierschke and Garthe, 2006), and so it is probable that they will not be greatly susceptible to disturbance.

Divers

Red-throated diver *Gavia stellata*

Conservation status
There are 14 UK SPAs where red-throated diver is a qualifying species, four of which are wintering areas, and ten of which are Scottish breeding areas. Of these ten, all are freshwater sites. While the international status of red-throated diver is least threatened, the species is listed on Annex 1 of the EU Birds Directive and is on the *BoCC3* amber list. The British breeding population is estimated to be 1143 breeding pairs (Dillon *et al.*, 2009) and the wintering population to be around 17 000 individuals (O'Brien *et al.*, 2008).

Distribution
The UK breeding population is located almost entirely in the north and west of Scotland, particularly the Outer Hebrides, Orkney and Shetland. They breed in freshwater lakes. The wintering distribution is uneven. The greatest concentration has been found off southeast and east Britain, in the Thames estuary and along the coast of East Anglia, with other significant aggregations off the English south coast, north Wales and Liverpool Bay, and eastern Scotland (O'Brien *et al.*, 2008). In the winter they are almost entirely marine, previously thought to remain largely within 2km of the shore, although the data are biased by land-based counts, which inevitably overestimate the proportion of birds closer to shore. More recent data describe birds being considerably further offshore, over suitable shallow sandbanks away from shipping disturbance (Webb *et al.*, 2010). The highest densities of wintering birds are associated with shallow water, especially <20-25m (I K Petersen pers comm. & H. Skov pers comm.).

Ecology

They are largely piscivorous and considered to be opportunistic feeders (Skov and Prins, 2001; Guse *et al.*, 2009) eating both pelagic and bottom-dwelling species although most dives are no deeper than 9m.They are pursuit divers, and dive from swimming on the surface of the water. When breeding they will forage both at sea (Bergman and Derkson, 1977) and in larger freshwater lakes (Eriksson *et al.*, 1990). They catch prey items individually, and deliver them as such to the nest. When feeding at sea, they do so largely in coastal waters (Guse *et al.*, 2009), although aerial surveys in the Greater Thames area and subsequent modelling show an association with shallow sandbanks (Skov pers comm.) not only in inshore waters but considerably further offshore up to 30km. Their mean foraging range from the nest site has been calculated as 11.06 km, preferably foraging on tidal estuaries, mudflats and at surface fronts, although they can fly up to 50km from the nest. They are almost entirely diurnal. They have low flight manoeuvrability, and most flights will be between five and ten metres above the water (Garthe and Hüppop, 2004).

Vulnerability

Garthe and Hüppop (2004) gave their highest vulnerability scores to red-and black-throated divers, based in part on their conservation status as an Annex 1 species, but also other key ecological factors. Their assessment of flight manoeuvrability was low, which is not as important for below surface structures as it is for wind turbines, the focus of their analysis. There remains, however, a collision threat with any above surface infrastructure of wave or tidal stream devices, magnified by the low flight altitude and poor flight manoeuvrability of divers. Beneath the surface, they are likely to have a lower collision risk than plunge divers, since they will have a controlled and highly targeted foraging dive. However, the subsequent active pursuit of prey potentially increases collision risk. As relatively shallow divers, collision will depend in part on the position of the device infrastructure in the water column. Prior to diving they swim on the surface, searching for prey with their heads immersed or loafing. Because of this high proportion of time spent on the water surface, they are highly vulnerable to any contamination or pollution.

Despite a catholic diet, red-throated divers are dependent on a fairly narrow range of habitats, and therefore can be considered to be very vulnerable to displacement and habitat loss. During the breeding season they confine foraging to relatively close to the nest; any developments within this range would have a strong negative effect. Furthermore they are considered very susceptible to disturbance (Garthe and Hüppop, 2004) and early evidence from wind farms including Horns Ref (DONG Energy *et al.* 2006) and Kentish Flats (Vattenfall 2010), suggest that they have been displaced from the operational area of offshore wind farms (Gill *et al.*, 2008) and up to 4km beyond the wind farm footprint. Such displacement has persisted in the post-construction wind farms, with little indication of recovery to pre-construction densities in the wind farm footprint and partial recovery in the buffers. A growing number of case studies are indicating similar responses by red-throated divers, highlighting concerns about the potential for cumulative effects of multiple installations. They are also susceptible to disturbance by shipping traffic (Schwemmer *et al.*, 2011), and construction, maintenance and repair vessels are particularly likely to cause displacement, owing to the temporary and unpredictable nature of their occurrence.

Black-throated diver *Gavia arctica*

Conservation status

There are twelve SPAs where black-throated diver is a qualifying species, all in Scotland and all designated for breeding birds, and therefore freshwater habitats. Black-throated diver is listed in Annex 1 of the EU Birds Directive and is *BoCC3* Amber listed. The breeding population is estimated at 217 pairs, the wintering population roughly estimated at 700 individuals.

Distribution
The breeding population is concentrated in north western Scotland including the western and northern isles. Less is known about the wintering population, although significant concentrations are found on the west and east coasts of Scotland.

Ecology
Although always breeding by freshwater they forage in both coastal and freshwater systems. In winter they can occur in flocks of around 50 birds, as well as individually, almost entirely in marine areas. Very little is known directly about their foraging ecology, however much can be inferred by examining the more widely studied red-throated diver with which they share a number of ecological characteristics. Though there is no direct evidence, their mean foraging range from the nest has been estimated at 4km. They are considered to have low flight manoeuvrability.

Vulnerability
There is a paucity of direct information on black-throated divers on which to base any assessment of vulnerability. Garthe and Hüppop (2004) describe them as low flying and with low flight manoeuvrability, and so they will be at some risk of collision with above surface structures. There is evidence from a number of marine wind farms (review in Diersche and Garthe, 2006) that they show a strong avoidance of turbines, however this does not necessarily transpose to the less visible wave and tidal structures. In the absence of evidence to the contrary above surface collision should be considered a risk.

As pursuit divers, they will be less at risk of sub surface collision than plunge divers, although as far as is known they forage in relatively shallow water and this will decrease the risk, dependent on the position of any device or infrastructure in the water column. Turbidity may increase this hazard. There will also be a risk of entanglement in pursuit of prey, and this risk will be magnified if any structures act as Fish Aggregating Devices. In common with all divers they spend a lot of time on the water surface, and so will be at risk of contamination by pollutants.

Black-throated divers seem to be very susceptible to disturbance, either by human activity (Garthe and Hüppop, 2004; Schwemmer *et al.*, 2011), or by site infrastructure (Dierschke and Garthe, 2006). This disturbance will lead to displacement, and a potential reduction in breeding performance. As a particularly vulnerable species, any development that might compromise their population status must be avoided.

Great northern diver *Gavia immer*

Conservation status
Great northern diver is not a qualifying species of any designated SPA and has never certainly bred in the UK. There are however qualifying numbers in winter around Orkney, notably Scapa Flow, and Tiree and Coll, areas which are being reviewed as a possible SPAs. Great northern diver is amber listed in *BoCC3* and in Annex 1 of the EU Birds Directive. There are an estimated 2500 to 3000 individuals overwintering in UK waters (Baker *et al.*, 2006).

Distribution
The UK, particularly northern and western Scotland, holds very important numbers in winter. In part because they occur further offshore and in deeper waters than other divers, they are difficult to census and estimates of numbers wintering are likely to be conservative (Heubeck *et al.*, 1993). However there is an increasing concern, in Shetland at least, that numbers are in sharp decline (Heubeck and Mellor, 2007). In general, great northern divers prefer rocky to sandy shores and large concentrations are found in particular along the rocky shores and bays of the northern isles, notably at Scapa Flow, and Outer Hebrides.

Ecology

There has been more research into the ecology of great northern divers than the other two congeneric species, however most of this has focused on the breeding period. During foraging they usually search for prey by peering into water while swimming, with eyes beneath surface. They will also search and probe around vegetation and objects in the water column and on the bottom while swimming underwater. In pursuit their eyes are fixed on the prey item (Barr, 1996; Evers *et al.*, 2010). Adults ingest most prey underwater although larger items will be brought to the surface and repeatedly manipulated before swallowing or discarding (Barr, 1996). In winter, great northern divers use two general foraging strategies: solitary and group foraging. Solitary foraging is an efficient strategy where fish prey is evenly spaced whereas group foraging is more effective where prey abundance is patchy, such as shoals of fish (Evers *et al.*, 2010).

Vulnerability

While there is a scarcity of direct data on great northern divers in the wintering period, it is known that they hunt visually, diving from the surface. As such, they are likely to detect any object before the dive has commenced and therefore be at low risk of sub-surface collision, although there is a risk of entanglement during pursuit. Although not included in either Garthe and Hüppop's (2004) or King *et al.* (2009) sensitivity indices, it can be assumed that their flight behaviour will be similar to the two congeneric species, and so they will be at risk of above surface collisions. Similarly, they will be vulnerable to disturbance.

They spend a high proportion of time on the water surface, so therefore will be susceptible to pollution.

Grebes

Great-crested grebe *Podiceps cristatus*

Conservation status

There are eight UK SPAs where the great-crested grebe is a qualifying species, six of which have a marine component. The majority are in England, with one each in Wales, Scotland and Northern Ireland. It is green listed in *BoCC3*, and is not included in Annex 1 of the EU Birds Directive. A resident breeder, there are 8000 breeding pairs and 16000 wintering individuals in the UK (Baker *et al.*, 2006).

Distribution

Great-crested grebes are almost entirely associated with fresh water during the breeding season. However during the winter they will forage in marine areas, largely in inshore coasts and bays, and brackish estuaries, rarely in water deeper than 10m. These coastal areas are predominantly in the south of Scotland and throughout England, notably the eastern English Channel, and Wales, but particularly Belfast Lough and Loughs Neagh and Beg in Northern Ireland (Calbrade *et al.*, 2010; Holt *et al.*, 2011).

Ecology

Wintering great crested grebes feed almost entirely on fish, which they capture by pursuit diving from the surface and eat both below and above the surface (Gwiazda, 1997). They are also now known to feed cooperatively, as a flock, where a tight group of birds dives synchronously to encircle shoaling fish (Kallander, 2008).

Vulnerability

Great-crested grebes will be mainly vulnerable to offshore developments during the winter. Garthe and Hüppop (2004) assessed the species' flight characteristics as fairly low manoeuvrability although the majority of flights will not be at the height of above surface structures of wave and tidal stream devices. Very little is known about their dive profile in marine habitats, however as an inshore species they are unlikely to dive deeply, and will not be vulnerable to sub-surface collisions. Garthe and Hüppop (2004) assess them as moderately disturbed by boat and helicopter traffic. Since they spend much of their time on the surface, they will be susceptible to contamination by oil-based pollutants.

Red-necked grebe *Podiceps grisena*

Conservation status

There are no UK SPAs for which the red-necked grebe is a qualifying species. It is amber listed in *BoCC3*, and is not included in Annex 1 of the EU Birds directive. Around 200 individuals overwinter in Britain (Baker *et al.*, 2006).

Distribution

Red-necked grebes are located mainly in inshore coasts and bays in the south and east of Britain. They occur mostly in marine habitats over winter. At their main site, the Firth of Forth, moulting adults appear from mid-summer and are present until spring.

Ecology

They feed on small fish and marine invertebrates (Wagner and Hansson, 1998), though little is known about how they obtain them.

Vulnerability

Garthe and Hüppop (2004) assessed red-necked grebe as having poor flight manoeuvrability and a fairly low flight height, so they will be at risk of above surface collision. Feeding in shallow sheltered areas they are not at risk of below surface collisions. They were assessed as being moderately disturbed by ship and helicopter traffic. Spending much of their time on the surface of the water, they will be at risk of contamination with oil-based pollutants.

Slavonian grebe *Podiceps auritus*

Conservation status

There are eight UK SPAs for which Slavonian grebe is a qualifying species, six of which are for breeding birds and therefore freshwater areas and the remaining two are for wintering birds. The species is amber listed in *BoCC3* and on Annex 1 of the EU Birds Directive. Around 40 pairs breed and 2100 overwinter in Britain (Baker *et al.*, 2006; Musgrove *et al.*, 2011).

Distribution

The Slavonian grebe is the most marine of the grebe species outside the breeding season when they will be found in coastal waters, as well as lakes or reservoirs. They can be found all around the UK coast, concentrating in large estuaries and sheltered sea lochs particularly in Scotland, notably at Scapa Flow in Orkney.

Ecology

During the breeding season, Slavonian grebes feed on fish, often caught by diving and chasing prey underwater, or insects such as mayflies or damselflies (Mendel *et al.*, 2008). They then migrate to wintering grounds in marine or brackish waters. The grebes prefer shallow waters of 4-14 m depth and occur only over sandy sediments. In one study in the Pomeranian Bight, their diet consisted mainly of demersal gobies typical of sandy bottom substrates. (Sonntag *et al.*, 2009).

Vulnerability
Assessed by King *et al.* (2009) as having a moderate flight manoeuvrability and relatively low flight height (5 – 10m), Slavonian grebes will have a moderate risk of above surface collision. Preferring shallow coastal water they will have a low risk of below surface collisions. They are moderately susceptible to disturbance by ship and helicopter traffic.

Slavonian grebes are vulnerable to changes in the quality of their inshore non-breeding habitats, and oil pollution has been to shown to cause high winter mortality (Thom 1986). Since they spend a large amount of time on the surface, contamination by oil-based pollutants will be the greatest risk.

Fulmar

Northern fulmar *Fulmarus glacialis*

Conservation status
There are 24 UK SPAs with breeding fulmar as a qualifying species, all of which are in Scotland. Fulmar is amber listed in *BoCC3* and is not included on Annex I of the EU Birds Directive. 538,000 pairs breed in the UK, the majority of them (90%) in Scotland (Mitchell *et al.*, 2004).

Distribution
Primarily an offshore species, high densities of fulmar are associated with the edge of the continental shelf to the north and west of Scotland, as well as offshore banks, such as Dogger and Rockall, in general preferring stratified and highly saline waters and the frontal zones between water masses (Camphuysen and Garthe, 1997). Although travelling considerable distances to feed, they remain associated with their breeding colonies through the year, most notably in Shetland, Orkney and the Outer Hebrides.

Ecology
There has been massive expansion in breeding numbers and range of the fulmar over the last two centuries. This is generally attributed to an increased availability of discards from commercial fisheries, although more southern birds seem to be less reliant on this food source (Phillips *et al.*, 1999) and it is not a determinant of their offshore distribution in the North Sea (Camphuysen and Garthe, 1997). Apart from anthropogenic food sources, they also actively forage for fish, squid and zooplankton. Primarily they are surface feeders and will seize prey seen from flight, although they also splash dive, particularly for discards. When catching prey they will rarely dive more than 3m from the surface, as revealed by birds fitted with data loggers in Shetland (Garthe and Furness, 2001). They hunt both during the day and night (Ojowski *et al.*, 2001).

An offshore feeder, birds regularly depart from breeding colonies for more than 4-5 days on foraging trips, travelling to over 500km from the colony (Weimerskirch *et al.*, 2001). During the provisioning of chicks, foraging is closer to the colony (Furness and Todd, 1984; Weimerskirch *et al.*, 2001) and the distribution of fishing effort relative to the colony size is believed to be an important determinant of the foraging range (Garthe and Hüppop, 1994).

Vulnerability
Northern fulmar was considered the least vulnerable seabird to offshore wind farm development by Garthe and Hüppop (2004) in their Wind farm Sensitivity Index. However wave and tidal stream devices will have different impacts, and the low flight altitude of fulmars will put them at greater risk of above surface collisions with such devices. There has been a record of a casualty at an onshore wind farm (Dierschke and Garthe, 2006). However in

terms of other impacts, they are likely to be less at risk. Below surface collisions are unlikely, since food is located by sight and taken from the top three metres of the water column, so any device would be visible to the bird. They do have some vulnerability to collisions with vessels and pollution, but this is less so than those species that spend considerably more time on the water surface. They will have a high tolerance of disturbance as they are used to exploiting human marine activities.

Shearwaters

Cory's shearwater *Calonectris diomedea*

Conservation status

There are no UK SPAs for either breeding or wintering Cory's shearwater, which is a rare passage migrant. It is not included in *BoCC3* but is listed on Annex 1 of the EU Birds Directive.

Distribution

Cory's shearwaters are only present during passage migration, mainly in August, and then only rarely, as they pass down the west coast of Scotland en route to wintering grounds in the southern hemisphere (Daunt, 2006). They are recorded more regularly in the ocean to the south-west of Britain (Stone *et al.*, 1995).

Ecology

Cory's shearwaters obtain prey from the surface of the water at shallow depths (Mougin and Mougin, 1998), and while their diet is dominated by fish they will also eat invertebrates, including pelagic cephalopods, driven to the surface by other predators (Granadeiro *et al.*, 1998).

Vulnerability

Despite their rarity in British waters, Cory's shearwaters must be considered at risk from collision with above surface structures, as they fly close to the water surface. Other risks are lesser; they are not at risk of below surface collisions or entrapment as they dive close to the surface and although they are a rafting species, they only occur on passage, so will spend only a relatively small amount of time on the water surface, therefore both collision with vessels or contamination with pollutants are lesser risks in UK waters.

Great shearwater *Puffinus gravis*

Conservation status

There are no UK SPAs with great shearwater as a qualifying species. It is a passage migrant in British waters, although it is regularly seen in the autumn. It is not included in either *BoCC3* or Annex I of the EU Birds Directive.

Distribution

Great shearwaters are present during passage in the late summer and autumn, as they pass down the west coast of Scotland (Daunt, 2006) and off the south west coast of England (Stone *et al.* 1995).

Ecology

Great shearwaters feed on fish and cephalopods, as well fishery discards. In general they obtain food by surface dives although recent studies using time depth recorders have recorded diving up to 19m (Ronconi *et al.*, 2010), and it is quite likely that they dive deeper than this as the data were obtained from only two individuals. Very little is known about behaviour during these deeper dives. It is also unknown how significant a part of their foraging routine these deep dives are.

Vulnerability
The greatest risk to great shearwaters will be that of collision with above surface structures, as they fly close to the water surface. They are not at risk of below surface collisions or entrapment when they dive close to the surface, although they have been recorded diving deeper, and when doing so they will be greater risk. They spend only a small amount of time in British waters therefore both collision with vessels or contamination with pollutants are lesser risks in UK waters.

Sooty shearwater *Puffinus griseus*

Conservation status
There are no UK SPAs for which the sooty shearwater is a qualifying species. The species is amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive. They are a passage visitor to the UK.

Distribution
Sooty shearwaters pass through UK waters on their return migration, mainly during July to November (Camphuysen, 1995), heading south. In the North Sea, large concentrations are found off the east coast of Scotland and England, south to the mouth of the river Humber, associated with spawning sites of herring (*Ibid.*). There can be considerable variation in numbers between years, ranging from low hundreds to several thousands recorded.

Ecology
The diet of sooty shearwaters is very catholic (Gould *et al.*, 2000). In Canada krill and soft bodied fish have been identified in the diet (Brown *et al.*, 1981), elsewhere cephalopods (Petry *et al.*, 2008), fishery discards (Valeiras, 2003), decapods and amphipods (Kitson *et al.*, 2000). They feed both by surface skimming and pursuit plunging (Weimerskirch and Sagar, 1996), during which they can make dives of considerable depth. One study in New Zealand (Taylor, 2008), recorded a mean depth of 42m, with one dive, the deepest recorded for any Procellariiformes, of 93m.

Foraging is by a combination of vision and smell, both grab and filter feeding (Hutchinson *et al.*, 1984; Lovvorn *et al.*, 2001), and can be carried out in low light conditions. They are very vulnerable to entrapment in driftnets or being hooked by longline fisheries (Uhlmann, 2003).

