Marine Renewable Energy Developments: an update on current status in Europe and possible conservation implications for cetaceans.

Vicki C. Brown, and Mark Peter Simmonds[1]

Whale and Dolphin Conservation Society, Brookfield House, 38 St Paul Street, Chippenham, Wiltshire SN15 1LJ, UK.

Abstract

There has been a rapid expansion of marine renewable energy devices (MREDs) in European seas as governments strive to meet renewable energy commitments. Today there are some 89 such sites in various stages of development (most of these are wind farms), representing a five-fold increase in numbers since 2000, and a concomitant major increase in the size of planned developments. This paper charts the rapid expansion of MREDs in Europe, including the very large new wind parks planned in UK waters.

These devices may impacts on cetaceans in ways ranging from collisions to the effects of noise and disturbance, with pile driving being a particular concern. These risks deserve further attention from MRED designers, developers and the consenting authorities.

Keywords: Marine renewable energy, cetaceans, noise

1. Introduction

Marine renewable energy is typically regarded as an abundant, inexhaustible and non-polluting resource. Spurred on by the growing global energy crisis, concerns about energy security, and to meet requirements to reduce greenhouse gases (DECC, 2009), governments around the world are investing in new renewable energy technologies. Much of the development is going on out at sea and Marine Renewable Energy Devices (MREDs) have the potential to contribute significantly towards the targets set by governments to produce energy from renewable sources (Simmonds and Dolman, 2008). However, as recently described by Prior and McMath (2007), MRED developments are "likely to be the most intensive engineering interventions in the UK's coastal waters in the next decade" and as such attention needs to be given to their environmental impacts on cetaceans (whales dolphins and porpoises) and other marine wildlife. Many European nations are regarded as particularly well placed to generate energy at sea, especially the more westerly nations such as Portugal and the UK (England, Wales and Northern Ireland), with their extensive coastlines and exposure to high winds, strong currents and powerful waves.

There have been some investigations into the impacts of marine wind farms on harbour porpoises (reviewed in Simmonds and Dolman, 2008) but as wave and tidal devices are still relatively new, little is known about their potential impacts on these and other marine species (ruralgateway.org.uk, 2009; Wright *et al*., 2009). The first commercial tidal stream converter, the 'SeaGen', became operational in Strangford Lough, in Northern Ireland in 2007 (seageneration.co.uk, 2008).

[1] Corresponding author: mark.simmonds@wdcs.org

Concerns about potential impacts on cetaceans from wind farms resulted in a resolution passed by the Parties to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) at their 5th Meeting in 2006. This called for further research to be conducted on the effects of wind farms on small cetaceans (ASCOBANS, 2006). In 2009, the same body highlighted concerns raised by construction noise during offshore construction at its Meeting of the Parties and passed a resolution calling for this to be addressed (ASCOBANS, 2009). Amongst other things, this resolution called for a 'strategic approach to siting marine renewable developments, including 'Strategic Environmental Assessments', and for the development of mitigatory measures. The IWC Scientific Committee also called for more research into this matter at its 2009 meeting (IWC, 2009).

Provided here is an overview of the present state of the wave, tidal and wind energy industries in Europe (from the westernmost peninsula of Eurasia, the border with Asia runs from the Urals to the Caspian and the Black Sea) and consideration of how they may affect cetaceans. The majority of the data available relates to offshore wind farms as they have been in operation since 1991 and the technology is well established; in contrast wave and tidal devices have only been in operation in recent years (with the exception of La Rance which became operational in 1966). Hence the technology is still in a state of flux and new devices are constantly being designed and tested. This means there is little relevant data on wave and tidal energy, although there are some similarities to wind farms (such as the possible use of pile driving).

2. Methods

Information on the location and scale of MREDs was gathered through consultation with developers, a survey of the web-based resources provided by various companies and governmental bodies, and a literature search. The locations of renewable developments were plotted on maps and are shown in figures 1, 2 and 3. The specifications of the same developments, including their energy generation capacities, are presented in tables 1-3.

