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Is there a conflict between cetacean conservation and marine renewable-energy developments?

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Abstract. There is currently an unprecedented expansion of marine renewable-energy developments, particularly in UK waters. Marine renewable-energy plants are also being developed in many other countries across Europe and in the wider world, including in the USA, Canada, New Zealand and Australia. Large-scale developments, in UK waters, covering thousands of square kilometres are now planned; however, data on the likely impact of this expansion on the 28 cetacean species found in UK waters are lacking, or at best limited. However, the available information, including inferences drawn from the impact of other human activities in the marine environment, indicates a significant risk of negative consequences, with the noise from pile driving highlighted as a major concern. The marine renewable-energy industry will also deploy some novel technologies, such as large submerged turbines, with unknown consequences for marine wildlife. Further research is urgently required, including distributional and behavioural studies, to establish baselines against which any changes may be measured. Precautionary actions, particularly with respect to pile driving, are advocated to minimise impacts on cetaceans.

Introduction

Globally, there are many human activities that threaten the whales, dolphins and porpoises that make up the mammalian order Cetacea (Evans 2009; Reeves 2009). Many of these activities occur in British waters (Reid *et al*. 2003; Parsons *et al*. 2010). While whale hunting in British waters ceased several decades ago, the incidental, or collateral, deaths of cetaceans in fishing apparatus (also known as 'by-catch') remain a significant threat to many cetacean populations. Other human activities with indirect impacts may also be significant. For example, boat traffic can cause collisions that injure or kill cetaceans. Although potential threats are relatively easy to identify, their significance can be difficult to evaluate. For example, the bodies of cetaceans killed at sea may be lost or recovered in a decomposed condition, precluding diagnosis of cause of death.

Human activities in the sea may have an impact on cetaceans in a variety of ways. For example, boat traffic also radiates noise into the marine environment and marine noise pollution is a threat that is particularly difficult to interpret (Marine Mammal Commission 2007; Weilgart 2007). Cetaceans have evolved to utilise the acoustic qualities of their environment, making hearing their primary sense. Many cetacean species use echolocation to help them navigate and find food. Because cetaceans are 'hearing-centric', the potential effects of new, different or loud noises are of 'critical importance to them' (Bradley and Stern 2008). Bradley and Stern (2008) noted that the cetaceans' acoustic environment influences all of the biologically significant things they do and, if it changes, it is reasonable to expect that their behaviour will change. Humans are primarily land-based and vision-centric, making the threats posed by noise to cetaceans difficult for us to perceive, although many people will easily recognise that loud noise can be irritating, disrupting, disturbing or even painful.

We focus here on the UK as both a case study and an area where marine renewable developments are proceeding particularly swiftly and at a large scale. Here, as elsewhere, the marine renewables industry is new and we shall consider whether it poses a threat to the cetaceans that live in British and contiguous waters, by examining its planned expansion, and the risk of potential impacts. We then make recommendations arising from the evaluation of the potential risk.

The development of marine renewable energy in Britain and Europe

Information on the status of marine renewable-energy developments was gathered through consultation with developers, a survey of the web-based resources provided by various companies and governmental bodies, and a literature search.

Sites

Britain has an extensive coastline and is exposed to high winds, strong currents and powerful waves, making it well placed for energy generation from the sea. The expansion of marine wind farms and other marine energy generators, described below, are likely to be the most intensive engineering interventions in the UK's coastal waters in the next decades (Prior and McMath 2008).

The locations of wind farms in the UK and contiguous waters are presented in Fig. 1, and the energy-generation capacity and other details for each site are summarised in tables and figures provided as an Accessory Publication to this paper, available on

