1.5.5.7 Special request Advice June 2010

SUBJECT Environmental interactions of wave and tidal energy generation devices

Advice Summary

Renewable energy developments (wave, tidal stream and barrage/fence) are likely to become important features of the OSPAR area. The likely ecological impacts of barrages/fences are large and reasonably well understood, but the impacts of wave, and particularly tidal stream, devices, are much less predictable and have the potential to be significant for some groups of organisms. It is important that the results of thorough monitoring of early deployments of wave and tidal stream devices are published and used to guide the management of subsequent developments.

Request:

Environmental interactions of wave and tidal energy generation devices (Marine wet renewables) (OSPAR 2010/4)

To provide advice on the extent, intensity and duration of direct and indirect effects and interactions of marine wet renewable energy production (wave, tidal stream and tidal barrage systems) with the marine environment and ecosystems of the OSPAR maritime area, and with pre existing users of these ecosystems, including:

a. actual and potential adverse effects on specific species, communities and habitats;
b. actual and potential adverse effects on specific ecological processes;
c. irreversibility or durability of these effects.

ICES Advice

Tidal barrages will alter tidal processes at the deployment site, and may be detectable over large sea areas. Tidal barrages represent a major modification to the coastal environment impinging on natural processes, and on many maritime activities. The scale of the construction projects for barrages and fences is potentially large and many of the major impacts associated with this phase, for example noise from pile driving, can be mitigated by careful planning, for example by avoiding critical times of year for marine mammals.

The principal environmental effects of a barrage are the changed tidal regime and its impact on bird communities and habitat availability. Many of the sites suitable for use will be designated sites for conservation value. The impacts on bird feeding habitat will be significant if intertidal mud/sand flats are affected. The use of a system that generates power on both ebb and flood tides (dual cycle generation) or the substitution of the barrage by a tidal fence may reduce some ecological effects as the tidal fences are not expected to alter the timing or amplitude of the tides. If the site was on a fish migration route (e.g. salmonids, eels, shad) fish passes need to be provided. Tidal barrages are likely to have a design life of more than 100 years and so effects will be persistent.

Tidal stream and wave energy devices are still in the experimental/trial phases and there are no data on the environmental effects of large scale commercial developments. Areas to locate tidal stream devices will be limited by the availability of the tidal resource but could occupy large areas of sea. However, wave energy resource is much more extensive in area than the tidal energy resource. Both technologies have the potential to occupy large sea areas for several decades.

The main ecological concerns regarding tidal stream developments are associated with their potential interactions with wildlife. The effect of the presence of turbines on the behaviour of marine mammals and migratory fish, and the potential for more direct interactions (e.g. collision) with marine mammals, birds and fish have not been well quantified.

Wave energy collectors have the potential to alter water column and sea bed habitats and by changes in the wave environment cause changes some distance from the installation. The effects of wave energy farms are poorly understood, making it hard to prioritize areas of environmental risk. The deployment of wave energy farms will potentially lead to change in benthic and pelagic habitat characteristics with consequential impacts on food web dynamics.

The environmental consequences of the construction and decommissioning of renewable energy projects will have considerable similarities to the consequences of other large scale marine or coastal projects. The processes will involve the operation of heavy lifting barges, increased shipping activity, anchoring, pile driving, construction of caissons, leading to the introduction of noise, vibration, disturbance of the sea bed, resuspension of sediment, disturbance of marine organisms, etc. The mitigation measures used in other contexts will be applicable to renewables, and may include management of the time of construction, noise mitigation measures, the use of marine mammal observers etc.

The installation of electrical transmission cables will entail some disturbance of the seabed and impacts on benthic habitats. Cables will act as sources of electromagnetic fields (EMF), although these will be less strong if paired DC systems are used. There is some uncertainty in the response of marine organisms to EMF, although mitigation measures, such as the use of buried cables, should greatly reduce the risk of significant impacts.

There are some general consequences of marine renewable developments. Their physical presence has the potential to affect utilisation of these areas by other marine sectors, mainly through restriction of access. This restriction has the potential to lead to conflicts with other sea users, primarily fishing and shipping. From a biodiversity point of view, restricted access may have some effects similar to those associated with the developing network of marine protected areas. For some installations, there may not be much visible infrastructure above the water surface, and so hindrance to normal marine navigation will need to be carefully managed. Conversely, their visual impact will be less than that of wind farms.

A recent review of the ecological effects of renewable energy devices in the coastal zone illustrated the sharp increase in the number of peer-reviewed science articles in this area since the early 1990s. However, less than 10% of these articles are related to environmental impacts and even fewer address ecological consequences related to the construction, deployment and decommissioning of renewable energy devices. There is a general paucity of peer-reviewed publications, particularly with respect to tidal barrages/fences, tidal stream and wave energy devices. It is important that appropriate scientific studies should therefore accompany the licensing of the first commercial scale installations, and that these are made available through the open literature. The influence of the development of renewable energy resources (e.g. wind, hydropower, tidal and waves) on marine habitat and biota is one on the priorities of the ICES Science Plan.

Recommendations

An iterative approach to the management of impacts is needed. As the types of technology develop, the environmental impacts and research needs will become more clear. All opportunities to monitor commercial scale developments should be taken to inform this process.