Vulnerability
While they are manoeuvrable in flight (King *et al.*, 2009), sooty shearwaters fly close to the surface of the water, and often do so in poor light conditions, so may be at risk of above surface collisions. Since they dive at a variety of depths, both surface skimming and pursuit diving, they will also be at risk of below surface collisions. The magnitude of the risk of both collision types may be magnified by their habit of foraging in low light conditions. Whilst their vision may be adapted for low light, their susceptibility to collision will depend on detection and response to the devices. They are also likely to be vulnerable to entrapment with underwater equipment.

As they spend much of their time in flight (King *et al.*, 2009), as for other shearwaters there will be a low risk of contamination by pollutants.

Manx shearwater *Puffinus puffinus*

Conservation status
There are six UK SPAs where one of the qualifying species is Manx shearwater, all for breeding birds, two each in Northern Ireland, Scotland and Wales. Largely within these SPAs are 90% of the European breeding population

(Mitchell *et al.*, 2004). They are on the *BoCC3* amber list, and not listed on Annex I of the EU Birds Directive. There are 299712 breeding pairs in the UK (Mitchell *et al.*, 2004).

Distribution

The main breeding colonies of Manx shearwaters are the islands of Skomer and Skokholm in Wales, and Rum, Scotland. Outwith the breeding season, they migrate to wintering grounds in the southern hemisphere, usually travelling along the western coasts of Britain. Within the breeding season there are temporal changes in the distribution. Initially, during May-June, the highest densities are found in the continental shelf areas west of Scotland and in the Celtic and Irish Seas, particularly around the main breeding colonies (Stone *et al.* 1995). Later in the season, during June-August, the highest densities are concentrated in the waters to the south and west of the Isle of Man, and in the Celtic Sea. See also Guilford *et al.* (2008) for GPS tracking maps based on foraging distributions of breeding birds at different stages of the season.

Ecology

Essentially piscivorous, Manx shearwaters will also eat cephalopods and small invertebrates. Piscine prey is largely small shoaling fish, especially clupeids such as herrings and sprats, associated with the frontal systems and stratified waters that are the preferred feeding areas. All prey is caught by seizing from the surface or by making shallow surface or plunge dives, mostly to depths of less than 3m (Brooke, 1990). However there is an increasing body of evidence from the application of remote sensing techniques of deep diving shearwaters (Burger, 2001; Burger and Shaffer, 2008) and depths of up to 70m have been recorded in five congeneric *Puffinus* shearwaters (Audubon's, Balearic, black-vented, short-tailed, sooty and wedge-tailed), (Ronconi *et al.*, 2010). It is therefore likely that Manx shearwaters also make deeper dives, although as for these other species little is known about their significance.

Feeding is often carried out within large rafts of birds, floating on the surface and diving for prey. These feeding rafts are distinct from those formed close to the colony, where birds gather before flying ashore at night (Wilson *et al.*, 2009), the rafts drifting closer to shore as the evening progresses. All visits to breeding colonies are made at night, and parent birds will be less active on moonlit nights, suggesting this is an anti-predator strategy (Storey and Grimmer, 1986). Dissection of the eye (Martin and Brooke, 1991) suggests that foraging is visual, and also reveals a high corneal refractive power, essentially the ability to gather light, although it is unclear whether this is related to nocturnal or amphibious habits.

Foraging trips can be over considerable distances and recent GPS tracking from Skomer Island showed that birds can fly more than 330km each way on foraging trips from the breeding colony (Guilford *et al.*, 2008). The mean duration of recorded foraging trips was 71.8 h, but 68% lasted only one or two days and the longest trip lasted 12 days. Females make longer foraging trips than males (Gray and Hamer, 2001).

Vulnerability

Manx shearwaters have been considered less susceptible to negative impacts from offshore wind farms (King *et al.*, 2009) and offshore renewables in general (Daunt, 2006). They have good flight manoeuvrability, but their low flight height and relatively high proportion of time spent in flight does put them at risk of collision with above surface structures. Other risks are likely to be lesser; as shallow/surface feeders with good visual acuity they are not at great risk of below surface collisions or entrapment. However it is not known if like other *Puffinus* shearwaters they make deeper dives and if they do so they would be at greater risk of collision and entrapment. As they raft on the sea prior to returning to their nest site, they are at risk of both collision with vessels or contamination with pollutants.

Balearic shearwater *Puffinus mauretanicus*

Conservation status

There are no UK SPAs for which Balearic shearwater is a qualifying species. A passage migrant, the species is red listed in *BoCC3*, largely because of its global conservation status, which is "Critically Endangered". It is also listed in Annex 1 of the EU Birds Directive.

Distribution

The Balearic shearwater is a rare passage migrant, seen off the southern coast of England, and also occasionally in the North Sea. There has been an increase in records of sightings, but this may be a function of increased awareness after a change in taxonomic status (Votier *et al.*, 2008).

Ecology

Balearic shearwaters feed mostly on small shoaling pelagic fish which they capture by plunge and pursuit diving. They will also scavenge fishery discards and have also been reported to capture fish from under floating drifting objects. (Arcos *et al.*, 2000). As with all *Puffinus* shearwaters, there are emerging data suggesting a capability for deeper dives than had been previously thought. One study, although limited to a single bird, found a majority of dives were within a depth of 10 m but with a maximum depth of 26 m (Aguilar *et al.*, 2003).

Vulnerability

Balearic shearwaters are considered to have good flight manoeuvrability (King *et al.* 2009) but their low flight height, relatively high proportion of time spent in flight and high proportion of nocturnal flying does put them at risk of collision with above surface structures. Other risks are likely to be lesser; as shallow/surface feeders with good visual acuity they are not at great risk of below surface collisions or entrapment, although deeper dives which they are physiologically capable of will put them at greater risk of entrapment.

Storm petrels

European storm petrel *Hydrobates pelagicus*

Conservation status

There are nine UK SPAs where one of the qualifying species is the European storm petrel, eight of which are in Scotland, principally in the Northern Isles and Outer Hebrides, and one in Wales. All are for breeding birds. European storm petrel is amber listed in *BoCC3* and listed in Annex 1 of the EU Birds Directive. There are 26000 pairs breeding in the UK (Mitchell *et al.*, 2004).

Distribution

European storm petrels are difficult to survey, both at colonies and at sea. They nest in burrows, occupancy of which can be hard to verify, and are difficult to spot at sea, particularly at high sea states. Consequently, the distributions of foraging storm petrels are poorly understood. Concentrations are to be found offshore to the west of the breeding colonies, notably at the Northern Isles, Hebrides, North West coast of Scotland, Kintyre and Pembrokeshire (Mitchell *et al.*, 2004), and the highest densities are above the shelf edge and continental shelf (King *et al.*, 2009). In winter they migrate to the tropics and southern hemisphere.

Ecology

The storm petrel is an entirely marine species, except for nesting. They feed mainly on small fish, squid and crustaceans, but will also feed on medusae and offal and will occasionally follow ships and attend trawlers. They forage on the wing, obtaining food from the surface of the water by snatching, dipping and skimming, or sometimes by "pattering", flapping their wings and kicking their feet across the water surface. Foraging is almost entirely carried out at night, and they commute between foraging sites and breeding colonies in the dark, probably as an anti-predator strategy. During summer nights, petrels will regularly forage inshore (D'Elbee and Hemery, 1998).

They return to breeding areas in April and May, and breeding begins in May and June. Colonies are formed on rocky ground, notably boulder beaches on offshore islands and stacks.

Vulnerability

While storm petrels are agile in flight, they fly low above the water surface, spend the majority of their time in flight, and when breeding most flights will be in darkness. Consequently they have a relatively high risk of collision with above surface structures. Conversely, as surface feeders they will have a low risk of below surface collision. They have a relatively high tolerance of disturbance, and spend little time sitting on the water, so will have a lower susceptibility to pollution.

Leach's storm petrel *Oceanodroma leucorhoa*

Conservation status

There are six UK SPAs for which Leach's storm petrel is a qualifying species, all in Scotland and all for breeding birds. Leach's storm petrel is amber listed in *BoCC3* and is in Annex 1 of the EU Birds Directive. Around 48000 pairs breed in Britain (Mitchell *et al.*, 2004). The majority of these will winter in the tropics.

Distribution

All the known breeding colonies of Leach's storm petrel are in the Northern and Western Isles, the largest of which is on St. Kilda. During the breeding season birds feed in an area concentrated at the continental shelf edge (Reid *et al.*, 2001) with the highest numbers in August including very large numbers of non-breeders.

Ecology

The concentrations of Leach's storm petrels at the continental shelf edge are associated with upwelling systems, which raise prey to the surface. Their diet comprises mainly small fish, cephalopods, and planktonic crustaceans which they catch on the wing by dipping, skimming or snatching from the surface. They sometimes follow marine mammals feeding on food scraps or faeces, and will forage on fishery discards. When provisioning nestlings, fish form the main prey brought to the nest and the bulk of this piscine prey comprises vertically migrating myctophids, which are associated with offshore habitats (Hedd and Montevecchi, 2006), although the crustacean component of their diet, parasitic amphipods, are more commonly found in nearshore habitats. All of their prey is taken from the surface of the water.

They are nocturnal (Watanuki, 1986; Abbott *et al.*, 1999), potentially as an anti-predator strategy, but also to exploit the migration to the surface of prey (Watanuki, 1985).

Vulnerability

Similarly to European storm petrels, Leach's petrels are considered to be agile fliers (King *et al.*, 2009), but fly low over the water surface, spend the majority of their time in flight, and make the majority of flights in darkness. Consequently, they have a relatively high risk of collision with above surface structures. Conversely, as surface feeders they will have a low risk of below surface collision. They are considered to have a relatively high tolerance of disturbance, and spend little time in contact with water, so will have a lower susceptibility to pollution.

Gannet

Northern gannet *Morus bassanus*

Conservation status

There are nine UK SPAs for which breeding gannet is a qualifying species, eight of which are in Scotland and one in Wales. Gannet is amber listed in *BoCC3* and is not listed on Annex I of the EU Birds Directive, There are 219000 pairs breeding in the UK (Wanless *et al.*, 2005), a significant percentage of the global population.

Distribution

The northern gannet is a common offshore bird, but as they breed in colonies, the greatest concentrations are around these, particularly St. Kilda, Bass Rock, Grassholm and Ailsa Craig, at highest numbers during incubation. The most important foraging areas are the outer continental shelf and shelf edge, (Stone *et al.*, 1995).

Ecology

The gannet is the largest seabird in the North Atlantic. Strictly marine, only coming to land to breed, they are opportunistic, generalist predators; their diet is primarily shoaling pelagic fish including mackerel, herring and gadoids, which they capture from plunge dives from 10-40m above the surface. However they also exploit a range of other prey species as well as fishery discards, in response to changes in prey availability (Martin, 1989). There is also a high degree of plasticity in foraging flight behaviour, which can vary as a function of sea temperature, primary production, copepod abundance, colony location and size, and human activities (Lewis *et al.*, 2001; Votier *et al.*, 2010). Their flights are made up of rapid direct flights interspersed with periods of slow sinuous travel, in response to prey encounters and physical conditions (Hamer *et al.*, 2009). Generally, they forage in the relatively shallow continental shelf or coastal waters. Sometimes these foraging trips are closely associated with marine bathymetric features (Hamer *et al.*, 2000) although often they are not.

Gannets generally dive to 12-15m, but can go to 19-20m (Hamer *et al.*, 2009), and in some cases will go considerably deeper. They plunge dive after visually locating prey, and sometimes they will pursue prey (Garthe *et al.*, 2000) subsequent to immersion, and extend the depth and duration of the dive with wing beats (Ropert-Coudert *et al.*, 2009). They tend to forage diurnally, but routinely spend nocturnal periods at sea, presumably loafing on the water.

As well as travelling several hundreds of kilometres on single foraging trips (Hamer *et al.*, 2000; Hamer *et al.*, 2001), they also spend considerable time in close proximity to the colony for loafing and feeding (McSorley *et al.* 2003). Sometimes travelling more than 1000km in a round trip, the foraging range varies with colony location, stage of breeding cycle and distribution of prey. Wintering British birds can stay comparatively close to the breeding colony or migrate as far away as west Africa (Kubetzki *et al.*, 2009).

Vulnerability

Most gannet flight activity is at more than 10m above the water surface (Garthe and Hüppop, 2004), and so they are less susceptible to above surface collisions with devices, associated infrastructure or vessels. However, as they plunge dive at speed they are at greater risk of below surface collisions, and subsequent pursuit of prey puts them at risk of collision or entanglement. Carcass recovery and analysis of underwater film has shown that accidental intraspecific collisions are not uncommon and can be fatal (Capuska *et al.*, 2011), as well as collisions with cetaceans. Since gannets have a very small degree of visual binocular parallax (Lee and Reddish, 1981) they have a poor ability to judge distance and this may increase their vulnerability to collision.

There is evidence of gannets avoiding offshore wind farms both during and outwith the breeding season (Dierschke and Garthe, 2006; Lindeboom *et al.*, 2011), but there is no evidence of how they would react to smaller wave and tidal stream devices. As regular discard feeders they are not disturbed by shipping traffic. It is unclear therefore how disturbance would affect gannets, although displacement is the likely consequence. As they are arguably better buffered against reductions in food supply than most other seabird species, displacement would be likely to have less of a population scale effect, although cumulative displacement from a number of foraging areas by multiple developments would be more likely to do so. There is a Crown Estate Strategic Ornithological Support Services (www.bto.org/soss) project on gannets currently seeking to establish population vulnerability to increases in mortality in relation to wind farms; this will be of some relevance to wave and tidal stream in terms of indicating overall robustness of the population.

Cormorants

Great cormorant *Phalacrocorax carbo*

Conservation status

There are 13 SPAs for which great cormorant is a designated species, five of which are for breeding birds, six in Scotland, five in England, and one each in Northern Ireland and Wales. Cormorant is not listed in Annex I of the EU Birds Directive and is in the *BoCC3* green list. There are approximately 8400 breeding pairs (Mitchell *et al.*, 2004) and some 23000 individuals winter in UK waters (Baker *et al.*, 2006).

Distribution

During the breeding season, they are widely distributed around the UK, largely breeding in coastal areas in mixed species colonies, but also, and increasingly, inland, usually in trees. These inland breeders are thought to be mainly of the subspecies *Phalacrocorax carbo sinensis,* and so distinct from the coastal subspecies. The wintering population is also widespread, although there are large concentrations in Liverpool Bay in England and Wales, and to a lesser extent the Firth of Clyde and inshore Moray Firth in Scotland.

Ecology

The great cormorant is a very well studied bird, and through the use of a broad selection of investigative techniques a considerable amount is known about the foraging ecology of this species. Until recently they were considered to be pursuit dive foragers, though they were known to show flexible behaviours, for example social foraging in turbid waters (Vaneerden and Voslamber, 1995) and nocturnal foraging in response to arctic winters (Gremillet *et al.*, 2005). This flexibility allows them to exploit a range of aquatic habitats and prey species, although in general they prefer soft-bottomed, shallow estuarine habitats. A number of studies have quantified foraging ranges (see review in Birdlife Seabird Wikispace: http://seabird.wikispaces.com/Great+Cormorant accessed on 22/10/2011), both from winter roosts and breeding sites, and a mean range of 8.5km from both has been calculated, although flights as far as 25km from nests and 35km from roosts have been recorded. Foraging bouts are short and regular, and while capable of diving to depths of 35m they prefer shallower water, less than 10m deep (Gremillet *et al.*, 1999). Prey selection is also rather flexible; while in general they prefer benthic fish, such as flatfish, they are opportunistic feeders and will eat pelagic shoaling species, as well as fresh water fish and invertebrates. In the double-crested cormorant, a similar species, prey density was found to have a negative relationship with foraging costs (Enstipp *et al.*, 2007), that is, less effort was expended catching prey in shoals as opposed to solitary prey.

Key to this flexibility in foraging seems to be physiological constraint; cormorants have poor eyesight, and instead of being pursuit divers as previously thought, they are now known to capture their prey at close quarters, just after detection (Martin *et al.*, 2008), and are therefore little affected by light conditions (Gremillet *et al.*, 2005; Enstipp *et al.*, 2007).

Vulnerability

Low flying, and with limited flight manoeuvrability (Garthe and Hüppop, 2004) cormorants will be very vulnerable to collision with any above surface structures. Their foraging strategy of close quarter prey detection will have competing influences on the risk of collision with underwater structures. The bird's poor visual acuity will increase collision risk; conversely the somewhat cautious, exploratory nature of the foraging will likely reduce risk. Other foraging techniques used by cormorants will also have different risks. Communal foraging, particularly associated with shoaling prey and turbid conditions (when fish are driven to clearer water (Vaneerden and Voslamber, 1995)) is likely to be less focused on the abiotic environment (such as energy generating devices) as the biotic (conspecifics and prey) and therefore carry a greater risk of collision. Furthermore, simply by virtue of increased numbers there will be a greater probability of collision. Compounding this, devices potentially act to increase the likelihood of communal foraging behaviour occurring by not only increasing turbidity, but also by increasing prey density, acting as Fish Aggregating Devices. Night foraging birds (Gremillet *et al.*, 2005) may have an increased risk of collision, although there is no evidence of this.

As well as spending time floating on the water surface, cormorants spend considerable time perched on rocks, or other haul-out points, often wing-spreading. This means that their susceptibility to contamination by floating pollutants will be less than some species which spend more time on the water although they may be susceptible to oiling where there is contamination of haul-out points. They may be attracted to above surface structures to use as haul-out points. Because of their flexibility in foraging strategy and habitat, they will be less susceptible to habitat loss through any development. Their sensitivity to disturbance is considered to be high (Garthe and Hüppop, 2004).

European shag *Phalacrocorax aristotelis*

Conservation status

There are 11 UK SPAs for which the European shag is a qualifying species, ten of which are in Scotland, and one in England, and all for breeding birds. Shag is amber listed in *BoCC3* and is not listed on Annex I of the EU Birds Directive. There are approximately 27000 pairs breeding in the UK (Mitchell *et al.*, 2004).

Distribution

The European shag nests in colonies, most of these occur on the north and the west coasts of Britain (Mitchell *et al.*, 2004). The largest colonies occur at Foula in Scotland, the English Farne Islands and Lambay Island in Northern Ireland and at sea distribution is concentrated at these and also around the colonies of Orkney, Shetland, the Moray Firth, the Firth of Forth, and the west coast of Scotland (Stone *et al.*, 1995). It is almost entirely a coastal bird, and outside the breeding season, remains in coastal waters. While some disperse further along the coast (Skov *et al.* 1995), a number of birds will roost at the deserted breeding colony during winter (Cramp 1998).

Ecology

Shags are foot propelled pursuit divers that feed on a variety of benthic, pelagic and demersal fish. While showing a strong preference for rocky coasts and islands, they are also found over shallow sandy sediments, where they feed on sandeel. They are wholly diurnal and need to either return to land, or to use other haul out points.

Radio-tagged individuals from the Isle of May, in Scotland, have shown that most shags forage no further than 17 km from their colony (Wanless *et al.* 1991), although they will go as far as 20km. The variability in foraging range is a function of prey availability, and switches of prey, habitat and foraging range can be abrupt (Wanless *et al.*, 1998). As such they are considered to be an opportunistic, and highly dynamic predator (http://seabird.wikispaces.com/European+Shag accessed 24/10/2011).

The plasticity in prey and habitat is also reflected in foraging strategy, as recently revealed by a study using camera loggers mounted on the birds (Watanuki *et al.*, 2008). This work showed that shags will forage solitarily for bottom-living fish in rocky habitats, but communally over sandy habitats where they forage for sandeel. In the rocky habitats they seek out prey in crevices or amongst kelp, travelling along the bottom; in the sandy habitats they are more stationary, probing the seabed with their bills. Rocky habitats are utilized at a variety of depths, 10 – 40m, whereas sandy habitats were foraged over at predominantly only two depths, 24 or 32m. No explanation was given for the precision of these two depths, but they occur within the range of depths indicated over rocky habitats, so suggest similar depth range.