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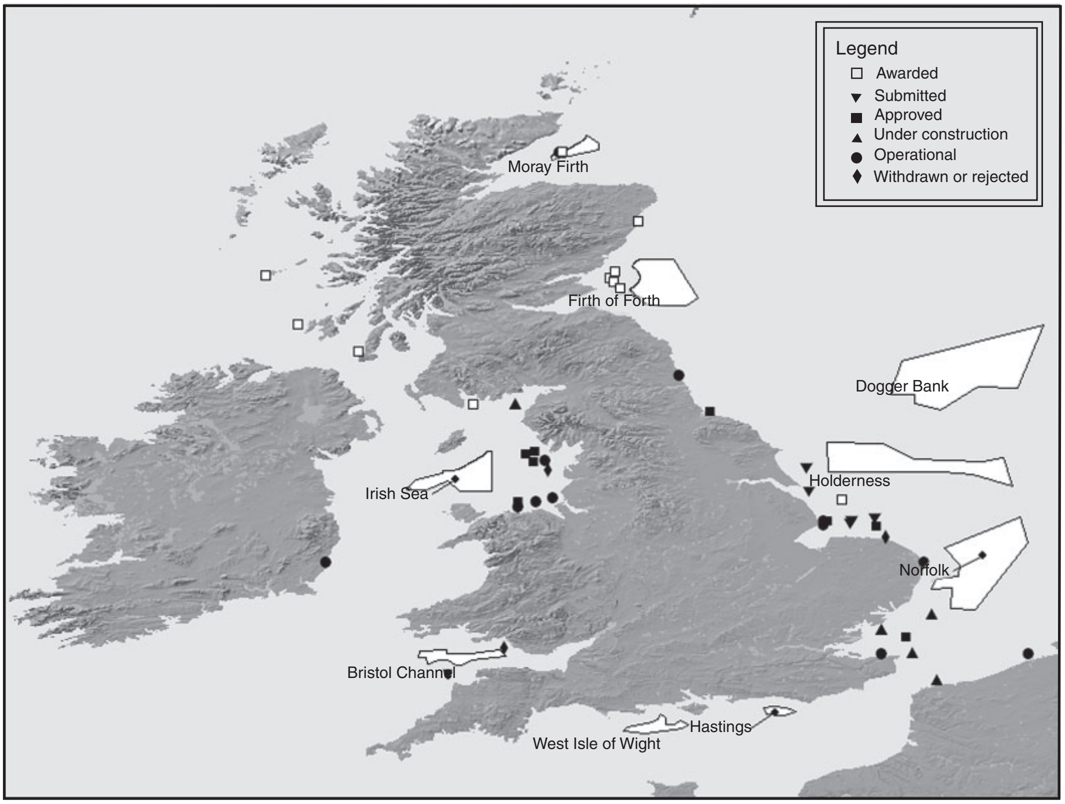

Fig. 1. Location of Round 3 zones in the UK and current wind farms.

the web. This supplementary information includes figures showing the locations of tidal power sites (and details about each) and, similarly, information about wave-power sites in the North-east Atlantic region.

The present assessment includes information available up until November 2009. Before 2000, there were just 16 sites (14 wind farms and two tidal-energy plants); by 2004, there were 34 sites (27 wind farms, five tidal-energy and two wave-energy plants); and at the time of writing, there are 89 sites (61 wind farms, 15 tidal-energy and 13 wave-energy plants) either operational, under construction, planned, submitted, awarded or approved.

Wind farms have been developed more swiftly than other marine renewables, with concentrations around the UK coastline, in the North Sea, and along the Baltic Sea coasts of Germany and Denmark. In this northern part of Europe, there are currently 28 wind farms in operation, 10 under construction, 16 that have been given approval, seven where plans have been submitted, two that have been withdrawn or rejected and 10 that have been awarded. Tidal-power sites are currently concentrated around the UK coast, in particular to the west, and in northern France. There are currently six operational, two approved and seven submitted tidal-power sites in northern Europe. Wave-power sites are still relatively uncommon in Europe and they are scattered between the UK, Spain and Denmark. There are currently six that are operational, four under construction, two approved and one submitted.

On 8 January 2010, the UK's Crown Estate announced the list of successful bidders for the latest (third) round of offshore wind-zone licensing, noting that this aims to deliver a quarter of the UK's total electricity needs by 2020 (Crown Estate 2010). The wind-farm zones are shown in Fig. 1 and are far larger and further out to sea than any sites previously licensed. For example, the Dogger Bank development zone is located off the eastern coast of Yorkshire between 125 and 195 km offshore and extends over ~8660 km^2 with its outer limit aligned to UK continental-shelf limit; and the Moray Firth wind-farm zone will cover 520 km^2 (Crown Estate 2010).

Marine renewable developments outside Europe

Marine renewable developments are also going on elsewhere in the world and although we do not have the scope here to consider this in detail, this includes Australia, Canada, the USA and New Zealand (Brown and Simmonds 2009; HSUS 2010). Australia currently has plans for wave power only. Canada and the USA have plans for both wind and wave power, with wind being favoured on the eastern coast and wave power on the western coast. Other countries are purchasing the technology, particularly for wind farms, from companies that are already running projects in Europe. In New Zealand, there are concerns about placing current driven turbines within the habitat of the endangered Hector's dolphin, *Cephalorhynchus hectori* (HSUS 2010).