Basis of advice

The various nations that border the OSPAR region are all committed to significant reductions in CO_2 emissions in the near term. Against this background energy demand continues to grow and restrictions on energy use are likely to be seen as economically and socially damaging. The challenge is therefore to move to a new low carbon economy where energy demands can be met while levels of CO_2 emitted are reduced.

1. Tidal Barrage/Fence[1]

1.1 Habitat change

Building tidal barrages across and within a bay/estuary will destroy the former habitat under the physical structure and modify other areas within the development footprint. The presence of a barrage also influences habitats upstream and downstream of the facility. Upstream, under ebb-only generation, the upper intertidal remains submerged for a longer period; there is then a steady fall in tide level until the tide starts rising again. The former lower shore remains submerged. These changes will shift the balance between marine intertidal species with upper shore specialists potentially being squeezed out. The retention of water also significantly alters the exposure of tidal flats to feeding birds although the resource in the tidal flats when they are exposed may increase in quantity and quality. The availability of alternative feeding/roosting sites is therefore often critical. The implications for tidally feeding fish are the opposite to those of the birds with greater periods for foraging available due to the retention/raising of water levels.

Downstream of the barrage tidal range is often reduced close to the barrage but enhanced in other parts of the basin (Wolf *et al*., 2009). The outflow will delay the falling tide from around mid-tide downward, such that the tide falls as

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[1] The request specifically mentions wave, tidal stream and tidal barrage systems. ICES recognises that there are additional technologies that use temperature and pressure differentials, however, the three mentioned in the request are the only ones considered here as these are at the most advanced stage of development. Tidal fences are considered as a variation of tidal barrages. Both these systems can either span across an estuary or can be located so as to utilise tidal flow only.

normal, or more rapidly, from high water until the turbines open at mid-tide after which the rate of fall declines or is halted. This has potential negative implications for birds, although this effect occurs as the flats above the barrage become exposed.

Energy generation using barrage systems that generate power on both ebb and flood tides reduces considerably the changes in exposure of the intertidal area and so reduces potential impacts on the bird community. Tidal fences are not expected to alter the timing or amplitude of the tides.

The economics of a barrage or fence scheme scale with the volume of the tidal prism and hence the most favoured schemes tend to involve large estuaries or bays. For example, one option proposed for the Severn barrage in the UK would see 520 km^2 of the estuary impounded, compare this with the 17 km^2 at La Rance and 6 km^2 at Annapolis Royal. Given the very large environmental concerns with Severn development, the smaller Mersey barrage may be the first in the UK to get regulatory approval. The Mersey scheme would involve an impoundment of 61 km^2 but even this would be sufficient to generate changes in the tidal range at locations all around the Irish Sea (Wolf *et al*., 2009).

Changed spatial flow patterns will result in altered patterns of sediment deposition and movement. These will have impacts on benthic communities. The outflow will be constrained to the locations where the turbines are, and in these areas sediments will be scoured and coarsened while upstream of the barrage the reduced flows and periods of no flow will lead to increased siltation and potentially an increasing quantity of fine material in the deposits.

Changes in the nature of the habitats will alter their suitability as nursery or spawning areas for fish. While some species may benefit from larger areas of appropriate conditions this still represents a deviation from the normal, pre-impact system.

1.2 Water column processes and hydrography

Downstream of the barrage during outflow and immediately upstream on inflow, the constraining of the flow will lead to turbulent flows that will increase mixing. Upstream for much of the tidal cycle the water in the basin will be fairly static and this could lead to stratification, and changes in the phytoplankton dynamics.

In the Severn Estuary, for example, the strong tidal flows lead to highly turbid conditions and hence low primary productivity. Underwood (2010) suggested that following construction of a barrage the increased water clarity upstream could lead to increased phytoplankton derived primary production. However, this is thought to be less than the loss of primary production from microbial primary producers in the sediments due to the impounding of water and the reduction in the emergent area of the tidal flats.

Studies of the impact of passage through turbines on marine plankton are currently lacking. Reported mortality of freshwater zooplankton following entrainment in hydroelectric turbines can be high (Jenner *et al*., 1998). However, in many estuaries where tidal ranges are large plankton populations are low and derived from individuals advected into the estuary. This suggests that even if mortality of entrained individuals is high this is not likely to be significant at the population and community level.

Levels of direct mortality of fish passing through high-speed turbines can be high and the disorientation caused may lead to lowered ability to avoid predation in the period after passage. These fish will include both migratory species as well as those that move into shallow waters to feed and/or reproduce. However, there is considerable experience of engineering sluices, cooling water intakes and turbines to reduce fish entrainment (Coutant and Whitney, 2000) and such mitigation measures should be seen as a critical part of any system design.

Energy extraction may affect turbulent mixing, and change patterns of sediment distribution. Tidal fences in high energy coastal areas may encounter currents moving at 5 to 8 knots (9 to 15 km per hour) producing intense mixing processes continuously in the water column. At lesser velocities some degree of water column stratification can be expected (Gray, 1992). This may also bring increased water clarity through reduced sedimentation.

1.3 Spatial interactions with pre-existing users

The presence of the barrage or fence will have an impact on existing uses such as fishing, aquaculture, navigation, recreation and seascape and these could be both positive and negative and in some cases provide new opportunities. The necessity for exclusion zones will depend on the location, the device and the activity. On most large barrage proposals spanning an estuary the passage of shipping through the barrage is maintained by the provisions of appropriate lock systems with associated breakwaters and channels.