Information about the potential impacts of MREDs was gleaned from the literature as far as possible, noting that the literature remains scant (especially for developments other than marine wind farms). Many novel mechanisms are still being tested at sea and, for the most part, these have unknown environmental impacts.

3. Results

2.1 The expansion of MREDS

Several stages of development could be identified: operational, under construction, approved, submitted, rejected or withdrawn and awarded:

- Operational' sites are those that have been completed and are providing electricity. The information in the tables includes the year that operation started the developer and details of location (where the information is available).

- 'Under construction' sites are those that have been approved and construction is currently underway. The information includes the year that confirmation was given, the developer and details of the location (where the information is available).

- 'Approved' sites are those for which the submitted plans have been consented to, but construction has not been started. The information includes the year that approval was given, the developer and details of the location (where the information is available).

- ‘Submitted’ sites are those where plans have been completed and reports submitted for consideration. At this stage sites can either be approved or rejected. The information includes the year that plans were submitted, the developer and details of the location (where information is available).

- ‘Rejected or withdrawn’ sites are those that submitted a plan, but it was either rejected based upon the submitted plans, or withdrawn by the developer. The information includes the year the plans were rejected or withdrawn, the developer, details of the location and the reason for the rejection or withdrawal (where this information is available).

- ‘Awarded’ sites are those where developers have been granted exclusivity by the UK’s Crown Estate to develop an offshore wind farm. At this stage only consent has been given to the developer and no plans have been drawn up or submitted. Once a site has been awarded the developer develops a proposal to submit for the site.

When all developments, up to November 2009 are considered together, their rapid expansion in Europe can be clearly seen, with a more than five-fold increase since 2000. Before 2000 there were just 16 sites (14 wind farms and 2 tidal energy plants); by 2004 there were 34 sites (27 wind farms, 5 tidal energy and 2 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, or submitted.

The locations of wind farms are presented in figure 1, and the energy generation capacity and other details for each site are summarised in table 1. The locations of tidal power sites are shown in figure 2, and the details for each site are in table 2. The locations of wave power sites are in figure 3, and the details for each site are in table 3. In all of the tables ‘energy generated’ or ‘proposed energy generation’ refers to the energy produced annually; ‘energy capacity’ refers to the maximum energy that can be generated during peak conditions (where this information has been published).

2.1.2 Wind

Of all the types of MREDs, wind farms have been developed the most swiftly, with concentrations around the UK coastline, in the North Sea, and along the Baltic Sea coasts of Germany and Denmark. There are currently 28 wind farms in operation, 10 under construction, 16 that have been given approval, 7 where plans have been submitted, 2 that have been withdrawn or rejected and 10 that have been awarded (figure 1 and table 1). The growth of wind farms in Europe can be seen in Figure 4; between 2000 and 2004 the number of wind farms increased by 92.86%. They then expanded even more rapidly between 2005 and 2009, when they increased by some 125.93%.

This is set to expand exponentially after the Crown Estate (the body that manages the seabed) in the UK announced proposals for the third round of offshore wind farm leasing. There are 9 round 3 zones which will significantly increase the area of UK Waters being developed as wind farms. Their total area is 26,947.4 km²; this is equivalent to the area of the British counties of Cornwall, Devon, Dorset, East Sussex, Gloucestershire, Somerset, Wiltshire, Bristol, Isles of Scilly and Berkshire combined (or 5,389,400 football pitches). However, we understand (JNCC pers comm.) that not all of the areas within the designated zones may be fully developed. The locations of these zones can be seen in figure 5.

The largest site is Dogger Bank with an approximate size of 8,660 km² (equivalent in size to North Yorkshire), and will be the worlds largest offshore wind project. It is followed in size by the Norfolk site which, at 6,036.8 km², is actually 10% larger than the county of Norfolk itself. Even the smallest of these new zones, Hastings at 270.2 km², is still the size of 54,000 football pitches. The depth of these zones range from 5m to 70m and given this depth range, their size and extent they, therefore, have the potential to impact a wide range of marine species.

The zones that are of immediate concern to the authors are those in the Moray Firth and the Irish Sea because of their proximity to areas of importance to cetaceans.