Technology

Wind farms

The turbines used in offshore wind farms are horizontal-axis turbines (HAWT), typically having three rotor blades 20–40 m long, facing into the wind, mounted on a tubular tower some 60–90 m tall, bedded into the sea floor. Some trends in the present and future development of marine wind farms are evident. Turbine size has been increasing; e.g. Germany and the Netherlands are developing a turbine more than 100 m tall that will produce in the region of 5 MW (Hörter 2002). The size of wind farms, as noted above, is also greatly increasing.

Wave-power devices

Waves have two types of exploitable energy, kinetic, from their horizontal motion, and potential, from the vertical difference between the wave's crest and its valley. The converters are floating, moored or fixed, and they can be sited on shore, near to shore or offshore. There are up to 35 different wave-energy devices currently being considered in the European region (see e.g. BERR 2009; EMEC 2009).

Tidal

'Tidal stream power' (also called marine current energy) is produced from the horizontal movement of water in a current (kinetic energy). Useful energy can be extracted from marine currents by using completely submerged turbines and hydrofoil devices called tidal-energy converters. They are a relatively new technology and to maximise efficiency they need to be in fast currents, such as at the entrance of a bay, around headlands or between islands.

'Tidal range power' is produced from the vertical movement of water in the rise and fall of the tide. The Ocean Energy Council (2010) stated that for a site to be viable, the difference between high and low tides apparently needs to be at least 7 m and there are only ~40 such sites around the world. Tidal barrages may be superseded by recent, more efficient technologies, such as tidal fences and tidal lagoons. A tidal fence is a continuous fence of underwater turbines stretching across an estuary or strait, with some spaces to allow the passage of ships and migrating species such as salmon. A tidal lagoon is an area of coastline enclosed by a structure typically of aggregate, rubble or rock. Turbines are set into the walls of the lagoon under the water's surface, and are driven as the sea flows in and out with the rise and fall of the tide.

Impacts of marine renewable developments on cetaceans

Potential impacts

Information about the potential impacts of marine renewable was gleaned from the literature, focusing on key reports of field investigations and references that provide authoritative reviews. It has been proposed that the marine renewable industry might negatively affect cetaceans in a variety of ways (Gill 2005; Evans 2008; Prior and McMath 2008; Simmonds and Dolman 2008) outlined here in Table 1.

Other factors potentially moderating such impacts could include the following:

- the nature of the foundations of structures that will affect the transmission of noise from the operating turbines (Ødegaard and Danneskiold – Samsøe A/S 2000); typically, turbines are seated on either steel monopiles driven into the seabed with large pile drivers or on concrete gravitational foundations placed on pebble cushion layers (Carstensen *et al*. 2006);
- the topography of the local seabed and the nature of the seabed substrate; and
- the scale of developments and the fact that neighbouring developments may have combined impacts; for example, Madsen *et al*. (2006) commented that 'if the very large offshore wind farms are realised this could involve construction activities at several locations in the area [of the German Bight] simultaneously every summer for the next decade'; in a British context, it is not clear at the time of writing how long construction activities might go on for in any of the large wind-farm zones declared in round three, including the Moray Firth which is an area of some importance for cetaceans.

The likely implications of the impacts outlined in Table 1 can be further hypothesised (and there might be similar consequences for other large marine animals). Entanglement in cables, entrapment in structures or collision, e.g. with rotating turbine blades, could lead to death or wounding; extra-noise and disturbance in the marine environment could lead to masking of important biological sounds, disruption of normal behaviour,

Table 1. Potential impacts of the marine renewable-energy industry on cetaceans

1. Increased noise	2. Physical interactions	3. Habitat changes	4. Increased contamination	5. Effects on prey
Construction phase: pile driving, drilling, dredging, increased shipping/ aircraft movements. **Operation phase**: operating turbines and other renewable devices and other, maintenance vessels/aircraft. **Decommissioning phase**: explosives, cutting equipment, increased movements of vessels/aircraft.	**Entrapment/ entanglement** with e.g. mooring or other cables. **Collisions** with e.g. floating or submerged structures potential including rotating blades of current driven turbines.	**Predominantly transient**: increased turbidity, re-suspension of potentially polluted sediments during construction and cable laying. **More persistent**: physical and biological consequences of presence of structures in water column, e.g. artificial reef effect.	**Leaks or spills** of e.g. hydraulic fluid from operating devices or from increased shipping. **Use of biocides** to control marine fouling organisms on operating devices.	**Changes in food webs and prey** caused by increased noise, physical interactions, habitat changes and increased contamination alone or in combination.

stress, displacement from habitats, as has been demonstrated for e.g. boat traffic (see e.g. Lusseau 2005) and, at worst, loud noise could be physically damaging, including by causing physiologically damaging levels of stress (Weilgart 2007; Wright and Highfill 2007). Increased chemical pollution could affect the health of the cetaceans and/or their prey and if prey is adversely affected by this, or other habitat changes, either in terms of quality or quantity, the fitness of predators could in turn decline.