Exclusion zones will be required during both construction/decommission and operation phases. These zones would likely be larger during the construction period and reduced once the system was operational.

1.4 Noise

Possible effects on marine mammals include noise and vibration during operation affecting species that use sonar to pursue prey or affecting communication between animals; direct collision or contact; and indirect effects on the distribution and abundance of prey species. Overall, operational noise of tidal barrages/fences is unlikely to be ecologically significant unless the area is intensively used by marine mammals.

1.5 Food chain

The principal food chain effect of tidal barrages is the reduction in availability of infaunal food to the bird population. In the UK, and probably northern Europe in general, the quantity and quality of the food on the feeding grounds of over wintering waders determine survival to the next breeding season. Thus reduced feeding areas, increased foraging costs (extra flights between sub-optimal grounds) or lower food quality will directly impact on population size. The greater foraging time available to fish predators in the intertidal may also alter species composition of the fish assemblage by favouring species able to exploit this resource efficiently, but the consequences in individual cases are difficult to predict. Food chain effects produced by tidal fences are expected to be much less.

1.6 Reproduction

Locating a barrage on or near a nursery or spawning area will clearly have an impact. These are site specific considerations. More generally by producing a barrier across the estuary/fjord the barrage will impact on migrations of anadromous and catadromous species including economically important salmonids and eels and protected species such as shad.

Tidal fences will also restrict fish and marine mammal passage through physical blockage, although there is room for mitigation through engineering of the fence structure to allow spaces for fish to pass through between the caisson wall supporting the turbines and the rotors. Further, placement of the fence (in-parallel or in-series to water flow) can greatly influence impacts on species and habitats.

2 Tidal Stream Farm

2.1 Habitat change

Energy generation using the tidal stream uses turbines or other devices placed in the water column to extract energy. The installation and operation of individual or multiple tidal stream devices, as with other forms of wet renewable energy systems, directly affect benthic habitats by altering water flows, wave structures, or substrate composition. Physical impact from small-scale tidal stream generation pilot projects have been found to be reversible on decommissioning, especially as the areas most suitable for tidal power generation are located where high current flow causes natural disturbance to the sediments. However, the cumulative effects of multiple turbines also need to be considered with respect to far field impacts.

Installation will alter benthic habitats over the longer term if trenches containing electrical cables are backfilled with sediments of different size or composition than the previous substrate. The use of large particles as a cover may be required to reduce the likelihood of cables becoming exposed and emitting electromagnetic fields into the water column.

When operational, regardless of design and size, all tidal stream farms will include a large anchoring system made of concrete or metal, mooring cables, and electrical cables that lead from the offshore facility to the shoreline. Electrical cables may simply be laid on the bottom, or more likely anchored or buried to prevent movement. Movements of mooring or electrical transmission cables along the bottom (sweeping) have been shown to be a continual source of habitat disruption during operation. The strumming action of cables has been shown to cause incisions in rocky outcrops, but effects on seafloor organisms have generally be shown to be minor (Kogan *et al*., 2006). Large bottom structures will alter water flow and may result in localized scour and/or deposition. Because these new structures will affect bottom habitats, consequential changes to the benthic community composition and species interactions may be expected (Lohse *et al*., 2008).

Mobile bedforms resulting from the effects of new installations could modify the benthic habitat nearby, though the extent of these modifications depends on the character of the bottom in question. Tidal stream farms will likely be located in dynamic areas of exposed bedrock, which could reduce downstream drifting of sediment.

At this time, there are insufficient data to state definitively how fish and fish habitat will be impacted by the operation of tidal stream power projects. No published data on the interactions between turbines and fish in the marine environment could be found except for some information from the Roosevelt Island tidal energy project in New York city's East River (Anon, 2008). That study showed that densities observed in and around the turbines were generally low (range of 16-1400 fish per day seen); the fish were predominantly small but still swam faster than the turbines rotated; and fish movement tended to be restricted to the direction of the tide and during slack water when the turbines were non-operational (Anon, 2008).

There remain large information gaps concerning the collision risk of marine mammals with structures such as tidal stream farms (but see SeaGen, 2009). The literature reviewed suggests that the probability of cetaceans failing to detect and avoid a large static structure is considered to be extremely low, particularly for species that echo-locate and are agile and quick moving. The exact placement of tidal farms for species that frequent particular areas, either through site fidelity or seasonally, should be considered in mitigation. Feeding and breeding sites in particular for marine mammal species should be avoided when tidal farm sites are selected. This is logical risk management strategy in the face of uncertainty even though there are no documented cases of any negative impact on marine mammals.

The impacts of tidal stream farms on seabirds are also reported to be small (e.g., Anon, 2008). Risk of collision is expected to be minimal as for many species of sea birds, including gulls, terns, kittiwakes, fulmars and skuas, their normal depth range would not allow them to encounter operating turbines. For some deep diving species, e.g. auks, shags, there is the chance of an encounter as these species regularly dive to depths of 45-65m. The critical issue is the relative swimming speed of the bird, and the ability to sense and respond to the turbine. It is thought that the slow turbine speeds relative to the agility of diving bird species would make the risk of mortality very low (Awatea, 2008). However, a typical swimming speed for these species is of the order of $1.5 ms^{-1.}$. For comparison, the tip turning at 15rpm would be moving faster than this and so potentially be difficult for a bird to avoid. The possible interactions are further complicated by the possibility that diving birds may respond to the moving blades as potential prey and be attracted to their vicinity. Further work is needed to elucidate the scale of this phenomenon and to develop mitigation measures, i.e., painting the blades.