Vulnerability

European shags are considered to be low flying, and with limited flight manoeuvrability (King *et al.*, 2009) and so will be very vulnerable to collision with any above surface structures. Although little is known about their visual acuity, it is though they are pursuit divers, in which case they will be more at risk of collision. However their foraging modes, either probing or searching for prey, are not associated with high collision risk, although they may be at some risk of entanglement. They feed at depths where submerged structures would not necessarily be detectable from the surface.

Similarly to cormorants, shags spend considerable time perched on rocks and other haul-out points. Consequently their susceptibility to contamination by floating pollutants will be less than those species which spend more time on the water. They will be attracted to above surface structures in order to use them as haul-out points. Because of their flexibility in foraging strategy and habitat, they will be less susceptible to habitat loss through any development, although their sensitivity to disturbance is considered to be high (King *et al.*, 2009).

Phalaropes

Red-necked phalarope *Phalaropus lobatus*

Conservation status

There is a single UK SPA for breeding red-necked phalarope, on Fetlar. Red-necked phalarope is red-listed in *BoCC3* and is listed in Annex 1 of the EU Birds Directive. There are 39 – 40 males breeding in Britain (Eaton *et al.*, 2009).

Distribution

The red-necked phalarope breeds in small numbers in Shetland, Orkney and the Inner and Outer Hebrides. They are likely to fly along the west coast of Scotland on passage. Overall numbers of breeding and migrating individuals will be small.

Ecology

There has been little work on the wintering ecology of red-necked phalarope. In marine habitats, red-necked phalarope feed on copepod-sized zooplankton, brought to the surface by the passage of strong tidal currents over shallow, rocky ledges (Brown and Gaskin, 1988). They obtain these by pecking at the water surface while swimming (Mercier and Gaskin, 1985). The upwellings and convergances associated with bringing the zooplankton to the surface are thought to be the main determinant of the phalarope distribution (Brown and Gaskin, 1988).

Vulnerability
There are no published data on flight manoeuvrability or height. As such the risk of above surface collisions cannot be determined at present. They do not dive for prey, obtaining it instead from the surface of the water, so will be at low risk of below surface collisions. It is unclear how they would respond to disturbance. A high proportion of their time is spent on the water surface, so they will be highly susceptible to contamination by oil-based pollutants.

Grey Phalarope *Phalaropus fulicarius*

Conservation status
There are no UK SPAs for which grey phalaropes are a qualifying species. They are amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive.

Distribution
Grey phalaropes are scarce winter migrant to the UK. Wintering at sea, they are usually found offshore, (Brown and Gaskin, 1988), although storms can bring them closer to the coast.

Ecology
There has been little work on the non-breeding ecology of grey phalaropes. They feed on zooplankton, brought to the surface by upwellings and convergences, which concentrate the prey (Brown and Gaskin, 1988). They obtain these with quick downward pecks at the water surface while swimming, usually with only the tip of the bill immersed (*Ibid.*).

Vulnerability
There are no published data on the flight manoeuvrability or height of grey phalaropes. As such the risk of above surface collisions cannot be assessed. When at sea, they are entirely surface feeders, so will be at low risk of below surface collisions. It is unclear how they would respond to disturbance. The majority of their time is spent on the water surface, so they will be highly susceptible to contamination by oil-based pollutants.

Skuas

Pomarine skua *Stercorarius pomarinus*

Conservation status
There are no UK SPAs for which the pomarine skua is a qualifying species. Green listed in *BoCC3*, pomarine skua is not included in the EU Birds Directive.

Distribution
During spring passage, pomarine skuas are found at the English south coast, Outer Hebrides and Shetland. In autumn, they are more associated with North Sea coasts.

Ecology
The diet of pomarine skua consists of fish, seabirds, rodents, insect and marine invertebrates and carrion. This food is obtained by surface skimming, kleptoparasitism and scavenging.

Vulnerability
Considered highly agile in flight, and flying relatively high above the surface of the water (King *et al.*, 2009) pomarine skuas are of relatively low risk of above surface collisions, taking food either directly or via

kleptoparasitism, from the surface of the water, they are also of low risk of sub surface collisions. They are tolerant of disturbance, and will be at a low risk of contamination by pollutants.

Arctic skua *Stercorarius parasiticus*

Conservation status

There are six UK SPAs, for which breeding Arctic skua is a qualifying species, all in the Northern Isles. Arctic skua is red-listed in *BoCC3* but is not included in the EU Birds Directive. There are around 2100 breeding pairs in the British Isles (Mitchell *et al.*, 2004), and the species is in sharp decline in the UK (*Ibid*).

Distribution

Arctic skua is confined to breeding in colonies in north and west Scotland. Most colonies are on moorland close to aggregations of auks, kittiwakes and terns. During the breeding season the birds stay close to the colonies, but at the end of the breeding season they move south throughout the UK coastal waters (Stone *et al.*, 1995). They winter in the southern hemisphere.

Ecology

Arctic skuas are highly specialised kleptoparasites. They are also capable of taking a variety of other food, including birds, eggs, mammals, fish, insects and berries. However in the UK their main food is sandeel, obtained by kleptoparasitism (Furness, 1987) following aerial pursuit. The principal host is Arctic terns, although kittiwakes and auks can also be targeted (http://seabird.wikispaces.com/Arctic+Skua accessed on 05/11/2011). As kleptoparasites, their foraging distribution is largely determined by the distribution of host species. Their population decline is considered to be due to shortage of prey fish, perhaps exacerbated through interspecific competition with Great skua.

Vulnerability

Arctic skuas are considered highly manoeuvrable in flight and fly at a relatively high altitude (Garthe and Hüppop, 2004). As such they will not be at risk of above surface collisions. They will only obtain food from the water surface, dropped by their hosts, and do not dive (http://seabird.wikispaces.com/Arctic+Skua accessed on 05/11/2011). They will therefore not be at risk of sub-surface collisions. They are relatively tolerant of disturbance (Garthe and Hüppop, 2004), even while breeding (Berry and Davis, 1970). Spending little time on the surface of the water and not diving for prey, they will not be susceptible to contamination by pollutants.

Great skua *Catharacta skua*

Conservation status

There are seven UK SPAs for which breeding great skua is a qualifying species, all in the northern and Western Isles of Scotland. Great skua is amber listed in *BoCC3* and is not included in Annex 1 of the EU Birds Directive. There are 9634 pairs breeding in the British Isles (Mitchell *et al.*, 2004), and they are infrequent during the winter (Stone *et al.*, 1995).

Distribution

At sea, Pollock *et al.* (2000), Bloor *et al.* (1996) and Stone *et al.* (1995) describe the highest densities of great skua during the breeding season as present around the breeding colonies on Orkney and Shetland, notably Foula, Hoy and Unst. Moderate densities occur along the edge of the shelf, in the northern Minches of western Scotland, and south to the Wash on the east coast of Britain (Stone *et al.* 1995).

Ecology
Great skua diet varies according to stage of breeding season and age of the bird. Early and late in the breeding season, they feed to a great extent on whitefish discarded from trawlers. During June and July, they feed mostly on sandeel, obtained by kleptoparasitism in multi-species flocks (Furness and Hislop 1981). Associated with this plasticity in prey and foraging method, associated foraging ranges also vary greatly; for example in one Shetland study birds specialising in seabird prey seldom flew more than two km from their nest site while those feeding on discards flew several tens of km away (Votier *et al.*, 2004). Great skuas also regularly forage at night catching storm petrels (Votier *et al.*, 2006).The highest densities are likely to be close to the largest breeding colonies.

Vulnerability
Great skuas are considered highly manoeuvrable in flight and fly at a relatively high altitude (Garthe and Hüppop, 2004). As such they will not be at risk of above surface collisions. However, night-feeding birds will be at an elevated risk of collision. While they have a variety of techniques for obtaining prey, they rarely occur deeper than the upper water column and so are not at great risk of sub-surface collision. They are tolerant of disturbance (Garthe and Hüppop, 2004), and discards feeders are attracted to human activity. This attraction may make them slightly more vulnerable to collision. They spend little time on the water surface so will not be susceptible to contamination by oil based pollutants.

Gulls

Mediterranean gull *Larus melanocephalus*

Conservation status
There are three UK SPAs for which Mediterranean gull is a qualifying species, as a breeding bird, all in southern England. Mediterranean gull is amber listed in *BoCC3* and is included in Annex 1 of the EU Birds Directive. Approximately 108 pairs breed in the UK (Mitchell *et al.*, 2004).

Distribution
Although still an uncommon bird, the population of Mediterranean gulls is increasing. They breed in the colonies of other gulls, especially black-headed gulls (Zielinska *et al.*, 2007), and these breeding sites are concentrated along the south-east coast of England. Observations at sea also have been concentrated in this area (Stone *et al.*,1995), mainly outwith the breeding season, although the range has expanded since these survey data were collected.

Ecology
Mediterranean gulls are opportunistic foragers feeding on a wide range of food items. During breeding, a large part of their diet consists of ground-dwelling invertebrates from agricultural fields (Dauwe *et al.*, 2009). Chick diet has been described as gastropods, insects and plant grains (Goutner, 1994), although this is likely to vary with location. When not breeding, the species takes marine fish, molluscs, insects, offal and occasionally sewage and refuse, feeding more in marine areas. When feeding at sea, they obtain food by surface-plunging, dipping and picking from water surface while swimming. There is no published information about flight behaviour.

Vulnerability
While there are few direct data, and the species was not assessed for vulnerability by Garthe and Hüppop (2004) or King *et al.* (2009), the Mediterranean gull can be considered broadly analogous to the black-headed gull. Under this analogy, they rarely forage beyond the intertidal zone, spending much time in terrestrial habitats, maintain a relatively high flight altitude and are tolerant of disturbance. Mediterranean gull is unlikely to have much exposure to pollutants. As such, it is unlikely to be at anything other than low risk from wave and tidal stream devices.

Little gull *Larus minutus*

Conservation status

A regular migrant, there are no UK SPAs for which little gull is a qualifying species, although this is under review. Little gull is amber listed in *BoCC3* and is not listed in Annex 1 of the EU Birds Directive.

Distribution

Little gull occurs in Britain both on passage and in winter. Distribution data are lacking and often dated, but indicate that passage birds are most common on the coast between Tayside and Yorkshire in eastern Britain (Stone *et al.*, 1995), north west England (Holt *et al.*, 2011) and along the East Anglian coast (Brown & Grice 2005). Wintering birds are relatively scarce, recorded in the Solent, Morecambe Bay (England) and the Firths of Forth and Tay (Scotland) (Stone *et al.*, 1995). There are more recent distributional data, notably from surveys initiated for offshore wind energy development, but these tend to be dispersed. The current SPA review may shed more light on the distribution of little gulls.

Ecology

Little gulls are primarily insectivorous during the breeding season although the proportion of their diet made up by fish and marine invertebrates increases during the winter, and they will eat offal discarded from fishing boats (http://seabird.wikispaces.com/Little+Gull, accessed 20/10/2011). They forage by flying or hovering just above the water surface, dipping in to catch prey on or just below the surface. To a lesser extent they also catch prey by plunge diving and surface pecking (Schwemmer and Garthe, 2006). The relative importance of pelagic foraging is unknown. They are social feeders, associating with other small gulls, terns and occasionally auks.

Vulnerability

Although the data on little gull are limited, from what is known it is likely that they will have a low vulnerability to most risks associated with offshore renewables. While its low flight height will increase its vulnerability to above surface collision, it is considered to have considerable flight manoeuvrability (Garthe and Hüppop, 2004), so the risk will be reduced. It is also tolerant of disturbance by ship and helicopter traffic, although work in the Netherlands, hampered by low sample sizes, suggests that they may avoid offshore wind farms (Lindeboom *et al.*, 2011). Most of its time at sea is spent in flight so the risk of contamination by pollutants is also low.

Black-headed gull *Larus ridibundus*

Conservation status

There is one UK SPA, in Lancashire, for which breeding black-headed gull is a qualifying species. Black-headed gull is amber listed in *BoCC3*, but not listed in Annex 1 of the EU Birds Directive. There are 128000 pairs breeding in the British Isles (Mitchell *et al.*, 2004) and 1700000 individuals overwinter.

Distribution

The black-headed gull is the most widely distributed seabird breeding in the UK, and it breeds both inland and on the coast, although it is typical of terrestrial and freshwater habitats (Kubetzki and Garthe, 2003). The majority of the breeding population is resident throughout the year. The wintering population occurs especially in the east and southeast of England (Mitchell *et al.*, 2004). Its marine distribution is primarily coastal (Kubetzki and Garthe, 2003), with small concentrations in Liverpool and Morecambe Bays, the North Channel, East Dorset and the Solent (Stone *et al.*, 1995).

Ecology

The black-headed gull has a broad dietary niche, made up to a large extent of bivalves and crustaceans. It obtains these in marine habitats almost entirely in the intertidal zone (Kubetzki and Garthe, 2003). It changes from terrestrial to marine foraging on a daily and seasonal basis, relating to the tidal cycle and breeding status (Schwemmer and Garthe, 2005).

Vulnerability

Considered by Garthe and Hüppop (2004) to have a low sensitivity score for vulnerability to offshore wind farms, the black-headed gull is also unlikely to be at anything other than low risk from wave and tidal stream devices. Rarely foraging beyond the intertidal zone and spending much time in terrestrial habitats, it maintains a relatively high flight altitude and is tolerant of disturbance. It is unlikely to have much exposure to pollutants.

Common gull *Larus canus*

Conservation status

There is one UK SPA for which breeding common gull is a qualifying species. It is amber listed in *BoCC3* and is not included in Annex 1 of the EU Birds Directive. There are 48000 pairs breeding in the British Isles (Mitchell *et al.*, 2004), and 670000 to 721000 individuals overwinter in the UK (Banks *et al.*, 2007).

Distribution

Common gulls breed on coasts and at inland sites, and spend the winter inland, on estuaries and at sea. In the UK their breeding distribution is virtually confined to Scotland and Northern Ireland (Mitchell *et al.*, 2004). In the winter there are high densities in the north Wash and Liverpool and Morecambe Bays (England) (Stone *et al.*, 1995). Marine birds are concentrated in coastal, inshore areas (Kubetzki and Garthe, 2003; Garthe *et al.*, 2009).

Ecology

Common gulls feed on a large range of food items. Marine food largely comprises small fish and intertidal organisms, as well as fish spawn (Bishop and Green, 2001). Where there is an upwelling of zooplankton, they will forage on these (Vermeer *et al.*, 1987), and will also feed on discarded fishery wastes. Terrestrial foods include earthworms, beetles and other insects (Mitchell *et al.*, 2004), as well as eggs and chicks of other birds. Their marine food is obtained from the surface of the water, or from the intertidal zone. They have considerable flight manoeuvrability, and fly at medium altitude (Garthe and Hüppop, 2004; Garthe *et al.*, 2009).

Vulnerability

The common gull was considered by Garthe and Hüppop (2004) to have a low sensitivity score for vulnerability to offshore wind farms; it will also be at low risk from wave and tidal stream devices. Rarely foraging beyond the intertidal zone and spending the majority of its time in terrestrial habitats, it is unlikely to have much contact with the devices, is tolerant of disturbance and is unlikely to have much exposure to pollutants.

Lesser black-backed gull *Larus fuscus*

Conservation status

There are six UK SPAs for which the lesser black-backed gull is a qualifying species, two in Scotland, the remainder in England, and all for breeding birds. The species is listed as amber in *BoCC3* and not included in Annex 1 of the EU Birds Directive. The British population is 110000 breeding pairs (Mitchell *et al.*, 2004) and 118000 to 131000 wintering individuals (Banks *et al.* 2007). The UK hosts over 50% of the biogeographical population of breeding lesser black-backed gulls.

Distribution

The data are patchy and scant on the winter distribution of lesser black-backed gull. During winter, this species was recorded as widespread along the coasts of the North Sea but more scattered in the Irish Sea. A few dispersed locations with high densities were present in the Celtic Sea and at the South-west Approaches (Stone *et al.* 1995). WeBS counts (Holt *et al.*, 2011) though lacking in comprehensive data with a small sample of monitored sites, indicate a reduction in recorded numbers, with concentrations in Morecambe Bay, Cotswold Water Park and the Ribble Estuary in England. Winter roost counts estimate approximately 92% of the GB wintering population are in England (Banks *et al.*, 2007).

Ecology

Lesser black-backed gulls have a varied diet, including fish, molluscs, crustaceans, eggs and rubbish obtained inland (Bustnes *et al.*, 2010) At sea, particularly during winter, they are often associated with fishing vessels and feed on discarded fish (Furness *et al.*, 1992). At breeding colonies, there is also widespread intraspecific predation of eggs and chicks (Davies and Dunn, 1976). Their distribution is related to food supply, particularly discards from fishing vessels, which encourage them to feed further offshore than they would if feeding on natural prey (Schwemmer and Garthe, 2005). Feeding on natural prey also tends to occur more in the mornings and evenings. When offshore all food is obtained from the surface of the water.

Vulnerability

Lesser black-backed gulls are very manoeuvrable in flight, and they tend to fly relatively high above the water surface (Garthe and Hüppop, 2004), so they will be at a relatively low risk of above surface collisions. As surface feeders, they also will have a low risk of below surface collisions. They are used to the presence of man, both offshore and on and so will be tolerant of disturbance. Pollution risk is moderate due to their habit of loafing on sea.

Herring gull *Larus argentatus*

Conservation status

There are eight UK SPAs for which breeding herring gull is a qualifying species, all in Scotland. The species is red listed in *BoCC3* and not listed in Annex 1 of the EU Birds Directive. There are 131000 breeding pairs in the UK (Mitchell *et al.*, 2004) and between 696,000 and 763,000 individuals overwinter (Banks *et al.*, 2007).

Distribution

Herring gulls are common throughout the British coast, and while mainly coastal in spring and summer they can be found throughout the North Sea during the rest of the year (Stone *et al.,* 1995). However there has recently been a substantial decline in the British breeding and non-breeding populations, hence their elevation to BoCC3 red listing (Eaton *et al.*, 2010).

Ecology

Herring gulls are widely opportunistic omnivorous scavengers. While generalists, individual birds often specialise in one type of diet, such as intertidal organisms, other birds or human refuse (Pierotti and Annett, 1991). Breeding marine birds will eat marine invertebrates especially crabs (Rome and Ellis, 2004), and benthic molluscs, which they obtain from the shallow intertidal zone. They will also kleptoparasitise food from other predatory seabirds, and catch fish at sea after plunge-diving into the water. Otherwise they may sit on the water, dipping into the water to catch prey.

Vulnerability

Garthe and Hüppop (2004) considered herring gull to be one of the least sensitive seabirds to negative effects from offshore wind farms. However, there are quite a few records of collisions, probably because of high levels of flight activity at these sites (Hötker *et al.*, 2006; Everaert and Stienen, 2007). It is unlikely that wave or tidal stream devices will pose much of a threat. Considered to be manoeuvrable in flight, they fly relatively high above the water surface and will therefore be at a relatively low risk of above surface collisions. As surface or near surface feeders, they also will have a low risk of below surface collisions. They are highly tolerant of the presence of man, and so will be tolerant of disturbance. With an extremely broad diet, they are unlikely to be susceptible to habitat loss.

Iceland gull *Larus glaucoides*

Conservation status

There are no UK SPAs for which the Iceland gull is a qualifying species. The species is amber listed in BoCC3 and not included in Annex 1 of the EU Birds Directive. A winter visitor, approximately 200 individuals were found each winter in the UK in 2004 to 2009 (Musgrove *et al.*, 2011).

Distribution

Iceland gulls breed on the coast of Greenland and are scarce winter visitors to the UK, typically seen in the north of Scotland, the Outer Hebrides and the Northern Isles (Stone *et al.*, 1995).

Ecology

There is little published information on the ecology of wintering Iceland gulls, although they are known to scavenge for discards (Valeiras, 2003), and can be considered opportunistic generalists.