Possible benefits

The area occupied by an array of renewable-energy devices, potentially including a surrounding 'buffer zone', may become in some respects a 'protected area' where certain activities, such as fishing or shipping are excluded or limited either by law or simply because manoeuvring around the devices is not viable. It has been suggested (Inger *et al.* 2009) that marine renewable structures may enhance biodiversity, by, for example, providing hard surfaces ('artificial reefs') for fouling organisms to grow on. These in turn might provide food or shelter for fish. For cetaceans, this could mean that the threat of by-catch in fishing nets is removed, whereas prey increases. However, this is yet to be shown.

The available evidence

Evidence comes either from the relatively small number of studies that have been conducted on plants during construction and in operation (limited to wind farms only) or from other similar marine activities and modelling exercises. Between 1999 and 2006, monitoring was conducted at Horns Rev and Nysted wind farms in Denmark. This included gathering baseline data and then studying the construction and operation phases. The only cetacean commonly encountered on this coastline is the harbour porpoise, *Phocoena phocoena*, although seals were also present. The seals and porpoises were found to react differently (Teilmann *et al*. 2008; Wind Energy 2010). Seals were affected during the construction phase when they were sighted less frequently; they were not found to be affected during operation. However, at Horns Rev, the density of the porpoise population decreased during construction, and then recovered. At Nysted, porpoise densities decreased significantly during construction and, then, only after 2 years of operation, did the population recover.

From the literature it appears that the construction phase of wind farms, when pile driving is typically used, has the greatest potential to cause acute effects and pile-driving noise is potentially audible to cetaceans over hundreds of kilometres, with behavioural responses of cetaceans potentially extending across tens of kilometres (Weilgart 2007; Tougaard *et al*. 2009*b*; Bailey *et al.* 2010). Certainly, pile driving is indentified as among the most intense anthropogenic sound sources in the marine environment (Weilgart 2007). On the basis of recordings made of the piling of two deep-water turbines in the Moray Firth, Bailey *et al*. (2010) suggested that bottlenose dolphins, *Tursiops truncatus*, and northern minke whales, *Balaenoptera acutorostrata*, and other mid- and low-frequency hearing cetaceans, may exhibit behavioural disturbance up to 50 km away from the source. These authors also noted that physical harm could have occurred if cetaceans had been within 100 m of the pile driving. Bailey *et al*. (2010) also commented that offshore wind farms have never before been installed in water this deep (42 m), and the estimate of transmission loss (geometric spreading loss factor of 20) more closely approximated spherical spreading typical of deeper water. This illustrates how important it will be to consider how the physical circumstances of each development will affect the noise generated at each site. Bailey *et al*. (2010) concluded that 'as the marine renewables industry develops, our understanding of the noise produced and potential effects on marine species must be improved so that appropriate mitigation procedures can be developed'.

The noise produced by operational marine turbines has recently been considered by Koschinski *et al*. (2003) who showed that harbour porpoises and harbour seals, *Phoca vitulina*, would be likely to react to this. Tougaard *et al*. (2009*a*) considered operational noise from three types of wind turbines deployed at sites in Denmark and Sweden and how this might affect the same species. These authors found that wind-turbine noise was measurable only above ambient noise at frequencies below 500 Hz, and they estimated the maximum range of audibility was under two extreme assumptions of transmission loss (3 dB and 9 dB per doubling of distance, respectively). Audibility was low for harbour porpoises, extending 20–70 m from the foundation, whereas audibility for harbour seals ranged from <100 m to several kilometres. Tougaard *et al*. (2009*a*) concluded that it was unlikely that harbour porpoises would show behavioural reactions unless they were very close to the foundations, whereas behavioural reactions from seals might occur up to distances of a few hundred metres. They did not find the levels of operating noise dangerous, nor did they think it would mask (i.e. obscure biologically important sounds) the acoustic communications of either species. However, Lucke *et al*. (2007) showed that the operational sound from wind turbines may have a masking effect on porpoises. This effect would occur only at short ranges in the open sea and was based on the sound made by smaller inshore turbines rather than the bigger ones now being built and which may be significantly noisier.