There is a lack of information on the interaction of marine mammals, fish and birds and the moving parts of tidal stream devices. The risk of collision with the moving parts of turbines is dependent on a wide range of factors, including the ability of organisms to detect and avoid them. However, while some bird species appear to dive and feed at all states of the tide, there are field observations that suggest that seals may tend to congregate in near-shore, relatively quiescent, areas at times of maximum tidal flow when turbines will be operating at full capacity and thereby reduce their risk of collision.

2.2 Water column processes and hydrography

Tidal energy power generation devices have the potential to increase turbulence in the water column, which in turn will alter mixing properties, sediment transport and, potentially, wave properties. In both the near field and far field, extraction of kinetic energy from tides will decrease tidal amplitude, current velocities, and water exchange in a region in proportion to the number of units installed, potentially altering hydrography and sediment transport. The effect on transport and deposition of sediment may also influence organisms living on or in the bottom sediments, and plants and animals in the water column. Moving rotors and foils have been shown to increase mixing in systems where salinity or temperature gradients are well defined.

Changes in water velocity and turbulence will vary greatly, depending on distance from the structure. For small numbers of units, the changes are expected to dissipate quickly with distance and are expected to be only localized; however, for larger commercial arrays, the cumulative effects will extend to a greater area although it is still not known whether these would have significant effects on the ecosystem.

Tidal energy turbines may also modify wave heights by extracting energy from the underlying current. The effects of structural drag on currents are not expected to be significant (MMS, 2007), but few measurements of the effects of tidal/current energy devices on water velocities have been reported.

Changes in water velocities and sediment transport, erosion, and deposition caused by the presence of new structures will alter benthic habitats, at least on a local scale. Craig *et al*. (2008) reports that deposition of sand may impact seagrass beds by increasing mortality and decreasing the growth rate of plant shoots. While the new habitats created by such structures may enhance the abundance and diversity of invertebrates, predation by fish attracted to artificial structures can greatly reduce the numbers of benthic organisms (Davis *et al*., 1982; Langlois *et al*., 2005).

2.3 Spatial Interactions with pre-existing users

It is likely that tidal stream farms may have exclusion zones within and around them to provide a safety barrier from other activities, such as fishing and navigation (depth dependent), similar to those found at other marine energy structures. Exclusion zones are likely to be marked by cardinal buoys and navigation lights, noted on shipping charts in future and advised through Notices to Mariners. Whilst other human activities are likely to be excluded in the area of marine energy converters arrays, the resultant exclusion zones may create *de facto* marine reserves, in which marine life can flourish. The nature of the changes associated with these closed zones is not simple to predict but there is a considerable body of data showing the effects of such schemes (Balmford *et al.*, 2004; Murawski, 2005; Murawski *et al.*, 2005; Kaiser, 2005; Rice, 2005). They may lead to fishery displacement to other areas. Marine energy projects will add to the cumulative impact of closures for other reasons.

2.4 Noise

There are considerable information gaps regarding the effects of operational noise generated by tidal stream farms on cetaceans, pinnipeds, turtles, and fish. Sound levels from these devices have not been routinely measured, but it is likely that installation will create more noise than operation. Operational noise from generators, rotating equipment, and other moving parts may have comparable frequencies and magnitudes to those measured at offshore wind farms; however, the underwater noise created by a wind turbine is transmitted down through the pilings, whereas noises from tidal stream farms are likely to be greater because they are at least partially submerged. Operational noise from a small number of units may not exceed threshold levels, but the cumulative noise production from large numbers of units has the potential to mask the communication and echolocation sounds produced by aquatic organisms in the vicinity of the structures.

Resolution of the significance or otherwise of noise impacts will require information about the device's acoustic signature (e.g., sound pressure levels across the full range of frequencies) for both individual units and multiple-unit arrays, similar characterization of ambient noise in the vicinity of the farm, the hearing sensitivity of fish and marine mammals that inhabit the area, and information about behavioural responses to anthropogenic noise (e.g., avoidance, attraction, changes in schooling behaviour or migration routes).

2.5 Food Chain

Principal indirect effects of tidal power turbines will relate to the consequences for biota of local physical impacts, and to changes in hydrographic conditions that may result from tidal energy extraction. Few studies have been undertaken which help to specify the magnitude or importance of such effects, beyond those generic indirect effects resulting from the placement of structures on the seabed.

Numerical modelling methods are available to predict the effects of developments on stratification and mixing in the water column. Some consequences for primary production and larval settlement may be predicted, but are likely to be localised. Alterations in patterns of turbulence may affect the feeding behaviour of some seabirds, particularly terns.

2.6 Reproduction

In general reproduction of species is unlikely to be affected by these devices.

3 Wave Energy Farm

3.1 Habitat and Species

Wave energy farms show a wide variety of systems, at several stages of development, competing against each other, without it being clear which types will be the final winners (Falcão, 2010).