2.1.3 Tidal

There are fewer tidal power sites than wind farms (presumably because the necessary technology has been more difficult to develop). They are currently concentrated around the UK coast, particularly on the west coast, and in northern France. There are currently 6 operational, 2 approved and 7 submitted tidal power sites in Europe (figure 2 and table 2).

Between 2000 and 2004, the number of tidal power sites increased by 250%; and between 2005 and 2009 they increased by some 300%.

2.1.4 Wave

Wave power sites are relatively uncommon in Europe and they are scattered in distribution between the UK, Spain and Denmark. There are currently 6 that are operational, 4 under construction, 2 approved and 1 submitted. Figure 3 shows the location of these sites, and table 3 shows the details of each of the sites. Between 2000 and 2004, the number of wave power sites increased by 200% (figure 4). Between 2005 and 2009 they increased by a further 300%.

Wave power is also being developed outside of Europe (Brown and Simmonds, 2009). Australia has plans for wave power exclusively (as far as we are aware), Canada and USA have plans for both wind and wave power, with wind being favoured on the east coast and wave power on the west coast. The refinement of such technologies outside of Europe may in due course further affect what is developed in Europe.

2.2. The Status of Developing Technologies

2.2.1 Wind farms

Wind farm technology appears well established. The turbines used in offshore wind farms are horizontal axis turbines (HAWT), typically having three rotor blades 20-40m long, facing into the wind, mounted on a tubular tower, bedded into the sea floor and some 60-90m tall. Some trends in the present and future development of marine wind farms are evident. Turbine size has been increasing; for example, Germany and the Netherlands are developing a turbine more than 100 m long which will produce in the region of 5 MW (Hörter, 2002). Furthermore, until quite recently, marine wind farms have mainly been in near-shore waters, within approximately 5km of the coast. Now, however, as noted above, very large developments are planned in, at least, the UK.

2.2.2 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 devices 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 region.

Wave energy devices are generally categorised by the nature of the method used to harness energy. However there are variations in their categorisation. For example, according to the UK Department of Trade & Industry, there are 3 types of device; the 'buoyant moored device', 'hinged contour device', and 'oscillating water column' (BERR 2009). Whereas according to The European Marine Energy Centre (EMEC, 2009), there are at least 6 types of converter; the 'attenuator', 'point absorber', 'oscillating wave surge converter', 'oscillating water column', 'overtopping device', and 'submerged pressure differential'.

Below is a summary of how each type of wave converter works:

- Attenuator – A segmented floating device that follows the motion of the waves and collects energy by the movement of the joints driving hydraulic motors. Offshore, floating on deep water. Moored with cables and chains. Each device is some120m long and 3.5m in diameter.

- Oscillating Water Column – An onshore device with a hollow structure moored to the seabed or installed on shore, which allows the rising wave in, forcing compressed air above to drive a turbine, something like a large piston.

- Overtopping Device - An offshore device. This holds 'captured' water in a reservoir above sea level before being released through low-head turbines.

- Oscillating Wave Surge Converter – A nearshore device which has an oscillating pendulum, mounted on a pivoted joint, attached to the seabed.

- Buoyant Moored Device/Point Absorber: offshore. Part of which floats on the surface, rising and falling with the wave, and another part is moored to the seabed. Electricity is generated by turbines driven by a variety of mechanisms, such as hydraulic pumps.

- Submerged Pressure Differential: Nearshore. Mounted on the seabed, the rise and fall of the sea level above causes pressure changes in the converter which drives fluid through a generating system.

The main disadvantage to wave power is the variability and poor predictability of waves, making them a less reliable source of energy than tidal power. There may also be significant construction and maintenance problems, with devices having to withstand very severe conditions in the water. Harnessing the energy of waves evidently presents a considerable engineering challenge, hence the development of a wide range of possible devices to attempt to do so.