Very little research has been conducted on the potential impacts of wave- and current-driven devices in the marine environment; noise levels from construction, again in particular pile driving, and maintenance may be a significant issue, especially in areas of high abundance of marine mammals. Some of these devices will be large (e.g. the turbines of one device have a diameter of ~15–20 m) and the developers' preferred sites for tidal stream devices will be restricted passages where current movement is fast, such as between islands and the mainland, or around headlands, which are also favoured by marine mammals.

Wilson *et al*. (2007) conducted a modelling exercise to investigate the collision risk for porpoises with underwater turbines. Their model predicts an encounter rate of 13 individuals per year per turbine. Scaling this for 100 turbines, they would expect 1300 porpoise–turbine blade encounters per year, potentially representing 10.7% of the porpoises in the area.

In fact, the potential for there being negative consequences for marine mammals from marine renewable installations is not disputed. For example, the website of 'Wind Energy – The Facts' (a project of the European Commission's Executive Agency for

Competitiveness and Innovation) comments that 'Offshore wind farms can negatively affect marine mammals, both during construction and operational stages. The physical presence of turbines, the noise during construction, the underwater noise as well as [associated] boat and helicopter traffic can disturb mammals causing them to avoid wind farms' (Wind Energy 2010).

Similarly, the UK's 2009 Strategic Environmental Assessment (SEA) of Offshore Energy (which considers oil and gas exploitation as well as renewables) reported as follows: 'In general, marine mammals show the highest sensitivity to acoustic disturbance by noise generated by offshore wind farms and by hydrocarbon exploration and production activities. The severity of potential effect has therefore been related principally to marine mammal species composition and abundance...' (DECC 2009). The SEA also notes that pile driving of turbine foundations has been widely recognised as a potential concern, in particular for large developments where many piles may be installed sequentially, or where more than one piling rig might be used simultaneously, thus affecting a larger area.

The SEA goes on to note that there is a 'reasonable body of evidence to quantify noise levels' associated with wind-turbine foundation pile driving, and to understand the likely propagation of such noise within the marine environment. However, the SEA adds 'there is less clarity about the potential effects on marine mammals (and other receptors including fish), particularly in relation to distinguishing a significant behavioural response from an insignificant, momentary alteration in behaviour'.

Several recent reviews have considered the threat posed to cetaceans by marine noise pollution from a variety of sources (e.g. Gordon *et al.* 2003; Simmonds *et al*. 2004; Marine Mammal Commission 2007; Weilgart 2007; Bradley and Stern 2008). Weilgart (2007) emphasised that ocean background noise levels have doubled every decade for the last several decades in some areas, probably as a result of increases in commercial shipping. Noise from all the activities associated with the marine renewables industry can be expected to add to this.

The Marine Mammal Commission (2007) in their report to the US Congress commented that potential effects of anthropogenic sounds on marine mammals included 'physical injury, physiological dysfunction (for example, temporary or permanent loss of hearing sensitivity), behavioural modification (for example, changes in foraging or habitat-use patterns, separation of mother-calf pairs), and masking (that is, inability to detect important sounds due to increased background noise). For individual animals, such effects and their secondary consequences may vary in significance from negligible to fatal – the worst outcome being documented in a small number of cases'. However, the Marine Mammal Commission concluded that 'the implications for conservation of marine mammal populations are undetermined'. Weilgart (2007) commented that 'Anthropogenic ocean noise is clearly a serious issue for cetaceans, though the full scale of the problem is difficult to determine'. She also emphasised the problem involved in determining population-level impacts. Geraci and Lounsbury (2009) in their review of marine-mammal health noted that reactions to disturbance can be subtle and that in terrestrial animals, intense noise alone can cause disorders ranging from long-term hearing loss to physiological stress, hypertension, hormonal imbalance and lowered resistance to disease. However, they added that such effects are nearly impossible to document in marine mammals. This does not, of course, mean that they do not occur.

The evaluation of what constitutes a significant threat for cetaceans is often based on the relationship of the scale of the losses (e.g. from whaling or by-catch), with a notional total population size. For example, the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) in its consideration of by-catch has identified anthropogenic removal >1.7% of the best available estimate of abundance as unacceptable (Parsons *et al.* 2010). ASCOBANS also sets a precautionary objective to reduce by-catch to <%. However, the recently concluded conservation plan for the North Sea harbour porpoise agreed by ASCOBANS (2009) goes significantly further than simply establishing a simple target in relation to a population estimate. It records that 'This Plan aims to restore and/or maintain North Sea harbour porpoises at a favourable conservation status, whereby population dynamics data suggest that harbour porpoises are maintaining themselves at a level enabling their long-term survival as a viable component of the marine ecosystem; the range of harbour porpoises is neither reduced, nor is it likely to be reduced in the foreseeable future; habitat of favourable quality is and will be available to maintain harbour porpoises on a long-term basis; and the distribution and abundance of harbour porpoises in the North Sea are returned to historic coverage and levels wherever biologically feasible'.