The dampening of waves may alter coastal processes affecting the balance between erosion and deposition of sediments; this may have both societal and environmental impacts. Dampening may cause ecological changes but sheltering due to wave devices will have a negligible effect on the largest waves (Pelc and Fujita, 2002).

Some offshore wave energy farms are expected to contribute to an increase in submerged constructions on the seabed, including a possible impact on the surrounding soft-bottom habitats. As both pilot and commercial wave energy converting applications are limited, so are studies on habitat change. Langhamer and Wilhelmsson (2009) examined the function of wave energy foundations as artificial reefs. Langhamer *et al.* (2009) demonstrated that foundations serve as colonisation platform with a higher degree of coverage on vertical surfaces.

Regarding the pelagic habitat, buoys have positive effects on forage species, which consequently cause an attraction of large predators. On the other hand, lines on structures can cause the entanglement of marine mammals, turtles, larger fish and seabirds, but they also can produce an increase of settlement of meroplankton (Boehlert *et al.*, 2007; DFO, 2009). The pelagic habitat is also changed by creating platforms for predators, e.g. seabirds, and by changing the hydrographical conditions.

3.2 Water column processes and hydrography

Wave power plants act as wave breakers, calming the sea, and the result may be to slow the mixing of the upper layers of the sea, which could cause an adverse impact on the marine life and fisheries (Pelc and Fujita, 2002). The energy devices remove energy from the wave train, affecting the height of the splash zone, sediment deposition and ecosystem productivity. Similarly, erosion patterns along long stretches of coastline could be changed, being the effect beneficial or detrimental depending on the specific coastline (Pelc and Fujita, 2002). They may also modify some other local sediment transport patterns (including re-suspension and deposition) by localized hydrodynamic changes due to presence of physical structures and from energy extraction. Depending on the location, scale, technological characteristics and dynamical processes, all these effects can be extended along the environment. Substrate disturbance during deployment, decommissioning and maintenance processes, for example, can lead to increased suspended sediments and turbidity, especially in areas with finer substrates such as sand or silt. Sediment re-suspension may directly cause deleterious health effects or mortality to fish, and increased turbidity could hinder the prey detection ability of species that rely on visual cues (DFO, 2009). All these processes could alter the way the ocean interacts with the atmosphere locally but given the scale of the ocean they are unlikely to be of ecological significance for system functioning (Pelc and Fujita, 2002).

3.3 Spatial interactions with pre-existing users

Commercially operated wave energy farms are limited (e.g., Portugal and Scotland). Therefore, one can only speculate about possible configurations (e.g., Falcão, 2010). Length and width vary by number and type of Wave Energy Converters (WECs) with single devices ranging from 15 to 150 m. However, WECs are usually deployed in multiples and the footprint will therefore vary with the actual configuration. There is more likely to be navigation exclusions related to the surface positioning of these devices. However fisheries and recreation activities may also be affected.

3.4 Noise

A large number of species of different taxa (cetaceans, pinnipeds, teleosts, crustaceans) use underwater sounds for interaction and echolocation (Misund and Aglen, 1992; Popper and Hastings, 2009; Langhamer *et al.*, 2010). There have been very few (if any?) directed studies of the response of fish and marine mammals to noises and vibrations produced by operational WECs, (DFO, 2009). DFO (2009) reports existing modelling studies suggesting construction and operation noise levels can cause temporary, or in certain circumstances, permanent hearing loss in porpoises, seals and some fish and interfere with interactions between organisms (communication, finding prey, location of recruitment sites, etc.). As for other effects, the type of WECs and scale of application determine the production of noise and subsequent effects (Boehlert *et al.*, 2007). The constant low-intensity sounds from operating WECs have also been compared to low /normal density shipping noise or noise generated from a ferry (Anon, 2008), implying that effects may also be of a comparable magnitude.

3.5 Food Chain

Wave energy arrays provide a matrix of hard structures which will likely have ecological consequences from the fouling community up through the highest levels of trophic structure. Moreover, forage species are attracted by these devices, which is associated with an increase of presence of large predators and the corresponding changes in the food web.

Some marine species (cetaceans, pinnipeds, teleosts, crustaceans) are especially sensitive to acoustics (Popper and Hastings, 2009). Avoidance of areas by certain species or changes in foraging success due to interactions between anthropogenic noise with acoustic sensory apparatus could result in food chain effects (Boehlert *et al.*, 2007). The structural complexity that these devices give to the marine environment will alter the habitat and hence the trophic relationships. For example, they provide opportunities for ambush predators as well as shelter for prey and the presence of organisms attached to or hiding between the structures may serve to increase the range of potential prey items available (Langhamer *et al.*, 2010). Field evidence for these processes is currently lacking.

Some authors have speculated that changes in surface productivity linked to a reduced mixing may alter the food supply to benthic populations (Pelc and Fujita, 2002). Models are available to predict the extent to which wave energy farms will reduce water column mixing or the amplitude of waves impinging on to coastal habitats.

3.6 Reproduction

It has been hypothesised that noise might interfere with the ability of some fish species that locate their nursery areas by sound (Langhamer *et al.*, 2010) although specific data were not presented. Breeding vocalizations are important for mate attraction in freshwater goby (Lugli *et al.*, 1996), cod (Finstad and Nordeide, 2004) and haddock (Hawkins and Amorima, 2000).