Vulnerability

King *et al.* (2009) considered Iceland gulls to be manoeuvrable in flight and to fly relatively high above the water surface. It is therefore likely that they will be at a low risk of above surface collisions. Probably surface or near surface feeders, they also will have a low risk of below surface collisions. As discharge scavengers they will be tolerant of the presence of man, and so will be tolerant of disturbance. As generalists, they are unlikely to be susceptible to habitat loss. Spending time sitting on the water makes them moderately vulnerable to contamination by pollutants.

Glaucous gull *Larus hyperboreus*

Conservation status

There are no UK SPAs for which the glaucous gull is a qualifying species. The species is amber listed in BoCC3 and not included in Annex 1 of the EU birds Directive. A scarce winter visitor, approximately 150 individuals were found each winter in the UK in 2004-2009 (Musgrove *et al.*, 2011).

Distribution

Glaucous gulls are confined to the North Sea, and mainly to the Northern Isles and Scotland (Stone *et al.*, 1995).

Ecology

There is little published data describing the ecology of glaucous gulls. Breeding birds in Canada feed on guillemot eggs, chicks and carcasses (Gaston *et al.*, 2009). They can be considered broadly similar to herring gulls with which they hybridise (Palsson *et al.*, 2009), and as such as generalists capable of scavenging, kleptoparasitism and the capture of live prey by plunge diving or surface dipping. They are frequently associated with human refuse (Weiser and Powell, 2011) and trawler discards (Valeiras, 2003).

Vulnerability

King *et al.* (2009) considered glaucous gulls to be manoeuvrable in flight and to fly relatively high above the water surface. It is therefore likely that they will be at a low risk of above surface collisions. As surface or near surface feeders, they also will have a low risk of below surface collisions. As scavengers used to feeding on fishery discards and human refuse, they will be tolerant of the presence of man, and so will be tolerant of disturbance. As adaptable generalists, it is unlikely that they will be susceptible to habitat loss. Spending time sitting on the water makes them moderately vulnerable to contamination by pollutants.

Great black-backed gull *Larus marinus*

Conservation status

There are six UK SPAs for which great black-backed gull is a qualifying species, all for breeding birds. The species is amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive. 17000 pairs breed in the UK (Mitchell *et al.*, 2004) and 71,000 to 81,000 are estimated to overwinter (Banks *et al.*, 2007).

Distribution

Great black-backed gulls are widespread throughout the coastal areas of Britain particularly in the winter, and in the spring there are concentrations around Shetland, Orkney and the shelf edge to the north west of Scotland. They are resident in the UK. In winter, numbers are augmented by Norwegian breeders.

Ecology

Great black-backed gulls are omnivorous and opportunistic. Amongst other things their diet can contain fish, adult and young birds, birds' eggs, mammals, insects, marine invertebrates, carrion and refuse. Some studies have noted the importance of marine invertebrates, especially crabs, which are obtained from the shallow sub-tidal zone (Rome and Ellis, 2004). Harder food items, such as crabs and eggs are dropped whole to break open. Prey may also be pirated from other birds. They will forage both singly and in groups, and will do so both onshore and considerable distances offshore, when following fishing vessels or marine mammals.

When food is taken from the water, it is either taken from, or just below, the surface.

Vulnerability

Great black-backed gulls are considered to be moderately manoeuvrable in flight, and they tend to fly relatively high above the water surface (Garthe and Hüppop, 2004). They will be at a relatively low risk of above surface collisions. As surface or near surface feeders, they also will have a low risk of below surface collisions. They are tolerant of the presence of man, used to exploiting by-products of human activities, and so will be tolerant of disturbance. They have a remarkably broad diet, so are unlikely to be susceptible to habitat loss associated with deployment of marine renewables.

Black-legged kittiwake *Rissa tridactyla*

Conservation status

There are 29 UK SPAs for which the black-legged kittiwake (henceforth kittiwake) is a qualifying feature, all for breeding birds, and all in Scotland, except two, one of which is in England, and one in Northern Ireland. The species is amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive There are 367000 pairs breeding in the UK (Mitchell *et al.*, 2004).

Distribution

Wholly marine, kittiwakes are present throughout the UK. During the breeding season the highest densities occur along the coasts of Scotland and north-east England, over Dogger Bank and around Orkney (Stone *et al.* 1995, Skov *et al.* 1995). The Wee Bankie, off the Firth of Forth, has also been noted as a significant foraging area for kittiwakes breeding at the Isle of May (Wanless *et al.* 1998).

Ecology

Kittiwakes are pelagic surface feeders feeding in the upper couple of metres of the water column. They take fish from flight through dipping or shallow plunge-diving and during the breeding season feed mainly on small (15-20 cm) pelagic shoaling fish, such as sandeel, sprat and clupeids. Sandeel are especially important and their abundance has been shown to correlate with both breeding success and adult survival (Oro and Furness, 2002). Outwith the breeding season, planktonic invertebrates are likely to be important in the diet. During this time, they are essentially oceanic and are frequently associated with fronts, tidal upwellings and offshore sandbanks (Ratcliffe *et al.*, 2000).

The foraging range of kittiwakes has been described (Daunt *et al.*, 2002)as 73km for individuals from the Isle of May and a maximum foraging distance of 83km at the same location has been measured[1] (Humphreys *et al.*, 2006). Birds fitted with GPS recorders performed foraging trips close to a colony (within 13 km), while others had foraging ranges averaging about 40 km (Kotzerka *et al.*, 2010). The maximum foraging range was 59 km, and the maximum total trip length was 165 km. A close association between surface-feeding kittiwakes and diving guillemots has also been described (Camphuysen and Webb, 1999) – the former taking advantage of concentrations of prey brought near the surface by the latter. No information is available on dive depths but these are unlikely to be more than a metre.

Vulnerability

Garthe and Hüppop (2004) considered kittiwakes to be one of the least sensitive species to offshore wind farms. However, this was based in part on flight height, which is relatively low, and the collision window of wave and tidal stream devices will be considerably lower than that of wind turbines, so they will have a moderate level of vulnerability to above surface collisions. Sub surface collisions and entrapment are less likely, as they are visual surface feeders. They are also tolerant of human disturbance, so unlikely to be affected by construction and maintenance activities, and the presence of vessels and helicopters.

Terns

Sandwich tern *Sterna sandvicensis*

Conservation status

There are 18 UK SPAs for which the Sandwich tern is a qualifying species, the majority in England and all except two for breeding birds. The species is amber listed in *BoCC3* and included in Annex 1 of the EU Birds Directive. Around 11000 pairs breed in the UK (Mitchell *et al.*, 2004).

Distribution

Colonies of Sandwich terns are scattered around the UK coasts notably the North Norfolk coast, Minsmere, and Dungeness, in England. They are found primarily in shallow inshore waters close to these colonies, although they

[1] Recent, currently unpublished research, by the RSPB, has recorded greater foraging ranges by kittiwakes carrying GPS loggers.

can forage further offshore. Studies of birds in the Greater Wash observed individuals up to 53km offshore (Perrow *et al.*, 2010).

Ecology

Sandwich terns mostly plunge dive for prey when foraging, either entirely or partially immersing in the water, but will also snatch prey in flight from just below the surface or skim low over the waves to catch small fish emerging from the water. At the Greater Wash they spent 49% of their flying time above 20m height (Perrow *et al.*, 2010). The British population has a diet reliant on sandeel and clupeids, with sandeel important early in the breeding season, and clupeids increasing in importance during chick rearing. Their diet is less diverse than that of other terns, although they will eat fishery discards and invertebrates. While dive depths have been little studied, it is considered that prey are only taken from the upper two metres of the water column (http://seabird.wikispaces.com/Sandwich+Tern accessed 28/02/2012).

Vulnerability

Sandwich terns are very manoeuvrable in flight and fly relatively high above the water surface, so it is likely that they will be of a lower vulnerability to above surface collisions. As surface feeders, they are also at lower risk of sub surface collisions. While considered to be relatively tolerant of disturbance (Garthe and Hüppop, 2004) , this can only be considered in the context of foraging individuals; other species of terns are to known to be susceptible to disturbance by water traffic when at the breeding colony (Burger, 1998). As most of their time is spent in flight, they will be less susceptible to pollution.

Roseate tern *Sterna dougallii*

Conservation status

There are six UK SPAs for which the roseate tern is a qualifying species, all for breeding birds. Roseate tern is red listed in *BoCC3* and is included in Annex 1 of the EU Birds Directive. There were 103 breeding pairs in the UK in 2005 (Eaton *et al.*, 2010).

Distribution

Roseate terns breed in scattered colonies, mainly on the east and south coasts of Scotland and Ireland; with important colonies in Norfolk, Suffolk and Hampshire. They do not winter in UK waters.

Ecology

Roseate terns feed where there are high densities of prey, which they catch within the top 75cm of the water column (http://seabird.wikispaces.com/Roseate+Tern accessed 24102011). However they may dive deeper, as they have been observed initiating dives from greater altitude (Kirkham and Nisbet, 1987). They have a narrow range of prey, mainly sandeel. Very little work has been done on foraging ranges in north-west Europe, though it is assumed that they stay close to their colonies (Newton and Crowe, 2000).

Vulnerability

King *et al.* (2009) assessed roseate terns as having a high flight manoeuvrability and a medium altitude. As such they are unlikely to collide with above surface structures. To the best of our knowledge most dives are shallow, so collision risk below surface is also low. Spending the majority of their time in flight they are at a low risk of contamination. King *et al.* (2009) also attributed a fairly low susceptibility to disturbance.

Common tern *Sterna hirundo*

Conservation status

There 25 SPAs in the UK for which common tern is a qualifying species, all designated for breeding birds. Common tern is amber listed in *BoCC3* and included in Annex1 of the EU Birds Directive. 10000 pairs breed in the UK (Mitchell *et al.*, 2004).

Distribution

Common tern is a common and widespread breeding species in the UK, in both coastal and inland regions. Coastal sites tend to be mainly small rocky islets, shingle beaches, sand-spits and dunes, and inland sites beside freshwater bodies. The majority breed in Scotland, particularly in the western and northern isles and the west coast, but they are also associated with east coast firths. In England they are found in the north-east, East Anglia, and the south coast. They do not winter in the UK.

Ecology

Common terns are opportunistic, eating a variety of prey, mainly small fish, but also planktonic crustaceans and insects (Kirkham and Nisbet, 1987). They forage on the surface at low flight heights, often less than a metre above the water surface (Perrow *et al.*, 2010). At the Greater Wash (*Ibid*) the maximum distance they were recorded from the shore was 2km, although at Teesside (as part of the same study) they would forage up to 18km from the colony, and took larger prey (Perrow *et al.*, 2010). Only 6.7% of flight time was more than 20m above the surface.

Vulnerability

Garthe and Hüppop (2004) assessed common terns as having a high flight manoeuvrability, and medium flight height. However Perrow *et al.* (2010) describe flights just above the surface. As such the may be at some risk of collision with above surface structures. Garthe and Hüppop (2004) assess common terns as having a moderately low vulnerability to disturbance, although Burger (1998) described boats causing disturbance at breeding colonies. Most dives are shallow, so there is less risk of below surface collisions, and as they spend much of their time in flight there is a low risk of contamination by pollutants.

Arctic tern *Sterna paradisaea*

Conservation status

There are 18 SPAs in the UK for which Arctic terns are a qualifying species, all for breeding birds, and the majority in the northern isles. Arctic tern is amber listed in *BoCC3* and included in Annex 1 of the EU Birds Directive. 53000 pairs breed in the UK (Mitchell *et al.*, 2004), and they winter in the Antarctic.

Distribution

The majority of Arctic terns are concentrated at breeding colonies in the northern isles, although significant numbers are also found in the Hebrides and West coast of Scotland, Northumberland and North Wales.

Ecology

Arctic terns have a diet consisting of small fish, crustaceans, zooplankton and discarded offal, with sandeel particularly important (Ewins, 1985; Kirkham and Nisbet, 1987). They capture prey by plunge diving, usually within 20cm of the surface, (http://seabird.wikispaces.com/Arctic+Tern accessed 24/10/2011). Probably due to the high energetic demands of their flight (Uttley *et al.*, 1994), they forage within 10km of the breeding colony,

Vulnerability

Like other terns, Arctic terns will show the greatest response to disturbance at the breeding colony (Burger, 1998). As they show a limited behavioural plasticity in terms of foraging behaviour and range (Suddaby and Ratcliffe, 1997) they are likely to be more susceptible to changes and/or disturbance brought about by wave and tidal stream devices. While they fly low over the water surface, they are highly manoeuvrable in flight (Garthe and Hüppop, 2004) and so have a low to moderate probability of above surface collision, although this may depend on the focus of their attention. Constrained to foraging in the upper 20cm of the water column, they have a low probability of sub-surface collision. Spending much of their time in flight they will have a low susceptibility to contamination by pollutants.

Little tern *Sterna albifrons*

Conservation status

There are 25 SPAs in the UK for which little tern is a qualifying species, all for breeding birds; the majority of which are in England. The species is in chronic long term decline in the UK, is amber listed in *BoCC3* and is included in Annex 1 of the EU Birds Directive. 19000 pairs breed in the UK (Mitchell *et al.*, 2004). Little terns do not winter in the UK, instead migrating to the west coast of Africa.

Distribution

Little terns nest exclusively on the coast, on beaches, spits or onshore islets. Small, scattered colonies are found around the UK coastline, but the main concentration is in south and east England.

Ecology

The diet of little terns consists mainly of small fish, insects, annelid worms and molluscs, (http://seabird.wikispaces.com/Little+Tern accessed 21/10/2011). They plunge dive, from a hover, in very shallow water, which can be as little as a few cm deep (Davies 1981) up to about 100cm deep. They feed very close to the colony, rarely more than 5km from it (Perrow *et al.*, 2006) although failed birds could make foraging trips of up to 27km, however this was not directly out from the shore.

Vulnerability

Little terns are considered to be very vulnerable to disturbance, although the evidence can be conflicting. One study found areas subjected to strong human pressure were avoided by foraging little terns (Paiva *et al.*, 2008), although in Belgium birds frequently forage inside a busy port area (cited in http://seabird.wikispaces.com/Little+Tern accessed 21/10/2011). This difference is likely to be explained by the difference between recreational activities and industrial activities. Recreational activities, such as people on foot, often with dogs has unpredictable nature in time and space, compared with industrial activity, which is more likely to be contained, more predictable, and with potentially less “intrusion” by people on foot. Clearly any development close to breeding areas would cause disturbance, although such low energy environments would not be suitable for wave and tidal stream. However cabling or construction traffic to locations further offshore would cause disturbance, and with foraging birds so closely tied to the breeding area, could have negative impacts on the population. Collision with any devices either above or below surface is unlikely, and the potential for contamination is also low.

Auks

Black guillemot *Cepphus grylle*

Conservation status

There is a single UK SPA for breeding black guillemots, the Monach Isles in the Hebrides, Scotland. Black guillemot is amber listed in *BoCC*3, and not included in the EU Birds Directive. There are around 38000 individuals in Britain (Mitchell *et al.*, 2004).

Distribution

The highest numbers of black guillemots are on the Shetland and Orkney islands, and down the west coast of Scotland. Other small concentrations are on the Cumbrian coast at St Bees Head, along the N Ireland coast, and on the Isle of Man (Stone *et al.*, 1995). Their distribution is determined in part by the availability of suitable nest cavities that are safe from terrestrial predators such as rats, mink, stoats and otters (Mitchell *et al.*, 2004). They are resident throughout the year.

Ecology

Feeding primarily on benthic fish, black guillemots are surface divers, and mostly bottom feeders, actively searching among bottom vegetation for fish. They may also take prey in transit between bottom and surface. In Scotland the fish taken are sandeel from soft bottomed habitats, and butterfish, blennies and sea-scorpions from rocky substrates (Sawyer, 1998). Considered the most coastal of the alcids, in Canada during the breeding season, they feed in open-water, foraging principally in waters 10–30 m deep within 13 km of breeding colonies (Cairns, 1987); in Orkney they forage at a median distance of 300m from the shore, a median of 5.5 km from the nest. Studies have been initiated on the island of Stroma, in the Pentland Firth, on foraging and diving behaviour from GPS loggers and Time Depth Recorders (TDRs) respectively (E. Masden pers comm.).They prefer diving in moderate currents (Nol and Gaskin, 1987), probably to reduce energy expenditure. It is estimated that they spend around 10% of foraging trips in flight (Cairns *et al.*, 1987).

Vulnerability

Black guillemots fly low and have a low flight manoeuvrability (King *et al.*, 2009), and so are at risk of collision with above surface structures. This risk will be reduced by the low proportion of time they spend in flight (Cairns *et al.*, 1987). As bottom feeders, black guillemots are at risk of collision with devices placed anywhere in the water column. Furthermore, since they forage preferably in heterogeneous habitats, they may be attracted to devices that have created reefing effects. They will be moderately affected by disturbance (King *et al.*, 2009). Spending much of their time in water, they will be susceptible to contamination by oil-based pollutants.

Common guillemot *Uria aalge*

Conservation status

There are 31 UK SPAs for which the common guillemot is a qualifying species, all of which are for breeding birds. Only one, Rathlin Island in Northern Ireland, is not Scottish, and the majority of these are in the Hebrides and Northern Isles. It is amber listed in *BoCC3*, and is in Annex 1 of the EU Birds Directive. There are 1.3 million individuals in the UK (Mitchell *et al.*, 2004). It is the most abundant seabird in the UK.

Distribution

During the breeding season common guillemots are confined to around the breeding colonies, concentrated in the Northern Isles, but to a lesser extent, throughout the coast of Scotland, Wales and Northern Ireland, and the

Yorkshire coast in England (Stone *et al.*, 1995). During the early winter season, densities are high on the north-east coasts of Scotland and England, in the Minches, close to the Irish Sea Front and over Dogger Bank. As winter progresses, they disperse further over the southern North Sea, and off southern Ireland although high densities are still recorded in the inner regions of the Moray Firth and the Firth of Forth Bank (Stone *et al.* 1995; Skov *et al.* 1995).

Ecology

Common guillemots breed at most places around the coasts where there is suitable cliff habitat. They are gregarious; preferring colonial breeding and with colonies of many tens of thousands of individuals. The colonies are situated where the birds are safe from mammalian predators, which means that on the mainland they are usually confined to sheer cliffs or in among boulders at the bases of cliffs (Mitchell *et al.*, 2004).

The main prey items of the adult common guillemot are shoaling pelagic fish, mostly sandeel, herring and sprats, as well as small gadoids and they are capable of switching prey in response to availability (see review in http://seabird.wikispaces.com/Common+Guillemot, access 05/11/2011). The at-sea distribution of the species will be influenced by that of their important prey (Wright and Begg, 1997). They obtain prey by surface dives for food and are pursuit divers that use their wings for propulsion. Studies of birds fitted with data-loggers at the Isle of May showed that they forage predominantly slightly offshore from the colony and 10-20 km from the coast (Thaxter *et al.*, 2010), and other studies have recorded them 80 to 100km from the coast (Camphuysen *et al.*, 2007). They spend a moderate proportion of time away from the colony, one study recorded 68% of their time at the colony and 32% at sea (Tremblay *et al.*, 2003). The same study showed that when at sea they spend 77% on their time on the surface.

They may spot prey by head-dipping the repeatedly into water before diving and also may 'crash-land' over a fish shoal and dive almost immediately (http://seabird.wikispaces.com/Common+Guillemot, accessed 05/11/2011). When diving for prey, they have long dives, with an extended bottom phase of the dive profile time below the surface (Thaxter *et al.*, 2010). Associated with this is a fast rate of ascent, and long recovery time on the surface. They carry single items of prey back to the colony to feed their chicks.

Few birds fly in autumn due to moult and guarding of not-yet fledged chicks at sea (Markones *et al.*, 2010).