Despite the problems involved in identifying impacts and defining their significance, concerns have certainly become significant enough for ASCOBANS to call for more action. For example, a resolution passed by the ASCOBANS Parties in 2006 called for further research to be conducted on the effects of wind farms on small cetaceans (ASCOBANS 2006). In 2009, the Parties to the same agreement highlighted concerns raised by construction noise during offshore construction in a further resolution (ASCOBANS 2009). Among other things, this resolution called for a 'strategic approach' to siting marine renewable developments, including 'Strategic Environmental Assessments', and for the development of mitigation measures.

Conclusion

The word 'conflict' in the title of the present paper is used to indicate that the interests of the marine renewables industry and those of cetacean conservation are unlikely to be aligned. Reeves (2009) commented recently that the conservation challenges that lie ahead are 'truly endless' as the human appetite (and capacity) for consuming our planet's resources expands. He added that marine mammals will experience new threats even while long-standing ones persist. The swift development and deployment of marine renewable technologies is perhaps the epitome of a complex modern conflict between wildlife and human interests. To minimise one set of environmental impacts, we are planning to deploy new technology into wilderness areas, with little understanding of the possible consequences. For example, we have no present knowledge of how minke whales, which are relatively common in near-shore and deeper waters around the UK, may interact with, say, a line of large underwater turbines placed across what was previously a regular transiting area. However, this new technology is also at the forefront of government efforts to generate energy for the UK and many other nations while reducing carbon emissions, with climate change being also undeniably itself a significant threat to cetaceans (Simmonds and Eliot 2009).

This short review of the growth of the marine renewable industry in the UK and Europe illustrates a rapid expansion of new technologies into the marine environment. Whereas direct observations are few, there is a clear risk to cetacean populations, although the nature of specific impacts and their significance are still uncertain. This uncertainty is greatest for the deployment of devices other than wind turbines because the technology is still being developed and trialled. Impacts on different cetacean species are likely to vary because of the different ways in which different species will interact with renewable devices (and associated activities) and the varying environments in which these interactions will take place. Indeed, the 28 cetaceans species found in UK waters show a wide range of life strategies and habitats (Reid *et al*. 2003).

The marine renewables industry shares many of the characteristics of other human activities in the sea. Arguably, where the renewables industry differs from what has gone before is the introduction of novel structures, such as submerged current-driven turbines, the nature of the noise coming from renewable devices, and the distribution and extent of the developments, which increasingly include very large developments far offshore.

Increasing industrialisation of the seas may be dismissed or ignored because it is far removed from our lives and perceptions (i.e. 'out of sight and out of mind', as was the certainly the case in the past (Parsons *et al.* 2010)). The direct, and indirect, impacts on particular cetacean populations may be dismissed as being of little consequence when compared with the more generic benefits from this important green technology. However, the onus is really on the industry (and its backers) to minimise any adverse environmental impacts.

There is clearly a need for more research to help minimise the 'conflict' between the development of marine renewable energy and cetacean conservation. This should include monitoring renewable sites during all stages of their lifetime to help evaluate their impacts on cetaceans and other marine animals. The likely results of encounters between cetaceans and underwater turbines also need to be investigated as a priority. Establishing baseline data before building developments is also essential. (We would be in a much better position now to assess impacts if better baseline data had been available ahead of the wind farms now in operation.) Similarly, the modelling of interactions/collision risks should be comprehensive and incorporate data on the cetaceans likely to be living in and passing through development zones. Such modelling efforts – identifying where the likely zones of significant concentrations of animals might overlap with developments – should then be used to minimise adverse interactions, particularly the risk of collisions. Although such research is underway, as a priority precautionary action, the industry should develop and implement measures to reduce noise during construction and noise from maintenance craft (limiting the speed of maintenance vessels should also be considered as collisions are more likely at high speeds).

It can be expected that as the industry develops, if monitoring is adequately conducted, impacts and their significance will become clearer. Hence, there is also a need for rapid and transparent sharing of information and government guidelines on adaptive management of the marine renewables industry. For example, if some renewable energy-generating mechanisms or some methods of installation prove to be especially benign, they might be promoted and, conversely, cetacean-unfriendly mechanisms or methods could be replaced. Nations will also need to coordinate their activities in this field, especially those with shared marine boundaries, as mitigation efforts will have to consider pile-driving effects, and other potential impacts, across such boundaries.