4 Generic

4.1 New hard surfaces

Permanent structures on the bottom (ranging in size from anchoring systems to seabed-mounted generators or turbine rotors) will smother existing habitats. These new structures would replace natural hard substrates or, in the case of previously sandy areas, add to the amount of hard bottom habitat available to benthic algae, invertebrates, and fish. This could attract a community of rocky reef fish and invertebrate species (including biofouling organisms) that would not normally exist at that site. It has been speculated that depending on the location, the newly created habitat could increase biodiversity or have negative effects by enabling introduced (exotic) benthic species to spread. Marine fouling communities developed on monopiles for instance in offshore wind power plants have been found to be significantly different from the benthic communities on adjacent hard substrates (Wilhelmsson *et al.*, 2006; Wilhelmsson and Malm, 2008).

4.2 Cables including Electromagmetic Fields (EMFs)

The environmental impacts of electromagnetic emissions from cables, switch gear and sub-stations is the same irrespective of the energy generating device and thus the lessons learnt from offshore wind power developments are applicable to developments harnessing tidal stream or wave energy.

It is well documented that several marine species use magnetic and electrical fields for navigation and locating prey. Electrical fields (E fields) are proportional to the voltage in a cable, and magnetic fields (B fields) are proportional to the current. All fish are sensitive to a greater or lesser extent to electric fields. The background document working group report (ICES, 2010a) provides details on the available knowledge of these effects on a number of fish species and expands on the information listed in the OSPAR background document on cables (OSPAR, 2009).

Cables carrying direct current (DC) from individual installations are likely to carry only 10–15 kV, which is unlikely to generate any electrical field more than a few centimeters from the cable (Westerberg and Begout-Anras, 2000).

Langhamer *et al*. (2009) remarks that with the use of a better cable technology the electromagnetic fields only affect the nearest surroundings as the background earth magnetic field usually becomes more prominent only a few decimetres from the cable. In combination with cables buried into the seabed, issues with electromagnetic fields might disappear.
Electricity generated by the existing barrage facilities is carried away by cables running on the top of the barrage and so has no marine environmental impact.

5 Contaminants and anti-fouling

With regard to water quality, the loss of oil is the biggest impact identified. Subsurface electrical equipment will contain oil as an insulator and lubricant while some designs of wave and tidal stream energy collection devices use hydraulic systems that will contain oil. Modular design and appropriate valves should limit the volume of oil loss in the event of a structural failure or collision damage (Boehlert *et al*., 2007). Modern materials used in manufacturing and the regulations regarding placement in the marine environment will limit the risk of the devices introducing contamination into the sea (Boehlert *et al*., 2007; DFO, 2009).

One potential source of contamination is leaching from anti-fouling preparations. Modern anti-fouling preparations tend to be low in toxicity and biodegradable.

6. Construction and Decommission.

The environmental consequences of the construction and decommissioning of renewable energy projects will have considerable similarities to the consequences of other large scale marine or coastal projects. The processes will involve the operation of heavy lifting barges, increased shipping activity, anchoring, pile driving, construction of caissons, leading to the introduction of noise, vibration, disturbance of the sea bed, resuspension of sediment, disturbance of marine organisms, etc. The mitigation measures used in other contexts will be applicable to renewables, and may include management of the time of construction, noise mitigation measures, the use of marine mammal observers etc.

Activities likely to produced noise at levels of concern include pile-driving, explosive or seismic work. Even within the construction/decommissioning phases these are intermittent, short duration activities but they have the potential to effect cetacean or pinniped activity in the region at the same time (Madsen *et al.*, 2006). At offshore wind farms in Denmark, Henriksen *et al*. (2004) and Tougaard *et al*. (2003) both found effects on the behaviour and abundance of harbour porpoises during pile driving activities. Fewer animals exhibited foraging behaviour and there was a short-term reduction of echolocation activity. These effects were documented up to 15 km from the impact area. These effects were, however, short-lived once construction ceased (Carstensen *et al*., 2006). Studies suggest that high-level impulsive sounds have a greater effect on cetaceans than pinnipeds (McCauley and Cato, 2003; Gordon *et al*., 2004). Langhamer *et al*. (2010) remark that the production of noise by drilling and placing during construction, cable laying, as well as boat traffic can damage the acoustic system of species within 100m from the source and cause mobile organisms to avoid these areas during that time.

During construction noise and vibrations would affect different fish species in different ways (US Department of Energy, 2009; DFO, 2009). Pile driving would likely affect schooling fish or any species with a swim bladder. Effects on other species would be less certain. Effects could be direct, by damaging sensory or sensitive tissues, or indirect, by changing behaviours. Migratory shorebirds depend on benthic intertidal invertebrates, the abundance and distribution of which might be altered by tidal development through sediment changes. During the operations phase noise and vibrations could continue to affect some species. It is important when assessing noise effects that the cumulative effects of the entire system be evaluated and not just the levels produced by individual modules (US Department of Energy, 2009).

During the construction phase of tidal stream farms the impacts on habitats will be similar to those experienced in the construction of other wet renewable installations. Bottom disturbances will result from the temporary anchoring of construction vessels; digging and refilling the trenches for power cables; and installation of permanent anchors, pilings, or other mooring devices. Fish and other mobile organisms will be displaced and sessile organisms smothered in the limited areas affected by these activities. Species with benthic-associated spawning or whose offspring settle into and inhabit benthic habitats are likely to be most vulnerable to disruption during installation. The general mitigating considerations applied to marine construction should also be appropriate to wet renewables.