Vulnerability

Common guillemots fly low and have a low flight manoeuvrability (King *et al.*, 2009), and so are at risk of collision with above surface structures. They also have relatively long flight times to feeding areas, increasing this vulnerability. Furthermore, as single-prey loaders they may have to make numerous repeat flights to provision chicks, depending on the size of prey, and again this could increase vulnerability. When feeding they spend a high proportion of time under water and have a fast rate of ascent, meaning they have a high risk of below surface collision. Since they are very capable of prey switching, they may be less at risk from the negative effects of displacement, provided equivalent feeding opportunities are available close to the breeding colony. They are moderately affected by disturbance form helicopter and boat traffic (Garthe and Hüppop, 2004). Spending a relatively high proportion of time on the water surface, they will be at risk of contamination by oil-based pollutants.

Razorbill *Alca torda*

Conservation status

There are 18 SPAs in the UK for which razorbill are a qualifying species, the majority are in Scotland, with one in Wales and one in Northern Ireland. All are for breeding birds. Razorbill is amber listed in *BoCC3* and is not included in Annex 1 of the EU Birds Directive. 164000 individuals are present in the summer (Mitchell *et al.*, 2004).

Distribution

Razorbills are relatively common throughout the coastal waters of Scotland, Wales and Northern Ireland, but are restricted to the north east and south west coasts of England. The principal breeding sites are in northern Scotland, including the Western Isles, Shetland, Caithness and Sutherland. They breed on small ledges or in cracks of rocky cliffs, in associated scree, and on boulder-fields. Colonies are usually in association with other seabirds (Mitchell *et al.*, 2004). Outwith the breeding season, they occur widely in coastal waters off western Britain and Ireland, and in the North Sea.

Ecology

Razorbills feed mainly on shoaling fish; mostly sandeel for birds at breeding colonies in British Isles, supplemented by herring, sprat, and rockling (see review in http://seabird.wikispaces.com/Razorbill, accessed 05/11/2011). They catch their prey mostly by surface-diving, dipping their head into the water to locate prey before diving. They will also 'crash-land' over fish shoals and dive immediately (*Ibid*). Dive times are relatively short (Thaxter *et al.*, 2010) and dives are frequent. Dives are also relatively shallow with little time spent in the bottom phase of the dive (*Ibid.*) Razorbill generally feed in fairly shallow waters offering predictable feeding conditions, often over sandy sea beds, although in winter they can be more associated with nutrient upwelling tidal fronts (Skov *et al.*, 2000). Studies of birds fitted with data loggers at the Isle of May, which is approximately eight km from the mainland, recorded almost half of all razorbill foraging trips within 10 km of the coast (Thaxter *et al.*, 2010). The remainder of trips were to areas 30-40 km offshore. The maximum distance reached from the colony was 18.42 km. The mean distance travelled per trip was 47.8 km. (*Ibid.*). In July, chicks leave the colonies before they can fly and swim out to sea to fledge.

Vulnerability

With little flight manoeuvrability and low flight height (Garthe and Hüppop, 2004), razorbills will be at higher risk of above surface collisions. Their dives are relatively short and shallow, so they will be less at risk of below surface collisions. They are considered moderately susceptible to disturbance to boat and helicopter traffic. Spending much time on the surface, from which they dive to obtain prey, they will be vulnerable to contamination by oil-based pollutants.

Puffin *Fratercula arctica*

Conservation status

There are 16 SPAs in the UK for which puffin is a qualifying species, all but one in Scotland, and all for breeding birds. Puffin is amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive. 1579 pairs breed in the UK (Mitchell *et al.*, 2004), and they largely winter offshore.

Distribution

During the breeding season puffins are present in high densities close to their breeding colonies at Shetland, Orkney, the Faeroes, the Outer Hebrides, St Kilda, and the Firth of Forth in Scotland, and Skomer in Wales (Stone *et al.*, 1995). Adults arrive back at the breeding colony in March and April and leave again in mid-August. Some remain in the North Sea in winter, others move further south to the Bay of Biscay.

After the breeding season, when puffins leave their colonies, they move offshore within the western North Sea (Skov *et al.* 1995, Stone *et al.* 1995). To the north and west of Scotland they move into deeper waters and moderate densities are recorded south and west of the Faroes, around Shetland, Orkney and in the Minches (Pollock *et al.*, 2000).

Ecology

The diet of puffins is dominated by small to mid-sized shoaling pelagic fish, with sandeel the preferred prey item in the UK (see review in http://seabird.wikispaces.com/Atlantic+Puffin, accessed 07/11/20011). They can show considerable plasticity in diet; switching prey in relation to availability. They obtain prey by pursuit diving, locating it by head-dipping then initiating pursuit by surface diving (*Ibid.*). While during the breeding season they are thought to forage in relatively shallow water, there is relatively little published information. They are however known to be capable of dives up to 75m (Burger and Simpson, 1986) and another study (Barrett and Furness, 1990) recorded median dive depths of 25-30m. These depths are likely to reflect prey abundance rather than physiological capabilities. There is also little direct published information on foraging ranges in the UK. Radio tracking of a single individual at the Isle of May recorded 64% of flights within 2km of the colony and 29% more than 10km (Bradstreet and Brown 1985).Transects have recorded birds 40km away from the colony at sandbanks. Trip durations measured at various colonies around the Britain suggest a foraging range between around 35 – 100 km from the colonies (http://seabird.wikispaces.com/Atlantic+Puffin accessed 07/11/2011).

Puffins can catch and carry multiple prey items, although they may carry single items bent double to reduce flight impairment (Barret *et al.* 1987).

Vulnerability

With moderate flight manoeuvrability and low flight height (Garthe and Hüppop, 2004), puffins will be vulnerable to above surface collisions. They are capable of diving relatively deep in pursuit of prey and are also therefore susceptible to below surface collision. They are only moderately affected by disturbance from helicopter and boat traffic (*Ibid.*), and plasticity in diet means they may not be strongly affected by displacement, if alternative, accessible prey supplies exist. As they spend much time on the water surface, initiating dives from it, they will be vulnerable to contamination by oil-based pollutants,

Coastal waders

Species accounts presented here focus on those species for which substantial proportions of their respective UK populations are associated with open coasts, potentially bringing them into close contact with shore-based components of wave and tidal stream devices. Other species of waders and wildfowl also occur in these habitats and may require consideration at the scoping stage of wave and tidal stream development proposals.

Turnstone *Arenaria interpres*

Conservation status

There are 13 SPAs in the UK for which turnstone are a qualifying species, all for wintering birds. They do not breed in the UK but some 50000 individuals overwinter (Baker *et al.*, 2006). They are amber listed in *BoCC3*, and not included in Annex 1 of the EU Birds Directive.

Distribution
Turnstone are found throughout the coast of the UK, with concentrations on the coast of north-east England, the estuaries of north-west England, the north Kent coast, the east coast of Scotland, the Outer Hebrides, Orkney, and the east coast of Northern Ireland. Their preferred habitat is rocky, stony or seaweed covered shores.

Vulnerability
Turnstone are susceptible to human disturbance, with declines in local populations associated with increased disturbance (Burton *et al.*, 1996). As such, any developments on or close to the coast, and infrastructure and plant associated with developments further offshore, are likely to affect turnstone, leading to displacement.

Purple sandpiper *Calidris maritima*

Conservation status
There are two SPAs in the UK for which purple sandpiper are a qualifying species, one in Northumbria and one in Sanday, Orkney. Both are for wintering populations. They are amber listed in *BoCC3* and not included in Annex 1 of the EU Birds Directive. Some 18000 individuals overwinter in Britain (Baker *et al.*, 2006), and one to three pairs breed (Smith and Summers, 2005).

Distribution
The majority of purple sandpiper occur on the rocky coasts of Scotland, although significant numbers are also found on the Northumberland coast and Outer Ards in Northern Ireland (Holt *et al.*, 2011). The limited breeding population is confined to heath and bog in the Scottish Highlands (Dennis, 1983).

Vulnerability
Declines in numbers of wintering purple sandpiper associated with construction disturbance have been described (Burton *et al.*, 1996). Developments on or close to the coast, and infrastructure and plant associated with developments further offshore will affect wintering purple sandpiper, most likely through displacement. Wave and tidal stream developments will have no effect on the breeding population.

Sanderling *Calidris alba*

Conservation status
There are eight SPAs in the UK for which sanderling are a qualifying species, all for wintering birds. They are green listed in *BoCC3*, and are not included in Annex 1 of the EU Birds Directive. They do not breed in the UK, but there is a wintering population of 21000 individuals (Baker *et al.*, 2006).

Distribution
Sanderling overwinter on estuaries and open coasts, throughout the UK with concentrations in North West England and the Hebrides.

Vulnerability
Sanderling are susceptible to human disturbance, and can alter their behaviour in response to it (Thomas *et al.*, 2003) .Disturbance associated with developments on or close to the coast, and infrastructure and plant associated with developments further offshore, is therefore likely to affect any wintering sanderling in the area.

Ringed plover *Charadrius hiaticula*

Conservation status

There are 19 SPAs in the UK for which ringed plover are a qualifying species, six for breeding birds. These are all coastal sites. They are amber listed in *BoCC3*, and are not included in Annex 1 of the EU Birds Directive. The UK breeding population is between 5000 and 5500 (Conway *et al.* 2008), is in steady decline, and the wintering population is 32000 (Baker *et al.*, 2006).

Distribution

The breeding population of ringed plover is distributed widely around the British coast, with concentrations around the sandy and shingle beaches between the Thames and the Humber, the Hebrides, Orkney and Shetland. They breed on coastal beaches, saltmarshes, the shores of gravel pits and estuaries as well as machair and arable fields. The majority of the wintering population is also coastal, with small additional numbers at inshore waters. There are larger, and increasing (Holt *et al.*, 2011) non-breeding numbers in the passage periods of spring and autumn.

Vulnerability

The population decline of ringed plover has in part been attributed to human disturbance, and the potential for population scale effects demonstrated (Liley and Sutherland, 2007). Birds actively avoid areas of high disturbance (*Ibid.*). Developments on or close to the coast, and infrastructure and plant associated with developments further offshore may affect ringed plover breeding or wintering. The most likely outcome is displacement and/or disruption of breeding.

Raptors and chough

White-tailed eagle *Haliaeetus albicilla*

Conservation status

There are no UK SPAs for which the white-tailed eagle is a qualifying species. As a recently reintroduced species, when the last SPA review was carried out, the population was too limited, and the potential expansion too uncertain, to merit any SPA classification. This situation will most probably change under the current review. White-tailed eagle is listed as red in *BoCC3* and listed in Annex 1 of the EU Birds Directive. There are 52 breeding pairs, all in Scotland (RSPB 2011).

Distribution

The British population of white-tailed eagles has been re-established, after extinction, by a release programme from Norway, with all the birds released in Scotland (Evans *et al.*, 2009). The current breeding population is concentrated on the west coast of Scotland and the Hebrides, although one of the release sites is in Fife, on the east coast. The birds range throughout Scotland, and increasingly the north east coast of England and the coast of Northern Ireland. They nest in a variety of locations, in Scotland typically in trees or on cliffs, at relatively low altitudes (Hardey *et al.*, 2009; Evans *et al.*, 2010). Cliff nests in particular are close to (median 0.2 km) large bodies of water or the coast (Evans *et al.*, 2010).

White-tailed eagles forage over wetland, coastal or marginal habitats for a wide range of prey, including seabirds and estuarine and freshwater birds (Love, 1983; Madders and Marquiss, 2003), as well as other birds, mammals and fish. Juveniles disperse widely, although they often move closer to natal areas in spring (Nygård *et al.*, 2000) though this behaviour is not known in Scottish birds (Whitfield *et al.*, 2009). They breed at around five years old, although there is an emerging trend for Scottish birds to breed earlier (Bainbridge *et al.*, 2003), possibly as a function of being a reintroduced species currently at low population size.

Vulnerability
White-tailed eagles are known to be susceptible to collisions with man-made objects such as wind turbines (eg at Smøla in Norway, Follestad *et al.* 2007; Bevanger *et al.* 2010), and power cables (Bainbridge *et al.*, 2003). These structures are quite different from those associated with wave and tidal stream, and while collision with surface structures is theoretically possible during foraging, it seems unlikely. Their main vulnerability will be to disturbance, especially when nesting. As birds nesting on or close to the shore, they are likely to be susceptible to disturbance from the installation of wave and tidal stream devices and associated infrastructure including cables, as well as personnel during installation, operation and decommissioning. Any construction, or other, disturbance from February to mid-May is likely to cause nest failure (Hardey *et al.* 2009).

Golden eagle *Aquila chrysaetos*

Conservation status
There are 14 UK SPAs for which golden eagle is a qualifying species, all in the Scotland. Those with a marine component are all on the west coast and Hebrides. Golden eagle is amber listed in *BoCC3* and included in Annex 1 of the EU Birds Directive. There were 442 pairs recorded in the 2003 survey (Eaton *et al.*, 2007).

Distribution
Breeding golden eagles are now confined to uplands of Scotland with notably high densities on Mull, southwest Highlands, Skye, parts of Wester Ross and the Outer Hebrides, particularly Lewis and north Harris (Eaton *et al.*, 2007). In the west of their range they can be associated with coastal areas, and will nest on sea cliffs (Hardey *et al.* 2009).

Vulnerability
Golden eagles are generalist predators and a significant proportion of their diet can be made up of seabirds and waterfowl (Whitfield *et al.*, 2009). As such they will forage over areas where there is potential for the installation of wave and tidal stream devices. However it is unlikely that there will be negative interactions with any of the structures, as these would only occur above the surface where the probability of such an encounter is considered extremely low. While disturbance is unlikely to be a factor in the distribution of golden eagle (Whitfield *et al.* 2007), nesting birds are very susceptible to any disturbance (Hardey *et al.* 2009). Birds nesting on sea cliffs will be very vulnerable to any disturbance from the installation of devices and the presence of personnel.

Peregrine falcon *Falco peregrinus*

Conservation status
There are nine SPAs in the UK for which peregrine falcon is a qualifying species, four of which have a coastal component, namely, Hoy, the East and North Caithness Cliffs and Rathlin Island. Peregrine is green listed in *BoCC3* and is included in Annex 1 of the EU Birds Directive. There are 1400 pairs breeding in the UK (Banks *et al.*2003).

Distribution
Peregrines nest throughout the UK, and as a highly adaptable species, will nest in a variety of locations, including sea cliffs (Hardey *et al.*, 2009).

Vulnerability

Peregrines forage by the pursuit of other birds, notably passerines, waders and racing and feral pigeons. They are unlikely to interact with wave and tidal stream devices. However when nesting they are susceptible to disturbance, and therefore birds nesting on sea cliffs will be very vulnerable to any disturbance from the installation of devices and personnel in the vicinity of the devices, especially during the early stages of the nesting period.

Chough *Pyrrhocorax pyrrhocorax*

Conservation status

There are 24 SPAs in the UK for which chough is a qualifying species, nine of which are for breeding birds. The species is amber listed in *BoCC3* and included in Annex 1 of the EU Birds Directive The breeding population is between 428 and 496 pairs (Johnstone *et al.*, 2007).

Distribution

Choughs in the UK are largely confined to isolated coasts in west Scotland, Wales and the Isle of Man and increasingly in SW England, although a few isolated pairs remain in inland parts of north and central Wales and Northern Island and they are largely resident in breeding areas. They nest in shallow caves in cliffs. Non-breeders form large flocks that roam and forage over wide areas (Madders *et al.*, 1998).

Vulnerability

Choughs are very susceptible to human disturbance; even relatively minor disturbance can have dramatic effects on population viability in a protected area (Kerbiriou *et al.*, 2009). These effects can even occur when breeding individuals are not directly affected. Disturbance from installation of wave and tidal stream devices will therefore have the potential for impacts on the chough population.

4. Survey methodology

Identify birds present

For the Environmental Impact Assessment (EIA) of any proposed marine renewable development, information on the use of the development and surrounding areas by seabirds is essential (Appendix IV). In order to obtain these data, surveys are likely to be required because of the paucity of current data, and these surveys will then be used to determine potential receptors and impacts. Crucially, surveys should not just be of the "impact" area, i.e. wave or tidal stream development footprint, but should also provide ecological context, and so the methods used for survey must be carefully considered. Seabird distribution is stochastic, densities and behaviours are highly variable and therefore need to be surveyed with a high spatial and temporal resolution. Understanding the mechanisms of this natural variability is vital for any assessment of whether a development has caused change in bird behaviour or distribution. Therefore, distribution patterns need to be described in a context of geographical and oceanographic influences, as well as the effects of food supply and anthropogenic activity. Surveys must not just cover the range of temporal and spatial variation; weather conditions are critical to the behaviour of seabirds (Garthe *et al.*, 2009) and so coverage must include as broad a variety of conditions as logistically and safely possible. While it is the developer's responsibility to collect data for the development footprint and agreed buffer or reference area, potentially contextual data could be better delivered by collaboration between regulators and industry, in order to obtain appropriate temporal and spatial resolution. Marine Scotland has commissioned digital aerial surveys of the Pentland Firth and Orkney Waters for this purpose (boat-based surveys are problematic in the high-energy sea conditions likely to be encountered, due to the difficulty of holding any transect line).

A workshop organised by COWRIE (Collaborative Offshore Wind Research Into the Environment) in 2003 (Camphuysen *et al.*, 2004), in the context of offshore wind farms, identified the need for research targets to be clear before survey and defined them as follows:

- Seabird distribution patterns
- Seabird abundance
- Migratory pathways
- Foraging areas
- Factors explaining seabird distribution and abundance
- Variability in spatial and temporal patterns
- Seasonal
- Diurnal including tidal phases
- Spatial
- Evaluation of collision risks

These targets are also consistent with the survey needs for wave and tidal devices, and so provide a useful focus for survey design, prior to surveys beginning. There are four important general survey methods, all of which are very useful, but none of which would provide enough data in itself. These methods are useful for baseline data collection, notably for the EIA stage, but all but the first also have a potential role in monitoring pre-, during and post-construction, necessitating establishment of suitable study protocols to enable comparison of before and after data. Careful consideration of study objectives and bird species will help to identify the most appropriate methods and protocols to use, both for baseline data collection and for before/after comparisons.

Desk study

Before any surveys begin, site-specific knowledge should be obtained to fine-tune the methodology, including bathymetry, geographical characteristics, likelihood of use by breeding, migratory, foraging, wintering or moulting birds, by fisheries, by marine mammals and the use of the area for aggregates and shipping. There is a body of knowledge of seabird distributions around the British Isles, mainly through European Seabirds at Sea (ESAS), (Stone *et al.*, 1995), as described above, but coverage is often patchy both spatially and temporally. Some areas, notably around some seabird breeding colonies, have been surveyed in greater detail (McSorley *et al.*, 2003). As part of the SPA designation process, a detailed analysis of the ESAS data set has been carried out, (Kober *et al.*, 2010). This analysis aimed to extend the data set, which essentially comprises discrete survey transects, to a broader geographical area, using an interpolation technique known as Poisson kriging, which in turn informed the identification and delineation of seabird concentrations. Some information on local seabird movements is available from offshore platforms (Camphuysen *et al.*, 1982; Platteeuw *et al.*, 1985). Data from seabird breeding colonies are collated in the Seabird Monitoring Programme (JNCC, http://www.jncc.gov.uk/page-1550). Land-based count data, such as from the Wetland Bird Survey (WeBS), (Holt *et al.* 2011, http://www.bto.org/volunteer-surveys/webs/publications/wituk-200910) also may be useful for inshore distributions of some bird groups eg divers and seaduck, although it has to be realised that the extent of coverage from land is both limited and highly dependent on weather conditions. Data from bird observatories may yield useful information on migratory species, and county bird reports/recorders are another potentially useful source of information, albeit mainly land-based. Further information on countrywide distributions may be found in Birds of Scotland (Forrester *et al.*, 2007), Birds in England, (Brown and Grice, 2005) and Birds of Wales (Lovegrove *et al.*, 2010).