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References

ASCOBANS (2006). Report of the 5th meeting of parties. Resolution 4. Available at http://www.ascobans.org/index0501.html [accessed September 2010].

ASCOBANS (2009). Report of the 6th meeting of parties: resolution on adverse effects of underwater noise on marine mammals during offshore construction activities for renewable energy production. Available at http://www.ascobans.org/index0401.html [accessed September 2010].

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., and Thompson, P. M. (2010). Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. *Marine Pollution Bulletin* **60**, 888–897. doi:10.1016/j.marpolbul.2010.01.003

BERR (2009). UK Department for Business Innovation and Skills website. Available at www.berr.gov.uk/energy/sources/renewables/explained/wave-tidal/wave/page17058.html [accessed February 2010].

Bradley, D. L., and Stern, R. S. (2008). Underwater sound and the marine mammal acoustic environment. Prepared for the US Marine Mammal Commission, July 2008. Available at http://mmc.gov/reports/workshop/ [accessed September 2010].

Brown, V. C., and Simmonds, M. P. (2009). A further update on the distributions of marine renewable energy plants in Europe. Paper submitted to the Scientific Committee of the International Whaling Commission IWC/SC/61/E7.

Carstensen, J., Henriksen, O. D., and Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoise. *Marine Ecology Progress Series* **321**, 295–308. doi:10.3354/meps321295

Crown Estate (2010). The Crown Estate webpages. Available at http://www.thecrownestate.co.uk/home.htm [accessed February 2010].

DECC (2009). Offshore energy strategic environmental assessment. Department of Energy and Climate Change. Available at http://www.offshore-sea.org.uk/site/scripts/news_article.php?newsID=39 [accessed February 2010].

EMEC (2009). European Marine Energy Center website. Available at http://www.emec.org.uk/wave_site.asp [accessed February 2010].

Evans, P. G. H. (Ed.) (2008). Proceedings of the ASCOBANS/ECS workshop: offshore wind farms and marine mammals: impacts & methodologies for assessing impacts. San Sebastian, Spain, 21 April 2007. European Cetacean Society Special Publication Series No. 49, February 2008.

Evans, P. G. H. (2009). Habitat pressures. In 'Encyclopedia of Marine Mammals'. 2nd edn. (Eds W. F. Perrin, B. Wursig and J. G. M. Thewissen.) pp. 521–524. (Academic Press: New York and London.)

Geraci, J. R., and Lounsbury, V. J. (2009). Health. In 'Encyclopedia of Marine Mammals'. 2nd edn. (Eds W. F. Perrin, B. Wursig and J. G. M. Thewissen.) pp. 546–553. (Academic Press: New York.)

Gill, A. B. (2005). Offshore renewable energy: ecological implications of generating electricity in the coastal zone. *Journal of Applied Ecology* **42**, 605–615. doi:10.1111/j.1365-2664.2005.01060.x

Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M. P., Swift, R., and Thompson, D. (2003). A review of the effects of seismic surveys on marine mammals. *Marine Technology Society Journal* **37**, 16–34. doi:10.4031/002533203787536998

Hörter, A. (2002). German offshore wind projects planning and status quo. Report from the conference 'Offshore Wind Energy', Cuxhaven, Germany, 7–8 March 2002. Available at http://www.teknologisk.dk/_root/media/windandsee2002germany.pdf [accessed September 2010].

HSUS (2010). Hector's dolphin still declining. The Humane Society of the Unites States website. Available at http://www.hsus.org/hsi/oceans/dolphins/hectors_dolphin_2110.html [accessed September 2010].

Inger, R., Attrill, M. J., Bearhop, S., Broderick, A. C., Grecian, W. J., Hodgson, D. J., Mills, C., Sheehan, E., Votier, S. C., Witt, M. J., and Godley, B. J. (2009). Marine renewable energy: potential benefits to biodiversity? An urgent call for research. *Journal of Applied Ecology* **46**, 1145–1153.