Temporary increases in suspended sediments and sedimentation down stream from the construction areas can also be expected. When construction is completed, disturbed areas are likely to be re-colonized by these same organisms, assuming that the substrate and habitats are restored to a similar state (e.g., Lewis *et al*., 2003).

Consistent with other marine construction projects detailed site investigations including baseline monitoring and archaeological surveys are needed.

7 References

Anon. 2008. Roosevelt Island Tidal Energy Project FERC No. 12611., Draft Kinetic Hydropower Pilot Licence Application Volume 2 of 3. November 2008.

Awatea. 2008. Environmental Impacts of Marine Energy Converters, Report prepared by Power Projects Limited in association with the National Institute of Water and Atmospheric Research. 7 November 2008.

Balmford, A., Gravestock, P., Hockley, N., McClean, C. J. and Roberts, C. M. 2004. The worldwide costs of marine protected areas. Proceedings of the National Academy of Sciences of the United States of America, 101: 9694-9697.

Boehlert, W. G., McMurray, G. R. and Tortorici, C. E. 2007. Ecological Effects of Wave Energy Development in the Pacific Northwest. A Scientific Workshop, October 11-12. . NOAA Technical Memorandum NMFS-F/SPO-92.

Carstensen, J., Henriksen, O. D. and Teilmann, J. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echo-location activity using porpoise detectors (T-PODS). Marine Ecology Progress Series, 321.

CMACS. 2003. A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables, Centre for Marine and Coastal Studies: COWRIE Report EMF-01-2002 66. http://www.offshorewind.co.uk (accessed August 20, 2008), Liverpool, UK.

Coutant, C. C. and Whitney, R. R. 2000. Fish Behavior in Relation to Passage through Hydropower Turbines: A Review. Transactions of the American Fisheries Society, 129: 351-380.

Craig, C., Wyllie-Escheverria, S., Carrington, E. and Shafer, D. 2008. Short-term sediment burial effects on the seagrass *Phyllospadix scouleri*, EMRPP Technical Notes Collection (ERDC TN-EMRRP-EI-03). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Davis, N., VavBlaricom, G. R. and Dayton, P. K. 1982. Man-made structures on marine sediments: effects on adjacent benthic communities. Marine Biology, 70: 295-303.

DFO. 2009. Assessment of Tidal and Wave Energy Conversion Technologies in Canada, DFO Canada, Scientific Advisory Secretariat. Scientific Advisory Report 2009/064, Ottawa.

Falcão, A. F. D. O. 2010. Wave energy utilization: A review of the technologies. Renewable and Sustainable Energy Reviews, 14: 899-918.

Finstad, J. L. and Noreide, J. T. 2004. Acoustic repertoire of spawning cod, *Gadus morhua*. Environmental Biology of Fishes, 70: 427-433.

Gordon, J., Gillispie, D., Potter, J., Frantzis, A., Simmonds, M. P., Swift, R. and Thompson, D. 2004. The effects of seismic surveys on marine mammals. MarineTechnology Society Journal, 37: 16-34.

Gray, A. J. 1992. The ecological impact of estuarine barrages. p. 46. British Ecological Society/Field Studies Council, Shrewsbury.

Hawkins, A. D. and Amorima, M. C. P. 2000. Spawning sounds of the male haddock, *Melanogrammus aeglefinus*. Environmental Biology of Fishes, 59: 29-41.

Henriksen, O., Carstensen, J., Tougaard, J. and Teilmann, J. 2004. Effects of the Nysted Offshore Wind Farm construction on harbor porpoises: Annual status report for the acoustic TPOD monitoring programme during 2003, http://www.wind-energie.de/fileadmin/dokumente/Themen_A-Z/Offshore/report-nysted_environmental2002.pdf.

Jenner, H. A., Whitehouse, J. W., Taylor, C. J. L. and Khalanski, M. 1998. Cooling water management in European power stations Biology and control of fouling. Hydroécological Applications, 10: 1-225.

Kaiser, M. J. 2005. Are marine protected areas a red herring or fisheries panacea? Canadian Journal of Fisheries and Aquatic Sciences, 62: 1194-1199.

Kogan, I., Paull, C. K., Kuhnz, L. A., Burton, E. J., Thun, S. V., Greene, H. G. and Barry, J. P. 2006. ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations, environmental impact. Continental Shelf Research, 26 771-787.

Langhamer, O. 2010. Effects of wave energy converters on the surrounding soft-bottom macrofauna (west coast of Sweden). Marine Environmental Research, *In press*.

Langhamer, O., Haikonen, K. and Sundberg, J. 2010. Wave power-Sustainable energy or environmentally costly? A review with special emphasis on linear wave energy converters. Renewable and Sustainable Energy Reviews, 14: 1329-1335.

Langhamer, O. and Wilhelmsson, D. 2009. Colonisation of fish and crabs of wave energy foundations and the effects of manufactured holes - A field experiment. Marine Environmental Research, 68: 151-157.

Langhamer, O., Wilhelmsson, D. and Engström, J. 2009. Artificial reef effect and fouling impacts on offshore wave power foundations and buoys - a pilot study. Estuarine, Coastal and Shelf Science, 82: 426-432.