Boat-based survey

The majority of boat-based surveys are carried out using strip transects (Tasker *et al.*, 1984). Originally these were carried out with a 300m recording band on one side of the boat, used subsequently to calculate bird density, and a scan ahead of the boat to pick up easily disturbed birds, such as divers and seaduck, and to watch for rarer birds. Counts are carried out over short periods, usually one, five or ten minutes. This method means a reasonably accurate density of birds can be estimated over areas of water of known dimensions and in a known location. In more recent surveys, transects are subdivided into perpendicular distance strata, to improve the accuracy of estimation by compensating for reduced visibility of birds over greater distances. The DISTANCE programme is used to analyse these data, taking into account different models of bird detection (Buckland *et al.*, 2001). Also a second recording strip is sometimes included, on the opposite side of the vessel, requiring additional observers, which, although one side may have better visibility than the other dependent on the position of the sun, will give greater accuracy, especially at low densities (Camphuysen *et al.*, 2004).

In order to avoid bias from following birds, scavengers attracted to the boat (usually defined as those that remain with the boat for more than two minutes) are excluded from density analysis. To minimise such bias, it is also important that fishing boats are not used for survey. Survey guidelines provide minimum vessel requirements, as well as transect separation and other standards (Camphuysen *et al.*, 2004). Some aspects of boat-based survey methods, for example relating to control/reference areas, are updated in Maclean *et al.* (2009).

Boat-based surveys give the opportunity to record additional data that can be used in the ecological interpretation of the bird data. Using onboard sensory equipment, water depth, temperature, salinity, turbidity, and the presence of fish can be recorded simultaneously with the bird survey. Boat-based surveys can give detailed information, but boat speed limits the area that can be covered in a day – thus the larger the survey area the more days' required, increasing the risk of interruption by poor weather or movements of birds affecting counts.

Aerial survey

Aerial surveys facilitate rapid, near-simultaneous coverage of large areas, providing a snapshot of distribution and density. The move to digital aerial surveys, from visual aerial surveys, has several advantages, notably enabling higher flight elevation, thereby minimising or avoiding disturbance displacement of overflown birds. Digital media, - both video and stills - permit reanalysis of the data, both for the purpose of quality assessment and as part of the development of automated methods of image analysis. Species identification remains problematic, especially for certain similar species, eg auks, gulls. This is an impediment to the EIA process which requires species-based analysis of data. Enhancements are being made to digital aerial survey methods that will lead to improvements in species discrimination and it has to be remembered that species discrimination is not always feasible from boat-based surveys either; the different methods have their different limitations in this respect. For example, it is generally acknowledged that digital aerial surveys are better for collecting data on diver distributions. Depending on the bird species, supplementary information (sex, age, behaviour, flight height) may be more limited than can be obtained during boat-based surveys, in particular behavioural observations. Bird identification from above is a novel technique for most ornithologists, and so training must be provided; even the most experienced bird surveyors may need this training. Digital aerial surveys involve cooperation between high definition photography aerial surveyors and image analysts, and skilled ornithologists to interpret the data and facilitate training the automated systems being developed for counting and identifying closely similar species. This is a rapidly evolving bird survey technique and almost any guidance is quickly out of date (Thaxter and Burton, 2009).

Weather limitations apply, just as they do to boat-based methods. However, it is likely that boats can continue to operate in slightly higher sea states, although swell will affect observations, especially of birds sitting on the water surface.

There is considerable attention being given to developing sampling protocols and analysis of data from digital aerial surveys to improve the ability to collect robust data to enable assessment of change, in particular to facilitate before/after comparisons. CREEM (Centre for Research into Ecological and Environmental Modelling) at St Andrews University, is leading this work (www.creem.st-andrews.ac.uk). Surveys are either carried out along transect strips subsequently subdivided into equal subdivisions for analysis (digital video and stills), or on a grid sampling basis (digital stills). The key requirement is for the sampling density to be of adequate resolution to account for the spatial distribution patterns of key species, i.e. clumped versus dispersed distributions.

Remote sensing

Radar

Radar has the advantage of recording ability in daylight and darkness over long periods of time, and can "observe" beyond the human visual range. However, only high specification radar has the capacity to discriminate individual targets and to permit reliable species identification, at least to the level of closely-similar species, using wingbeat signatures. Generally, radar requires a supplementary means of species identification. Nonetheless, both basic marine radar and marine radar configured in an avian laboratory have been used successfully to monitor bird passage and avoidance behaviour at both onshore and offshore wind farms (Gauthreaux and Belser, 2003; Desholm and Kahlert, 2005; Walls *et al.*, 2009; Krijgsveld *et al.*, 2010; Lindeboom *et al.*, 2011). Radar can provide good quality information on migration volume and flight paths of birds entering a proposed development site, but has a number of limitations that will make it largely unsuitable for use in the context of wave and tidal stream devices. Radar can only operate in a single plane, although a combination of horizontal and vertical radars can be used in avian radar laboratory configurations. Radar requires a stable platform; deployment on a ship increases the problem of wave clutter. The main constraint in using radar at wave and tidal stream sites is wave clutter. Methods of overcoming this problem are only partially successful, especially in the most readily available radar options. Since the key above surface risks for birds with wave and tidal stream devices will be just above the water surface, any interference will impede detection of the bird. Moisture from rain or fog also reduces radar performance. As such, a system which relies on calm conditions at sea in order to record birds on or close to the water surface is currently of little use for remote sensing at proposed or operational wave or tidal stream schemes.

Sonar

Our knowledge of sub-surface interactions is extremely limited, as indeed is our knowledge of all the behaviour of birds underwater. Methods for identification and monitoring remain elusive. Sonar, and more specifically multi-beam, including sidescan, sonar, produces images based on the shape and reflective properties of an object with sound waves directed at it, and has been investigated as a biological monitoring tool. The current technologies were considered too limited to be of use (Norris, 2009). It has been used with some success to monitor marine mammals at the SeaGen Tidal turbine at Strangford Lough, however it is considered here to be not completely accurate, intensive and costly (Keenan, pers. Comm.). However EMEC and the Sea Mammals Research Unit are encouraging the development of new sonar technology, particularly multi-beam sonar, and are actively testing them, so there is potential for future developments that will increase the usefulness of marine sonar. This remains perhaps the most promising technology for obtaining information underwater, with the exception of telemetry.

Image intensifiers

Thermal image intensifiers, such as night scopes or goggles, are based on the magnification of existing ambient light. As such they require at least some light to be present, such as moonlight or starlight, and cloud cover, fog and wet weather interfere with their operational function. They have fairly poor resolution and generally short operational distance from a few hundreds of metres up to approximately 1km.

Thermal Animal Detection Systems

Thermal animal detection systems (TADS) detect radiation in the infrared range of the electromagnetic spectrum, and therefore, unlike image intensifiers, can detect a target in complete darkness, as well as in light fog, rain and smoke (Walls *et al.* 2009). Thermal imaging can provide data on offshore nocturnal activity that is currently impossible to obtain in any other way (Walls *et al.* 2009). TADS has been successfully used as a remotely controlled system for monitoring bird collision frequency in offshore wind farms (Desholm *et al.*, 2006), at Nysted in Danish waters. However there are a number of limitations. Similarly to radar, it does need to be mounted on a platform or vessel; at Nysted it was mounted on existing turbines, in each case directed vertically where it had a restricted field of view of approximately one third of the rotor-swept area of the turbine. It has a much lower optical resolution than conventional video equipment, giving it a reduced operational distance and range. As such it is really most suitable for flocks of birds; single birds require telephoto lenses, which further restrict the field of view. Therefore, while more suitable technology may develop, currently thermal imaging will have limited use for surveying at wave and tidal stream sites, although for above surface activity at single deployments and small arrays it will have some utility.

Cameras

Cameras can be used for the recording of visual images, above or below the water surface. As discussed above the use of digital recording during aerial surveying is an increasingly valuable technique, with an excellent audit trail.

However cameras operated remotely suffer from a short operational range; with a trade-off between range, field of view and image resolution, which may make discrimination of similar species difficult. This trade-off is especially marked underwater, where acquiring visual images is already difficult, since underwater cameras are prone to fouling of lenses, and require an artificial light source to operate in deep water or darkness, although lighting systems have improved to minimise behavioural disruption of target animals.

Device-mounted cameras

Cameras can be mounted, either above or below the water surface, on the device itself, allowing for remote detection of any interaction between birds and the device. This procedure is being tested at EMEC. Whilst useful for monitoring interactions, it may miss the eventual outcome, for example when a bird leaving the field of view after a collision may die of its injuries or recover completely.

Bird-mounted cameras

Increasingly technological advances have allowed for the mounting of video cameras on birds, to record both above (eg Watanuki *et al.*, 2008) and below (Yoda *et al.*, 2011) surface behaviours. Such cameras can capture detailed accounts of animal behaviour and offer valuable insights into aspects of ecology such as foraging behaviour. As such they could be an important tool in recording a bird’s response to a renewable device. However a major limitation is data storage, and the need to recover the unit to obtain these data. This raises the difficulty of capture and deployment on birds at breeding colonies which may or may not be the individuals using the potential development areas. As such this method may be most suitable at present in an experimental situation, or in association with other technologies. There are also welfare implications, with the necessity of capturing and handling the bird as well as potential impacts on behaviour from bird-borne instrumentation (see next section).

Telemetry

The following tracking technologies all suffer from the limitation that the transmitter must be attached to the bird. This has a number of welfare implications. Firstly the bird must be caught, and then handled, a process that can vary greatly in complexity with species, life stage and location. This disturbance must be carefully minimised and monitored. There are considerations in terms of the size and weight of any device and how it may affect the bird, as an irritant or a compromise on aerodynamics, or with diving species, hydrodynamic flow. There are a number of methods of attachment each with advantages and disadvantages, and they need to be considered in the context of the question being asked and the biology of the species. There is a trade off between the size of the battery, which makes up a significant proportion of the device’s weight, and longevity of the recording period. Increasingly efficient solar powered transmitters are being produced that allow for smaller batteries, reduced weight and therefore the ability to attach to smaller species, but require adequate insolation to recharge batteries.

These considerations notwithstanding, the remote tracking of birds has provided excellent information on the spatial ecology of a number of seabird species that would otherwise be unavailable (eg Thaxter *et al.* in press). While sample sizes are by necessity low, although this limitation is being increasingly overcome by lower cost units, this information can demonstrate habitat use of species relative to specific locations, such as breeding colonies, foraging sites or development zones.

Radio-telemetry

The radio tracking of birds using VHF transmitters is a well established technique. For example Perrow *et al.* (2006) used radio telemetry to identify important feeding areas for a colony of little terns in the context of a proposed offshore wind farm. The transmitters and receivers are relatively low cost, and with adequate survey effort generate accurate location data. Generally at least two surveyors are required to obtain an accurate fix, and this can make surveying in remote areas difficult. However the receivers can be operated from boats and aircraft, and there is potential for identifying the individual tagged birds during other surveys. This technology may be of particular utility in the case of nearshore wave or tidal stream devices.

Satellite/GPS

For satellite telemetry, the tag is a Platform Terminal Transmitter (PTT), and this is detected by Argos-CLS system satellites, which estimate the location of the tag through Doppler shifts in the frequency of transmissions. The accuracy of these location estimates vary with the point in a satellite pass that a transmission was made, as well as number of other variables, and so while accurate fixes are obtainable, sometimes there can be a fairly large margin of error. The tags are also expensive, and relatively heavy, although advances in solar panels and rechargeable batteries mean they are becoming lighter, with 5g tags now available.

More recent advances have meant that GPS units can be integrated into the tags. These determine position using GPS satellites, and transmit this position to the Argos-CLS system satellite. These are very accurate, but at present are heavy, the lightest being 22g, and expensive.

Data loggers

Recorders such as GPS or time depth recorders (TDR), do not transmit a signal, rather they record data on the position or behaviour of the bird to which they are attached. While there is a great constraint in that the recorder often needs to be recovered by recapturing the bird, they can provide insights into not only the location of a bird, but its behaviour. For example TDRs fitted to common guillemots and razorbills (Thaxter *et al.* 2010) provided data that helped to examine the differences in three-dimensional foraging behaviour of these species. Such information can be crucial in understanding how birds may interact with sub surface structures. Remote download techniques are being developed, initially requiring close approach to the bird to retrieve the data, but systems are under development that operate over increasing distances, thereby offering greater flexibility.

5. Recommendations for further research

In this review we have noted that there is a paucity of applicable data on the impacts of wave and tidal stream devices on birds. This lack of data has implications for understanding the overall impacts of these novel technologies, and for impact assessment of individual schemes. In this final section these knowledge gaps and approaches to filling them are discussed. Appendix IV details appropriate methods to use to address key questions that should be posed as part of the EIA of a wave or tidal stream development.

The key information that is lacking can be summarised as spatial and behavioural. The spatial data set required is a cohesive and comprehensive body of knowledge about which species are where and when, and why, for example foraging, loafing, moulting or a combination of these. Understanding bird distribution and usage contributes to understanding the risks associated with wave and tidal stream developments for the different species, thereby helping to identify focal species for assessment. Whilst the responsibility for assessing the proposal area and surrounding area lies with the developer, there is a need for contextual information over a larger geographical area. This requires a co-ordinated approach and involvement of the regulator, in conjunction with industry, to achieve the necessary level of coverage. Sensitivity mapping could be a useful tool to identify areas that may require additional studies to refine development proposals or, in some cases may indicate areas to be unsuitable for renewable energy projects, at least in the early stages of roll-out given the present level of uncertainty about environmental impacts. The main techniques for filling these knowledge gaps are comprehensive baseline survey and remote sensing.

While there is a growing body of data on the distribution of seabirds, particularly through the ESAS database, as previously discussed these data suffer from uneven spatial and temporal coverage, low resolution and are becoming increasingly out of date. Whilst some recent additions have been made, more data are required to provide information on the species present, their distribution and abundance and how these vary seasonally and diurnally. Additionally, there is a need to understand the predictability and determinants of the distribution.

Behavioural data relating to how different species interact with wave and tidal stream devices will be obtained mainly from monitoring test deployments and small arrays initially, progressing to larger arrays as results may not scale-up proportionally. As knowledge builds, the requirement for monitoring will diminish.

Practical issues of data collection

Need for standardisation throughout industry

A crucial element of baseline surveys is the need for consistency of data collection throughout survey areas and projects. As such the recent publication by SNH of draft guidance on survey and monitoring (Jackson and Whitfield, 2011) is welcomed. Since recent data are largely absent for many areas, a minimum of two years preconstruction data will be required. This is a compromise solution that aims to reconcile the short timeframes for deployment set against the pronounced inter-annual fluctuations that occur in at sea bird distribution and abundance, in an attempt to reflect that variability. At a few locations more than two years' data may be necessary, but at other, well-documented locations, there may be less need to acquire new data.

As seabirds are generally long-lived, with a significant proportion of any population being juvenile or non-breeding birds (Votier *et al.* 2010), surveys must encompass both breeding and non-breeding populations, across seasons. These data will be collected mainly by a combination of boat-based and aerial surveys, with high definition digital imaging an increasingly important tool (Thaxter and Burton 2009). Land-based visual observations also may be applicable for inshore and coastal development areas. While some aspects of survey design, such as transect spacing, will be governed by individual development requirements, it is vital that data are compatible across survey areas, and within survey areas over time, to facilitate comparison of before and after construction and different sites. This is particularly important to facilitate the assessment of the cumulative effects of multiple wave or tidal stream developments alone or in combination with other types of development.

Remote sensing

With far ranging species such as seabirds, the use of remote sensing technologies is crucial to developing an understanding of their spatial dynamics. Such technologies are developing rapidly, and COWRIE commissioned best practice guidelines for offshore wind farms (Desholm *et al.*2005, Walls *et al.* 2009) that have applicability for wave and tidal stream developments. These remote techniques will not be applicable in all cases, and when utilised, there must be clearly defined goals (Langston 2010). Whilst land-based radar may be useful for recording migration and other bird movements in inshore waters, problems of wave clutter are likely to reduce the value of radar In the case of wave and tidal stream developments. Various camera technologies (see section 4) are more promising for these developments.

Modelling techniques

Collision risk modelling

In terrestrial wind farm proposals, as part of the EIA procedure, a standardised method for assessing collision risk is utilised. This is the Collision Risk Model (CRM) (Band *et al.*, 2005). Inputs to this model include operational data for the turbines, biometric data for the bird species, and observational data from preconstruction ornithological survey. There is an element of estimation, primarily through the inclusion of an “avoidance rate” in the final stage of the standard model application. Despite this model input being an estimate, small variations in avoidance rates can result in relatively large changes in the predicted collisions (Chamberlain *et al.*, 2006). It is anticipated that these estimates will have greater accuracy as data from operational wind farms are collected.

For wave and tidal stream developments, no such model exists. An offshore wind farm Collision Modelling Tool and Guidance have been developed by Band (2011), under the auspices of the Strategic Ornithology Support Services (SOSS) framework, led by the Crown Estate (http://www.bto.org/science/wetland-and-marine/soss), and this may have some applicability for above surface collisions with wave and tidal devices, at least in identifying principles. More specifically an assessment of methods for determining collision impacts for tidal stream has been commissioned by Marine Scotland and SNH. Quantitative data on how seabirds interact with below surface structures will be essential to validate and if necessary modify such a model. Specifically, data on the behavioural responses of seabirds to the devices is needed; whether there is collision with or avoidance of such structures. This information will have to be obtained via post-construction remote monitoring, or by experimental studies. These data could be used to create a CRM, then to generate predictions from it. However it may be that a CRM is not the best approach to wave and tidal stream developments, and an alternative modelling technique may be developed.

Refining sensitivity indices

As a means of determining the potential impacts of offshore wind farms, Garthe & Hüppop (2004) developed a species sensitivity index for German sectors of the North and Baltic Sea. This approach was useful for prioritising the species at most risk from developments (Mendel *et al.*, 2008), and was subsequently modified for species applicable to UK waters (King *et al.* 2009, Langston 2010), and has been modified further for wave and tidal stream developments in the current document (Appendix I). Such indices are valuable as initial assessments, but are based on limited knowledge. Improvement of sensitivity indices requires improved knowledge and peer-review, through updated baseline data collection, detailed EIA, research and post-construction monitoring, and publication (Langston 2010).

Defining scale of impact

It is crucial that population-level impacts are examined. The relevant population scales need to be agreed at the outset, but are likely to include the biogeographical or UK or country population, together with regional and local populations; the latter may refer to a specific SPA. Indicative thresholds of population decline and the probability of decline of a given magnitude will be helpful to inform decisions as to the likely risk of impact due to losses caused individually or cumulatively by wave and tidal stream developments. Here the use of population models can assist in defining these boundaries, but such models are only informative if they have good data to work from. For example Population Viability Analysis (PVA) can be used to assess the impact of mortality on a population, but at least requires starting data consisting of population size, productivity, age-dependent survival and age of first breeding (Beissinger and Westphal, 1998). Such data are highly variable dependent on species, so PVA approaches may not be readily applicable to all species (Maclean *et al.*, 2009).

Potential Biological Removal (PBR) has less stringent data requirements and can be a useful tool for helping to determine the magnitude of additional mortality that a population can sustain, including that potentially attributable to wave and tidal stream developments. Developed in the USA to establish sustainable hunting bag limits, PBR requires regular feedback monitoring to determine whether the harvesting levels continue to be sustainable (Dillingham and Fletcher, 2008; Watts, 2010; Dillingham and Fletcher, 2011). This would be a requirement for employing this approach to assessing the potential consequences for priority bird species from wave and tidal stream energy generation.