Koschinski, S., Culik, B. M., Nriksen, O. D., Tregenza, N., Ellis, G., Jansen, C., and Kathe, G. (2003). Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2 MW windpower generator. *Marine Ecology Progress Series* **265**, 263–273. doi:10.3354/meps265263

Lucke, K., Lepper, P. A., Hoeve, B., Everaarts, E., van Elk, N., and Siebert, U. (2007). Perception of low frequency acoustic signals by a harbour porpoise (*Phocoena phocoena*) in the presence of simulated offshore wind turbine noise. *Aquatic Mammals* **33**, 55–68. doi:10.1578/AM.33.1.2007.55

Lusseau, D. (2005). Residency patterns of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecology Progress Series* **295**, 265–272. doi:10.3354/meps295265

Madsen, P. T., Wahlberg, M., Tougaard, J., Lucke, K., and Tyack, P. (2006). Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. *Marine Ecology Progress Series* **309**, 279–295. doi:10.3354/meps309279

Marine Mammal Commission (2007). Marine mammals and noise. A sound approach to research and management. A report to Congress from the Marine Mammal Commission. March 2007. US Marine Mammal Commission. Available at http://mmc.gov/sound/fullsoundreport.pdf [accessed September 2010].

Ocean Energy Council (2010). Where are good areas for exploiting tidal energy? Ocean Energy Council website. Available at http://www.oceanenergycouncil.com/index.php/Tidal-Energy/Tidal-Energy.html [accessed September 2010].

Ødegaard & Danneskiold – Samsøe A/S (2000). Underwater noise measurements, analysis and predictions. Rødsand Offshore Wind farm EIA technical background report: underwater noise, December 2000. Report no. 00.792 rev. 1.

Parsons, E. C. M., Clark, J., Warham, J., and Simmonds, M. P. (2010). The conservation of British cetaceans: a review of the threats and protection afforded to whales, dolphins and porpoises in UK Waters, Part 1. *International Journal of Wildlife Law and Policy* **13**, 1–62. doi:10.1080/13880291003705145

Prior, A., and McMath, M. J. (2008). Marine mammals and noise from offshore renewable energy projects – UK developments. In 'Proceedings of the ASCOBANS/ECS workshop: offshore wind farms and marine mammals: impacts & methodologies for assessing impacts', San Sebastian, Spain, 21 April 2007. (Ed. P. G. H. Evans.) European Cetacean Society Special Publication Series No. 49, February 2008.

Reeves, R. R. (2009). Conservation efforts. In 'Encyclopedia of Marine Mammals'. 2nd edn. (Eds W. F. Perrin, B. Wursig and J. G. M. Thewissen.) pp. 275–289. (Academic Press: New York.)

Reid, J. B., Evans, P. G. H., and Northridge, S. P. (2003). Atlas of cetacean distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough, UK.

Simmonds, M. P., and Dolman, S. J. (2008). All at sea: renewable energy production in the context of marine nature conservation. In 'Proceedings of the ASCOBANS/ECS workshop: offshore wind farms and marine mammals: impacts & methodologies for assessing impacts', San Sebastian, Spain, 21 April 2007. (Ed. P. G. H. Evans.) European Cetacean Society Special Publication Series No. 49, February 2008.

Simmonds, M. P., and Eliott, W. J. (2009). Climate change and cetaceans: concerns and recent developments. *Journal of the Marine Biological Association of the United Kingdom* **89**, 203–210. doi:10.1017/S0025315408003196

Simmonds, M. P., Dolman, S. J., and Weilgart, L. (Eds) (2004). Oceans of noise 2004. A WDCS science report. Whale and Dolphin Conservation Society, Chippenham, UK.

Teilmann, J., Tougaard, J., and Carstensen, J. (2008). Effects from offshore wind farms on harbour porpoises in Denmark. In 'Proceedings of the ASCOBANS/ECS workshop: offshore wind farms and marine mammals: impacts and methodologies for assessing impacts. 21 April 2007', San Sebastian, Spain. (Ed. P. G. H. Evans.) ECS (European Cetacean Society) Special Publication Series No. 49, 28 February 2008.

Tougaard, J., Henriksen, O. D., and Miller, L. A. (2009*a*). Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. *Journal of the Acoustical Society of America* **125**, 3766–3773. doi:10.1121/1.3117444

Tougaard, J., Carstensen, J., Teilmann, J., Skiv, H., and Rasmussen, P. (2009*b*). Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). *Journal of the Acoustical Society of America* **126**, 11–14. doi:10.1121/1.3132523

Weilgart, L. S. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* **85**, 1091–1116. doi:10.1139/Z07-101

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.

Wind Energy (2010). Wind energy – the facts. Available at http://www.wind-energy-the-facts.org/en/ [accessed September 2010].

Wright, A. J., and Highfill, L. (2007). Noise related stress and marine mammals: an introduction. *International Journal of Comparative Psychology* **20**, iii–viii.

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