Langlois, T. J., Anderson, M. J. and Babcock, R. C. 2005. Reef-associated predators influence adjacent soft-sediment communities. Ecology, 86: 1508-1519.

Lewis, L. J., Davenport, J. and Kelly, T. C. 2003. A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Part 2. Recolonization by benthic invertebrates after 1 year and response of estuarine birds Estuarine, Coastal and Shelf Sciences, 57: 201-208.

Lohse, D. P., Gaddam, R. N. and Raimondi, R. T. 2008. Predicted Effects of Wave Energy Conversion on Communities in the Nearshore Environment. *In* Developing Wave Energy in Coastal California: Potential Socio-Economic and Environmental Effects. . Ed. by P. A. Nelson, D. Behrens, J. Castle, G. Crawford, R. N. Gaddam, S. C. Hackett, J. Largier, D. P. Lohse, K. L. Mills, P. T. Raimondi, M. Robart, W. J. Sydeman, S. A. Thompson and S. Woo. California Energy Commission, PIER Energy-Related Environmental Research Program and California Ocean Protection CouncilCEC-500-2008-083. http://www.resources.ca.gov/copc/docs/ca_wec_effects.pdf (accessed November 19, 2008).

Lugli, M., Pavan, G. and Torricelli, P. 1996. The importance of breeding vocalizations for mate attraction in a freshwater goby with composite sound repertoire. Ethology, Ecology and Evolution, 8: 343-351.

Madsen, PT, Johnson M, Miller PJO, Aguilar Soto N, Lynch J and Tyack P 2006. Quantitative measures of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. J Acoustical Society of America, 120: 2366-2379.

McCauley, R. D. and Cato, D. H. 2003. Acoustics and marine mammals: Introduction, importance, threats and potential as a research tool. *In* Marine mammals: Fisheries, tourism, and management issues, p. 460. Ed. by N. Gales, M. Hindell and R. Kirkwood. CSIRO Publishing, Collingwood.

Misund, O. A. and Aglen, A. 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic trawl sampling. ICES Journal of Marine Science, 49: 325-334.

MMS (Minerals Management Service). 2007. Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Uses of Facilities on the Outer Continental Shelf. Final EIS. MMS 2007-046. October 2007. http://ocsenergy.anl.gov (accessed August 13, 2008).

Murawski, S. A. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. Ices Journal of Marine Science, 62: 1150-1167.

Murawski, S. A., Rago, P. and Fogarty, M. 2005. Spillover effects from temperate marine protected areas. American Fisheries Society Symposium, Tampa, FL.

OSPAR, 2009. Assessment of the environmental impact of cables. Biodiversity series, OSPAR, London. 19 pp.

Pelc, R. and Fujita, R. M. 2002. Renewable energy from the ocean. Marine Policy, 26: 471-479.

Popper, A. N. and Hastings, M. C. 2009. The effect of human-generated sound on fish. Integrative Zoology, 4: 43-52.

Rice, J. C. 2005. Ecosystem Effects of Fishing: Impacts, Metrics and Management Strategies. 187 pp.

Seagen: www.seageneration.co.uk.

Tougaard, J., Carstensen, J., Henriksen, O., Skov, H. and Teilmann, H. 2003. Short term effects of the construction of wind turbines on harbor porpoises at Horns Reef., Hedeselskabet Roskilde, Denmark.

Underwood, G. J. C. 2010. Microphytobenthos and phytoplankton in the Severn estuary, UK: Present situation and possible consequences of a tidal energy barrage. Marine Pollution Bulletin, 61: 83-91.

US Department of Energy. 2009. Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies, US Department of Energy, Washington D.C.

Westerberg, H. and Begout-Anras, M. L. 2000. Orientation of silver eel (*Anguilla anguilla*) in a disturbed geomagnetic field. *In* Advances in Fish Telemetry. Proceedings of the 3rd Conference on Fish Telemetry, pp. 149-158. Ed. by A. Moore and I. Russell. CEFAS, Lowestoft.

Wilhelmsson, D. and Malm, T. 2008. Fouling assemblages on offshore wind power plants and adjacent substrata. Estuarine, Coastal and Shelf Science, 79: 459-466.

Wilhelmsson, D., Malm, T. and Ohman, M. C. 2006. The influence of offshore windpower on demersal fish. Ices Journal of Marine Science, 63: 775-784.

Wolf, J., Walkington, I., Holt, J. and Burrows, R. 2009. Environmental Impacts of Tidal Power Schemes. Liverpool, Proudman Oceanographic Laboratory: 18 pp.

Extra information

H M Government (March 2010). Marine Energy Action Plan 2010. Executive Summary & Recommendations. Department of Energy and Climate Change. www.decc.gov.uk

Environmental Effects of Tidal Energy Development: A Scientific Workshop. University of Washington, Seattle, Washington March 22-24 2010. [Final report not yet available]. Workshop Briefing Paper available at http://depts.washington.edu/nnmrec/workshop/docs/Tidal_energy_briefing_paper.pdf

Wilson, B., Batty, R. S., Daunt F., and Carter, C (2007). Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for marine science, Oban, Scotland, PA37 1QA.

Sources

ICES 2010a. Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO). ICES CM 2010/ACOM: 23

ICES 2010b. Report of the Working Group on Integrated Coastal Zone Management (WGICZM). ICES CM 2010/ SSGHIE:05.