Cumulative impact assessment (CIA)

There is an increasing number of developments and activities in the marine environment, not only wave and tidal stream, but also other commercial and recreational activities that can impact on bird populations. There is therefore a need to assess the potential larger scale cumulative and in-combination impacts of each wave or tidal stream development in association with these multiple activities. For example, CIA needs to address the implications of eg cumulative mortality or cumulative displacement. COWRIE produced guidelines for assessment of the cumulative impacts of offshore wind farms (King *et al.* 2009), which are to some extent applicable to wave and tidal stream developments. These guidelines identified the importance of early scoping and the need for clear guidelines for the production of a cumulative impact assessment. There remain clear knowledge gaps that can only be filled by monitoring during and post-construction. The COWRIE guidelines provide a useful starting point but there is a need for further guidance, eg how to determine suitable reference populations.

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Appendix I: Species Sensitivities Tables

This table shows the predicted sensitivities of the key seabird species detailed in the text to the threats associated with wind and tidal stream devices, and the UK, biogeographic and international conservation status of these birds. These sensitivities have been largely derived from Garthe and Hüppop (2004) and King *et al.* (2009), modified where applicable by more recent literature. Season is coded b for breeding and w for wintering, threats are coded: * lesser, **moderate and ***greater. BoCC3 is taken from Eaton *et al.* (2009). Biogeographic status is the proportion of biogeographical population either breeding or wintering in the UK, from Mitchell *et al.* 2004 and Baker *et al.* 2006 respectively, where *<25%, ** 25-50%, ***>50%. SPEC is from Birdlife International 2004 where SPEC 1 – species of global conservation concern, i.e. classified as globally threatened, near threatened or data deficient, SPEC 2 – concentrated in Europe and with an unfavourable conservation status; SPEC 3 –not concentrated in Europe but with an unfavourable conservation status; Non-SPEC – Concentrated in Europe but with a favourable conservation status, and NE - not concentrated in Europe and with a favourable conservation status.

		Threat								
		Collision risk						**Conservation status**		
Species	Season	Above	Below	Vessel	Disturbance	Pollution	Entrapment	BoCC3	Biogeographic	SPEC
Greater scaup	w	**	**	**	**	**	**	Red	*	SPEC 3W
Common eider	b/w	***	**	**	*	**	**	Amber	*	Non-SPEC
Long-tailed duck	w	**	**	**	**	**	**	Green	*	Non-SPEC
Common scoter	w	**	**	**	**	**	**	Red	*	Non-SPEC
Velvet scoter	w	**	**	**	**	**	**	Amber	*	Non-SPEC
Goldeneye	w	**	**	**	*	**	**	Amber	*	Non-SPEC
Red-breasted merganser	w	**	**	**	*	***	***	Green	*	Non-SPEC
Red-throated diver	b	**	**	*	***	***	***	Amber	**	SPEC 3
	w	**	**	**	***	***	***	Amber	**	
Black-throated diver	b	**	**	*	***	***	***	Amber	*	SPEC 3
	w	**	**	**	***	***	***	Amber	*	
Great northen diver	w	**	**	**	***	***	***	Amber	**	Non-SPEC
Northern fulmar	b/w	***	*	*	*	*	*	Amber	*	Non-SPEC
Great shearwater	p	***	*	*	*	*	*	Green	*	NE
Sooty shearwater	p	***	**	*	*	*	**	Amber	*	SPEC 1
Manx shearwater	b	***	*	*	*	*	*	Amber	***	SPEC 2
Balearic shearwater	p	***	*	*	*	*	*	Red	*	SPEC 1

Species		Collision						Conservation status		
	Season	Above	Below	Vessel	Disturbance	Pollution	Entrapment	BoCC3	Biogeographic	SPEC
European storm petrel	b	***	*	*	*	*	*	Amber	*	Non-SPEC
Leach's storm petrel	b	***	*	*	*	*	*	Amber	*	SPEC 3
Great-crested grebe	w	**	**	**	**	**	**	Green	*	Non-SPEC
Red-necked grebe	w	**	**	**	**	**	**	Amber	*	Non-SPEC
Slavonian grebe	w	**	**	**	**	**	**	Amber	*	SPEC 3
Gannet	b/w	*	***	*	*	*	**	Amber	***	Non-SPEC
Cormorant	b/w	***	**	*	*	*	***	Green	**	Non-SPEC
Shag	b/w	**	**	*	**	*	***	Amber	**	Non-SPEC
Pomarine skua	p	*	*	*	*	*	*	Green	*	Non-SPEC
Arctic skua	b	*	*	*	*	*	*	Red	*	Non-SPEC
Great skua	b	*	*	*	*	*	*	Amber	***	Non-SPEC
Kittiwake	b/w	**	*	*	*	*	*	Amber	*	Non-SPEC
Black-headed gull	b/w	*	*	*	*	*	*	Green	*	Non-SPEC
Little gull	w	**	*	*	*	*	*	Amber	*	SPEC 3
Common gull	b/w	*	*	**	*	*	*	Amber	*	SPEC 2
Lesser black-backed gull	b/w	*	*	**	*	*	*	Amber	***	Non-SPEC
Herring gull	b/w	*	*	**	*	*	*	Red	*	Non-SPEC
Iceland gull	w	*	*	**	*	*	*	Amber	*	Non-SPEC
Glaucous gull	w	*	*	**	*	*	*	Amber	*	Non-SPEC
Great black-backed gull	b/w	*	*	**	*	*	*	Amber	**	Non-SPEC
Little tern	b	**	*	*	*	*	*	Amber	*	SPEC 3
Sandwich tern	b	*	*	*	*	*	*	Amber	**	SPEC 2
Common tern	b	**	*	**	*	*	*	Amber	*	Non-SPEC
Roseate tern	b	**	*	*	*	*	*	Red	*	SPEC 3
Arctic tern	b	**	*	*	*	*	*	Amber	*	Non-SPEC
Guillemot	b/w	**	**	**	**	***	***	Amber	**	Non-SPEC
Razorbill	b/w	**	**	**	**	***	***	Amber	*	Non-SPEC
Black guillemot	b/w	**	**	**	**	***	***	Amber	*	SPEC 2
Puffin	b/w	**	**	**	**	***	***	Amber	*	SPEC 2

Appendix II: Sources of threats

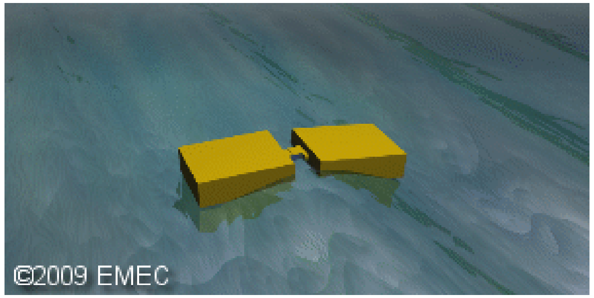
This appendix shows the level of threat from the component parts of wave and tidal stream developments as described in "Theoretical Background", page 8, and is designed to be used with Appendix I to identify the threats posed to individual species from proposed developments. Threats are categorised as * lesser, **moderate and ***greater.

		Threat				
		Collision				
Source		Above surface	Sub surface	Disturbance	Pollution	Entrapment
Vessels		**	*	***	*	*
Seabed strucures			***		*	
Subsurface structures						
Surface structures		***			*	
Mooring equipment			**		*	*
Turbines	Enclosed			*	*	*
	Unenclosed		**	*	**	***
Traps						***
Attractants	FADs		**			**
	Lights	**				

Appendix III: Devices already operational or under development

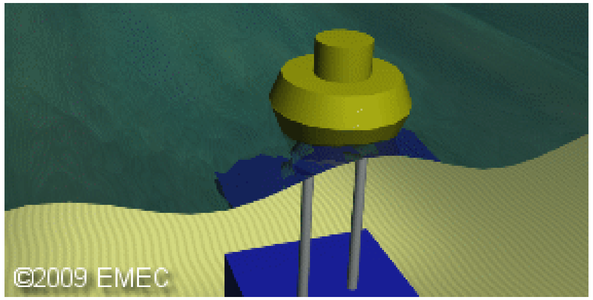
Wave

Attenuators



Device Type / Technology	Web link
B1 bouy	http://www.fredolsen.com/
Centipod	http://www.ecomerittech.com/centipod.php
Dexawave	http://www.dexawave.com/
Edinburgh duck	http://www.mech.ed.ac.uk/research/wavepower/
Floating Wave Generator	http://www.gedwardcook.com/
Hybrid float	http://www.perpetuwavepower.com/
Navatek WEC	http://www.navatekltd.com/waveenergy.html
Oceantec WEC	http://www.see.ed.ac.uk/~shs/Wave%20Energy/EWTEC%202009/EWTEC%202009%20(D)/papers/224.pdf
Pelamis	http://www.pelamiswave.com/
Pontoon Power Converter	http://www.pontoon.no/Technology.html
Poseidon's Organ	http://www.floatingpowerplant.com/?pageid=336
Rock n Roll WED	http://rocknroll.nualgi.com/
Sea Power Platform	http://www.seapower.ie/wave-energy/
WAG Bouy	http://www.ryokuseisha.com/eng/product/power_supply/ftw/ftw.html
Waveberg	http://www.waveberg.com/wavenergy/bod01.htm
Wavepiston	http://www.wavepiston.dk/index.html
Wello Penguin	http://www.wello.fi/

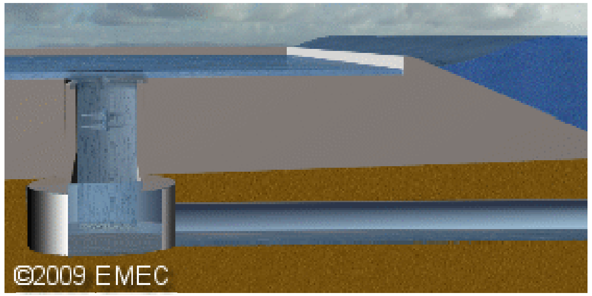
Point absorbers



Device Type / Technology	**Web Link**
Atmocean	http://www.atmocean.com/
AWS-III	http://www.awsocean.com/technology.aspx
EGWaP	http://www.abletechnologiesllc.com/egwap.htm
Brandl generator	http://brandlmotor.de/brandlgenerator_eng.htm
ConWEC	http://www.caddet-re.org/html/299art4.htm
Drakoo	http://hann-ocean.com/
Eel Grass	http://www.avinc.com/engineering/marine_energy/
Float Wave	http://www.atecom.ru/wave-energy/
Floating Absorber	http://www.eurowaveenergy.com/
Hidroflot WEC	http://www.hidroflot.com/en/index.php
Horizon Platform	http://www.elgenwave.com/
IWAVE	http://waveenergy.nualgi.com/
Linear generator	http://www.seabased.com/
LOPF Bouy	http://www.resenwaves.com/
Ocean Electric Bouy	http://www.amioceanpower.com/home
OWEC Bouy	http://www.ips-ab.com/
Ocean Wave Air Piston	http://greenoceanwaveenergy.com/technology%203.html
Pneumatically Stabilized Platform	http://www.floatinc.org/PSPTechnology.aspx
PowerPod	http://www.tridentenergy.co.uk/our-technology/
Purenco WEC	http://www.straumekraft.no/

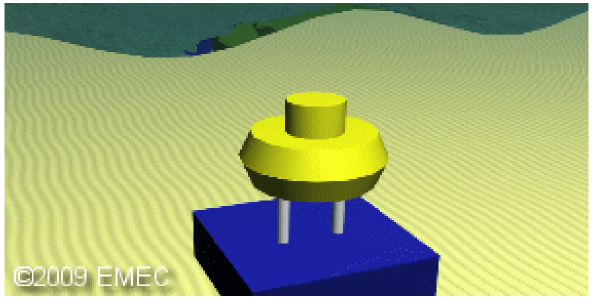
PS frog	http://www.engineering.lancs.ac.uk/lureg/group_research/wave_energy_research/
Motorwave	http://www.motorwavegroup.com/new/index1.html
OMI Combined Energy System	http://www.oceanmotion.ws/
Protean	http://www.proteanenergy.com/
Power Bouy	http://www.oceanpowertechnologies.com/
Resolute WEC	http://www.resolutemarine.com/
SeaHeart	http://www.oceanicpower.com/
Seatricity WEC	http://www.seatricity.net/content/technology
SEEWEC	http://www02.abb.com/global/gad/gad02077.nsf/lupLongContent/D74F5739AAE738F6C12571D800305007
SEADOG	http://inri.us/index.php/SEADOG
Searaser	http://www.ecotricity.co.uk/our-green-energy/our-green-electricity/and-the-sea/searaser
SeaRay	http://www.columbiapwr.com/technology.asp
Snapper	http://www.snapperfp7.eu/snapper-s-background
Sperboy	http://www.sperboy.com/index.html?_ret_=return
SurfPower	http://www.surfpower.ca/
TETRON	http://www.carbontrust.co.uk/SiteCollectionDocuments/Grant%20Funded%20Projects/2005%20projects/2005-3-2835.pdf
Uppsala/Seabased AB Wave Energy Convertor	http://www.el.angstrom.uu.se/forskningsprojekt/WavePower/Lysekilsprojektet_E.html
W2-Power	http://www.pelagicpower.no/today.html
Wavebob	http://wavebob.com/overview/
WaveSurfer	http://www.oceanenergyindustries.com/index.php?option=com_content&view=article&id=4&Itemid=4
Wave Star	http://wavestarenergy.com/
WET EnGen	http://www.waveenergytech.com/
WET NZ	http://www.wavenergy.co.nz/

Overtopping Devices



Device Type / Technology	**Web Link**
ITC	http://www.jospa.ie/
Mighty Whale	http://www.jamstec.go.jp/jamstec-e/30th/part6/page2.html
PowerGin Hybrid WEC	http://www.kineticwavepower.com/
SSG	http://www.waveenergy.no/WorkingPrinciple.htm
Wave dragon	http://www.wavedragon.net/

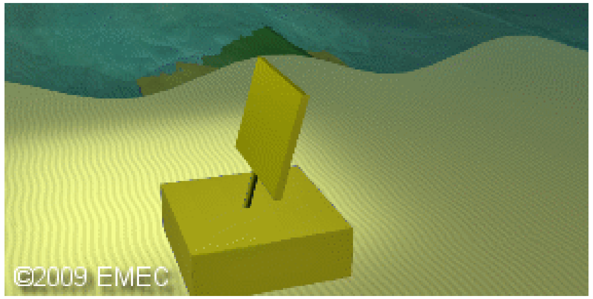
Submerged Pressure Differentials



Device Type / Technology	**Web Link**
AWS-III	http://www.awsocean.com/PageProducer.aspx
OWEC Bouy	http://www.owec.com/

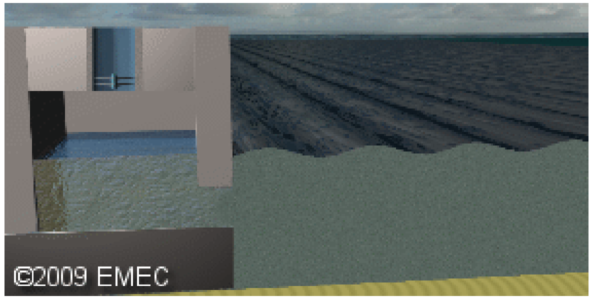
SARAH's Pump	http://www.cna.nl.ca/news/newsletters/Fall%202006.pdf
Syphon Wave Generator	http://www.gedwardcook.com/

Oscillating Wave Surge Convertors



Device Type / Technology	**Web Link**
Bio wave	http://www.biopowersystems.com/biowave.html
Langlee system	http://www.langlee.no/
OWEL WEC	http://www.owel.co.uk/owel-technology/
Oyster	http://www.aquamarinepower.com/
SDE bouy	http://www.sde.co.il/index.htm
WECA	http://www.daedalus.gr/weca.html
Wave roller	http://www.aw-energy.com/

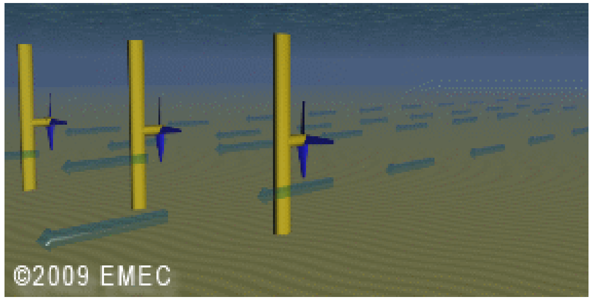
Oscillating Water Column Devices



Device Type / Technology	Web Link
HydroAir	http://www.dresser-rand.com/literature/general/2210_HydroAir.pdf
Limpet	http://www.wavegen.com/
MAWEC	http://www.leancon.com/technology.htm
OE Bouy	http://www.oceanenergy.ie/oe-technology/platform.html
PICO OWC	http://www.pico-owc.net/cms.php?page=542&wnsid=dbb177dd9668f08318207830330904df
SEAREV	http://www.bulletins-electroniques.com/actualites/52074.htm
Wave Water Pump	http://www.renewableenergypumps.com/

Tidal Stream

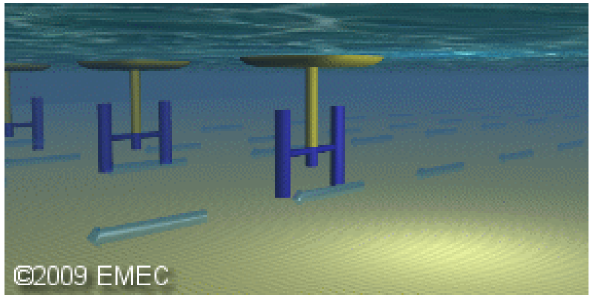
Horizontal Axis Turbine



Device Type / Technology	Web Link
Atlantisstrom	http://www.atlantisstrom.de/description.html
AK1000	http://www.atlantisresourcescorporation.com/
Cetus turbine	http://www.cetusenergy.com.au/index.php
Current Catcher	http://www.offshoreislandslimited.com/offshore%20islands%20limited_005.htm
Deep-gen	http://www.tidalgeneration.co.uk/
Delta Stream	http://www.tidalenergyltd.com/
Evopod	http://www.oceanflowenergy.com/
Hales Tidal Turbine	http://www.hales-turbine.co.uk/technology.html
Hytide	http://www.voithhydro.com/media/t331_Ocean_Current_Technologies_72dpi.pdf
HyPEG	http://www.hklabllc.com/
Magallanes Project	http://www.magallanesrenovables.com/
Morild	http://www.hydratidal.com/
Neo-Aerodynamic	http://www.neo-aerodynamic.com/
Open Centre Turbine	http://www.openhydro.com/
Osprey	http://www.freeflow69.com/
PLAT-O	http://www.susmartech.com/pages/contact.php
Rotech Tidal Turbine	http://www.lunarenergy.co.uk/
SR250	http://www.scotrenewables.com/
Sea Snail	http://www4.rgu.ac.uk/cree/general/

Seagen, Seaflow	http://www.marineturbines.com/
SmarTurbine	http://free-flow-power.com/
Swan Turbine	http://www.swanturbines.co.uk/
Tideng	http://www.tideng.com/
Tidevanndkraft	http://www.statkraft.com/
TiDEL	http://www.smd.co.uk/
TIDES	http://www.oceanaenergy.com/
Tidal Star	http://www.bourneenergy.com/
Tidal Stream Turbine	http://www.hammerfeststrom.com/
Tocado	http://www.tocardo.com/digi_cms/5/technology.html
Torcado	http://www.teamwork.nl/
Wave Rotor	http://www.c-energy.nl/index.php?option=com_frontpage&Itemid=1

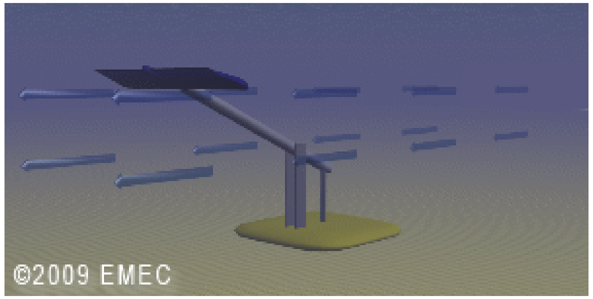
Vertical Axis turbine / Tidal Fence



Device Type / Technology	**Web Link**
Blue Energy Ocean Turbine	http://www.bluenergy.com/
Current Power	http://www.currentpower.se/index.php?Itemid=65
C-Plane	http://www.ecomerittech.com/aquantis.php
DHV Turbine	http://tidalenergy.net.au/
EnCurrent Vertical Axis Hydro Turbine	http://www.newenergycorp.ca/
Enermar	http://www.pontediarchimede.it/language_us/
Hydrovolts	http://hydrovolts.com/

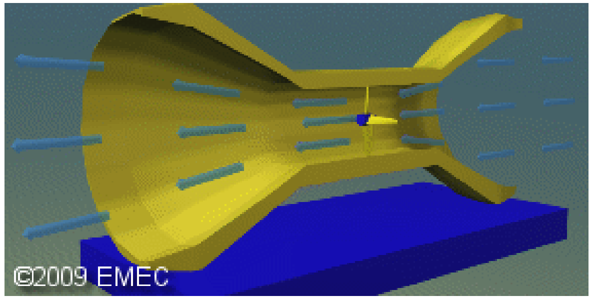
LucidPipe	http://www.lucidenergy.com/
Neo-Aerodynamic Hydro Turbine	http://www.neo-aerodynamic.com/
Polo	http://www.mech.ed.ac.uk/research/
Proteus	http://www.neptunerenewableenergy.org.uk/
Tidal Turbine	http://www.current2current.com/CURRENT2CURRENT_new_site/Our_Technology.html
THAWT	http://www.keplerenergy.co.uk/
Variable-axis, variable pitch tidal turbine	http://www.edesign.co.uk/

Oscillating Hydrofoil



Device Type / Technology	**Web Link**
bioStream	http://www.biopowersystems.com/
Pulse-Stream	http://www.pulsegeneration.co.uk/
Stingray	http://www.engb.com/
Underwater Electric Kite	http://www.uekus.com/

Venturi Effect Systems



Device Type / Technology	Web Link
Clean Current Tidal Turbine	http://www.cleancurrent.com/
Hydrokinetic Turbine	http://www.hgenergy.com/
Rochester Venturi	http://www.hydrocoilpower.com/

Other Tidal Stream

Device Type / Technology	Web Link
Aquascientific Turbine	http://aquascientific2.moonfruit.com/#
Fieldstone Tidal Energy	http://fieldstoneenergy.com/
Flumill Power Tower	http://www.flumill.co.uk/
Gentec WaTS	http://www.greenheating.com/
HydroCoil	http://www.hydrocoilpower.com/
Hydro-Gen	http://www.hydro-gen.fr/
Relentless Turbine	http://www.go-greener.com/
Tidal Delay	http://www.woodshedtechnologies.com.au/
Tidal Lagoons	http://www.tidalelectric.com/
Tidal Sails AS	http://www.tidalsails.com/
Water Wall Turbine	http://www.wwturbine.com/

Appendix IV: Wave and Tidal Stream Questions for EIA

What species are present, what is the distribution and abundance; is there seasonal/diurnal variation; what is their use of area etc?

Aerial Survey

Advantages	Disadvantages	Further development/ considerations	References
rapid coverage of large sea areas	Often poor species discrimination of certain groups e.g. terns, gulls	Rapidly evolving technology requiring refinement of sampling protocols and methodology including trade off between flight elevation and image resolution - likely some site and species specificity	Camphuysen *et al.* 2004, Maclean *et al.* 2009
generally considered better detection of red-throated diver & common scoter than from boats			Thaxter & Burton 2009, Burt *et al.* 2010

1.Visual surveys

Methodology	Advantages	Disadvantages	Further development/ considerations	References
transects usually flown at 80m elevation and 2km transect separation	specialist skills applied in real time	rapid overflight requires rapid assessment of species and numbers - potential for error and no opportunity to recheck low flight elevation causes flushing of some species	Distance sampling used to estimate numbers from transects	Camphuysen *et al.* 2004

2. Digital surveys: Hi-definition cameras, video or stills

Methodology	Advantages	Disadvantages	Further development/ considerations	References
generally transect strips (video) or point sampling across grid (stills)	area can be overflown at greater elevation, so overcoming disturbance to birds	novel technology so protocols still evolving	Rapidly evolving technology requiring refinement of sampling protocols and methodology including trade off between flight elevation and image resolution - likely some site and species specificity	Thaxter & Burton 2009 Burt *et al.* 2010
Initital recommendation for minimum 450m to achieve image resolution of 5cm, but reductions in both for improved species discrimination subject to not increasing disturbance to birds. Routinely using 3cm, sometimes less, to improve image resolution.		trade-off between image resolution and species ID with achieving sampling points to obtain reliable density estimates within acceptable levels of precision	recommendation to fly whole study area in a single day and to repeat on different days, offsetting transects, rather than cover the area progressively by flights over consecutive days	
strip transect spacing and number/sub-sampling within transect/grid, optimised to increase precision of density estimates according to focal species - increased sampling effort for clumped species; require pilot survey(s) to refine sampling protocol - optimise Coefficient of Variation	images can be scrutinised more closely and permanent record can be rechecked - good audit trail & QA potential	time-consuming to go through images post-survey; automated processing under development	recommendation to incorporate environmental covariates in analyses	
	potential to overcome problems of species ID e.g. wingbeat from video clips	increased survey time to obtain finer resolution may be disproportionately costly	flight height estimation under development	
	point sampling grid increases independent sample size and hence precision of density estimates		automation of image ID, and species discrimination using colour saturation etc.	
			as yet untested potential for use of infrared to survey in low light conditions (darkness?)	

Boat-Based Survey

Advantages	Disadvantages	Further development/ considerations	References
added value of behavioural observations generally good species discrimination especially auks, terns, gulls potential for simultaneous collection of environmental covariates	slower coverage of large areas may increase risk of weather curtailment to surveys	potential deployment of more than one boat to cover large zones simultaneously	Camphuysen *et al.* 2004 Maclean *et al.* 2009

Radar

Methodology	Advantages	Disadvantages	Further development/ considerations	References
assess temporal and spatial variation in bird movements, migration volume, during day & night	detection beyond the range of human vision, in terms of both distance and continued operation during darkness can be operated remotely, at least to assess overall volume of movements	generates potentially huge quantities of data, requiring good data storage and management procedures to facilitate analysis species discrimination limited and complex, e.g. wingbeat signature limited flock size determination requires groundtruthing, complementary visual and/or acoustic surveys for species discrimination, which may limit remote operation clutter caused by objects of greater reflectivity than the targets (ie birds) has to be identified and filtered; wave clutter problematic rain impedes operation requires a stable platform for optimal operation - costly offshore and problematic in high energy systems costly for sophisticated systems	advances in avian radar systems, e.g. doppler may improve discrimination of bird targets from wave clutter (DeTect introduced in 2010)	Desholm *et al.* 2005 Desholm *et al.* 2006 Table 2, Walls *et al.* 2009
1. Marine surveillance radar	cheap and portable	ship-based deployment is liable to pronounced wave clutter short operational range		
2. Avian Laboratory marine radar use to track shorter range movements or a network of radar to provide larger spatial coverage, or land-based to detect arrival bearings of migrants making landfall, or departure bearings	mobile units specialist software facilitates analysis of bird movements vertical radar provides flight height within narrow field	short range, up to c. 11-12km, depending on target size so individually limited area coverage problem (practical & cost) of how/where to deploy at sea, especially pre-construction	offshore research platform, e.g. OceanPod, or metmast deployment options	
3. Air defence radar (high spatial resolution) suitable for wide range of types of bird movement, or **weather radar** (low spatial resolution) suitable only for large scale migration volume (passerines)	long range detection >100km improved capability for species identification	bird data are classified as clutter, therefore often junked Limited use for site-based collection Although greater operational range, diminishing target resolution at greater distance, at least for weather radar Higher spec radar very costly and often not available for civilian use	co-operation to permit storage and extraction of bird data, development of analytical tools	

Nocturnal surveys

Methodology	Advantages	Disadvantages	References
assess nocturnal movements and species distributions		limited capability as most currently available methods operate only over short distances 0-500m	Walls *et al.* 2009
1. Radar	operational at night & low light levels	supplementary species ID usually required	
	military/weather radar long operational range	marine radar short operational range	
	can be operated remotely		
2. TADS (see below)	operational at night & low light levels	short operational range <1-2km Poor quality images with increasing distance from lens hence difficulty in species ID	
	can be operated remotely		
3. Night vision/ image intensifiers	operational at night & low light levels	short operational range	
		require some ambient light to function, e.g. moonlight require operator on site, probably on a boat, H&S implications & practical difficulties of use on boat (stability), but see R3 Bristol Channel offshore wind	
4. Sonar	operational at night & low light levels	not always accurate, expensive and labour intensive developmental stage for underwater bird studies proving challenging	
	can be operated remotely operational underwater		

What is the relevant regional population and what SPAs are relevant to the EIA and AA?

Connectivity between SPAs and other breeding colonies, and at sea foraging areas; bird tracking

Methodology	Advantages	Disadvantages	Further development / considerations	References
Tracking movements between land-based breeding colonies and offshore foraging, moulting, dispersal and loafing areas, using a range of bird-mounted tags:	ability to demonstrate linkages between land-based breeding colonies and birds at sea, augmenting information on offshore densities and distributions and helping to identify relevant SPA population for EIA	generally small samples so may be difficult to determine representativeness of data, although as technology evolves and cheaper reliable options emerge, larger sample sizes are becoming feasible	bird welfare is paramount; species behavioural ecology will influence the selection of tag type and means of attachment; trade-off battery life, detection range, and size/weight of bird, but technology evolving rapidly; capture method is an important consideration; special licence requirements	Burger & Shaffer 2008 Table 1, Walls *et al.* 2009

Tracking methods

Methodology	Advantages	Disadvantages	Further development / considerations	References
1. Satellite Transmitters/Platform Transmitter Terminals (PTTs)	single handling, at time of capture and fitting remote data download via Argos satellite battery powered will operate for c. 1-2 months depending on tag/battery size and duty cycle; solar powered tags may last for 2-3 yrs; some GPS tags	size and weight limit suitability to larger species; guidance recommends <3% (to <5%) of bird's body weight, but not fully tested position error variable from few 10s of metres (GPS) up to several kms	Currently smallest tag 5g	Hamer *et al.* 2000 Hamer *et al.* 2001 Hamer *et al.* 2007 Griffin *et al.* 2010 Hamer *et al.* 2007
2. GPS data loggers	precision of positional information c. 20-30 m small and lightweight, c. 20-30 g, so suitable for wider range of species generally require recapture of bird to download data, although the development of Bluetooth or similar models enable remote download from a few tens of metres to a few kms or more depending on model	batteries last a few days, so repeated deployment may be necessary	flight height estimation	Daunt *et al.* 2002 Daunt *et al.* 2006 Guilford *et al.* 2008
3. Global Location Sensing (GLS)/ geolocators	small, very lightweight, c. 1.5g, & inexpensive tags can be mounted on metal leg ring collect data for up to 2 years on large scale movements eg migration	coarse spatial resolution, mean error of c185 km require recapture of bird to download data	measure ambient light levels requiring conversion to Lat/Long for geolocation	Harris *et al.* 2010
4. Radiotelemetry	small, very lightweight tags, down to less than 1g, suitable for even the smallest seabird species	short detection range requiring following the bird - impractical at long distances offshore		Perrow *et al.* 2006 Perrow *et al.* 2008 Wilson *et al.* 2009
5. GSM cellphone	novel technology, limited availability but considerable potential for providing frequent positional information over extended time periods	currently, size and weight, 75-100g, limit suitability to larger species; guidance recommends <3% (to <5%) of bird's body weight but not fully tested	prototype technology	M. Lanzone pers comm.

Methodology	Advantages	Disadvantages	Further development / considerations	References
6. Time Depth Recorders (TDRs)	complementary information on dive depth and dive duration, relevant to assessing foraging areas and behaviour contribute data towards habitat modelling (see below)	Recapture of birds necessary to retrieve tag and download data		*Gremillet et al. 2004*
Other loggers, activity loggers etc	activity loggers provide information on time budgets, when feeding, incubating etc. Size?	Recapture bird?		Daunt *et al.* 2002
Individually mounted cameras	small video camera mounted on bird record foraging behaviour etc.	Recapture of birds necessary to retrieve camera and download data	useful supplementary behavioural information	Watanuki *et al.* 2008 T Guilford pers comm

What is the predicted risk of collision, above or below water?

Collision Risk Modelling (CRM)

Methodology	Advantages	Disadvantages	Further development / considerations	References
analytical model used to predict collision risk, based on flight activity levels and putative avoidance rate; in the UK the "Band" model has become the standard tool for offshore wind; Marine Scotland/SNH have commissioned similar for wave & tidal stream.	provides a quantitiative assessment of risk using a standardised method	relies on the concept of avoidance rate which is the most influential factor in model outputs and for which there are few robust estimates, notably for seabirds over-reliance on predicted outputs, but limited validation	robust post-construction validation of the model predictions by monitoring collision, but this also requires methodological development offshore	Band *et al.* 2007 Band 2011 http://www.bto.org/sites/default/files/u28/downloads/Projects/SOSS_02_Band_model_guidance_document_FINAL_SEP_2011.pdf
dive depth & duration - see TDRs above	input to underwater collision risk model			
flight elevation see flight height estimation (survey methods) above & tracking methods	input to above water collision risk model			

How predictable are bird distributions and what are the determinants of their distribution? How widely applicable are such associations?

Habitat modelling

Methodology	Advantages	Disadvantages	Further development / considerations	References
Use information about offshore bird distributions and densities, to develop models of habitat associations, incorporating environmental variables (e.g. bathymetry, tidal fronts and mixing zones etc)	predictive models of bird distributions and densities, utilising information on species ecology; depending on statistical power of models, useful extension to areas that are data deficient	value may be limited if there is a high degree of site and species specificity - requires groundtruthing and model validation to determine consistency	may require larger spatial scales for analysis than occupied by individual devices or small arrays	Skov *et al.* 2008 Skov *et al.* 2008a
augmented by information about behaviour, to identify areas of importance for e.g. foraging	a means of exploring and increasing our understanding of marine ecosystems and therefore improving assessment of risk	in dynamic systems, environmental variables may change leading to less predictable distribution and abundance of birds at sea so models likely to be time-limited		

Where do birds forage? What are the consequences of habitat/prey change/loss?

Behavioural model

Methodology	Advantages	Disadvantages	Further development / considerations	References
Use behaviour-based information to develop predictive models	a means of exploring and increasing our understanding of bird behaviour and therefore improving assessment of risk	require groundtruthing and model validation e.g. via post-construction monitoring, to determine suitability	Individuals Based Models, other models	Stillman *et al.* 2000 Kaiser et al. 2005 http://www.offshorewindfarms.co.uk/Pages/Publications/COWRIE_1_reports/Predicting_the_displac40e7238b/ Perrow *et al.* 2010

What are the consequences for the population?

Population analysis / PVA

Methodology	Advantages	Disadvantages	Further development / considerations	References
analysis of demographic parameters to determine resilience of the population to the factor under test (wave or tidal stream) biogeographical & regional to provide context for SPA	provides a measure of the ability of a population to withstand the effects of offshore wave or tidal stream devices/arrays and may facilitate the determination of a sustainable threshold population size or rate of mortality	even minimum data requirements for PVA may be deficient for some species and surrogates may lead to large errors	require clear objectives, assessment of uncertainties and assumptions, sensitivity analysis	Beissinger & Westphal 1998 Maclean *et al.* 2007 Nadeem & Lele 2011

What is sustainable mortality

Potential Biological Removal (PBR)

Methodology	Advantages	Disadvantages	References
provides a measure of offtake that a population can tolerate	standardised & quantitative measurement	uncertainties and assumptions implicit in the process	Dillingham & Fletcher 2008, Dillingham & Fletcher 2011 Watts 2010
	provides a trigger for (conservation) action if the cumulative mortalities exceed some predefined threshold		

What is the most appropriate method for measuring change?

BACI vs Gradient

Methodology	Advantages	Disadvantages	Further development / considerations	References
Before-After-Control-Impact (BACI) generally recommended for experimental before/after comparisons, but requires control sites comparable in all respects, except for the factor under test (wave or tidal stream), to the study/impact site.	Tests the likelihood that the observed changes are more or less likely to be attributable to the factor under test (wave or tidal stream)	It is often difficult to find adequately comparable control sites, especially at sea, for replication.	requires reality check	Petersen *et al.* 2004 Petersen *et al.* 2007
Given that likely effects may diminish with increasing distance from the source, a **gradient approach** has been applied instead of BACI in several studies of offshore wind farms, and may be applicable also to wave & tidal stream projects. This approach requires assessment along a gradient, often applied as a series of concentric buffer zones around the study/impact site, sufficient to detect a change or diminution of effect.	Assesses change over distance from the impact zone, so not dependent on reference/control sites	Less powerful statistical tool, but rather academic if requirements of BACI cannot be met, hence may be better option for offshore wind farms (S. Buckland pers. comm.) and hence also for wave & tidal stream, especially if reference/ control areas are subject to development (e.g. R1 & R2 offshore wind farm extensions). buffer zones may not comprise equivalent habitat, for example they may at least partially include deeper waters/shipping channels adjoining shallow sandbanks that are proposed for wind farm development; implications for distance over which gradient assessment undertaken and identification of buffers/ study design.		

Is there a reduction in site use following installation of wave or tidal stream device?

Disturbance, displacement, exclusion; loss of habitat

Methodology	Advantages	Disadvantages	Further development / considerations	References
assessment of change in distribution and density and likelihood of displacement due to the presence of a wave or tidal stream device(s) (or associated disturbance eg from maintenance vessels):	determine the extent of effective habitat loss and whether temporary or long-term	power to detect change often weak	develop sampling protocols to deliver adequate power to detect change within acceptable levels of variance; high interannual and intra-annual variation compounds ability to detect change	
digital aerial survey sampling to detect a halving or doubling of the population, at a predetermined level of statistical precision, as a minimum			dependent on above surface profile, possible noise/vibration, lighting, maintenance vessels etc.	Thaxter & Burton 2009

Tracking studies

See above

What level of collision occurs, above or below water?

Collision monitoring, behavioural responses

Methodology	Further development / considerations
Monitoring of behaviour/collision above and below water	further development and test applications of potentially suitable tools, e.g. Cameras/TADS, sonar most promising

Were collisions predictions borne out? What level of avoidance applies post-construction?

Collision / near-turbine avoidance

Methodology	Advantages	Disadvantages	Further development / considerations	References
measurement of collision/avoidance to validate CRM; no definitive method for measuring collisions offshore available yet:				
1. camera	species ID capability	short operational range; trade-off between range, field of view & image resolution especially underwater daylight only		
2. Thermal Animal Detection Systems (TADS)/ Forward Looking Infra Red (FLIR)	day & night, including total darkness	short operational range <1-2km; trade-off between range, field of view & image resolution - how well would these systems work underwater?		Desholm 2003 Desholm *et al.* 2005 Desholm *et al.* 2006
	species ID capability	species ID requires skilled interpreter		
3. Sonar	See above		More development required	
4. Radar	See above		More development required	

Does the wave or tidal stream device present a barrier to bird movement? What is the magnitude of effect?

Avoidance at distance / barrier effect

Methodology	Advantages	Further development / considerations	References
radar (marine surveillance or avian laboratory)	day & night	dependent on above surface profile, possible noise/vibration, lighting, maintenance vessels etc.	Desholm & Kahlert 2005

What are the in-combination and cumulative impacts associated with wave or tidal stream developments ?

Methodology	Advantages	Further development / considerations	References
Protocol for assessment of cumulative and in combination impacts of multiple wave or tidal stream devices alone or in combination with other marine infrastructure or activities	Although dealing with CIA, aspects of the approach are also relevant to EIA	COWRIE Report provides a protocol for CIA; this is a prototype which will require refinement as it is tested	King *et al.* 2009