2.2.3 Tidal

Tidal power can be subdivided into two categories:

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 using completely submerged turbines and hydrofoil devices called Tidal Energy Converters. They are a relatively new technology, converting energy from sea currents. Water is 832 times denser than air, which means that a single generator can provide a significant amount of energy. The location of tidal stream systems is important and to maximise efficiency they need to be in fast currents where sea flows are compressed, 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. Tidal barrages make use of the potential energy in the difference in height between high and low tides. For a site to be viable, the difference between high and low tides apparently needs to be at least 5m and there are only about 40 such sites around the world. Tidal barrages are also seemingly becoming outdated and 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 adaptation of the barrage, exploiting the height between high and low tides to generate energy. It 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. From a distance the lagoon resembles a breakwater or low rocky island. As there are two tides each day one advantage of both tidal stream and tidal range energy is that their energy production capacities are predictable, frequent and regular.

Several trial projects are planned in Europe, mostly around the British Isles, including, for example, one in the narrow Pentland Firth in Scotland. There are 3 types of tidal power converter which can be floating, or mounted on the seabed, on a pile, in a barrage (like a dam), and located in a tidal fence or a tidal lagoon.

Below is a summary of how each type of tidal converter works.

- Horizontal or Vertical Axis Turbine - these devices vary greatly, but the principle of how they generate power is the same; the kinetic energy of flowing water turns the turbine or rotor which drives a generator. They are typically sited in Estuaries, headlands, between islands, or where there are powerful, fast currents.

- Duct Turbine (Venturi Effect) housing a turbine in a duct, (or shroud), concentrates the flow of water and creates pressure, maximising the generating potential of the turbine. Estuaries with powerful currents. The pontoon is moored in the estuary stream and the turbine generates power in both the ebb and flow currents.

- Oscillating Hydrofoil – a hydrofoil attaching to an arm oscillates in the current, resulting in lift, the motion of which drives fluid through a generating system. They are typically sited in fast currents on the seabed.

3. Discussion

The devices used in each of the different types of renewables have many features in common; in particular as they all need to be anchored to the sea bed. The most likely attachment techniques will be monopiles, jackets, gravity structures, conventional anchors, chains and mooring ropes (Wilson *et al*., 2007)

3.1 Potential Impacts on Cetaceans

Information on the effects on marine mammals of constructing and operating offshore wind farms is still limited, with even less information available concerning the impacts of wave and tidal energy devices. With wind farm construction moving into deeper waters, in particular around the UK, and with planned increases in the size of turbines, there are potential impacts on a greater number of species. In addition, the situation is made more complicated as cetacean distributions and habitat use are rarely well characterised around the UK coastline, or elsewhere in Europe (Simmonds and Dolman, 2008). No studies to date look directly at impacts on any cetacean species, other than the harbour porpoise. Furthermore, the available reports tend to vary in their interpretation of the significance of the potential environmental impacts of marine wind farms, probably related to how precautionary the authors are being in their considerations.

Jefferson *et al*. (2009) provide a useful and recent review of the likely effects of marine industrial activities on cetaceans and attempts to mitigate them focused on the highly industrialised waters of Hong Kong. They note that most of the developments there have been very noisy and that this “has the potential to cause disturbance of the cetaceans’ normal activities. While such noise can occasionally be intense and loud enough to injure or kill dolphins or porpoises (potentially such as underwater explosions or perhaps percussive piling operations), the impacts are usually sub lethal”. This seems to be likely to be the case for MRED developments too. However, even though they are typically sub-lethal this does not mean they will be insignificant.

3.1.1 Noise

Noise is produced throughout the life of the development, including during construction, operational and decommissioning phases, and from associated vessel traffic. There is continual operational noise and vibrations emanating from the wind turbines.

Pile-driving is a particularly intense noise source and may disrupt the behaviour of marine mammals at distances of many kilometres, with hearing potentially impaired at closer range (Madsen *et al*., 2006). The U.S Department of Energy (2009) has recently stated that "it is known from experience with other marine construction activities that the noise created by pile driving creates sound pressure levels high enough to impact the hearing of harbour porpoises" and that this could lead to changes in their behaviour and increase stress levels leading to decreased foraging efficiency, displacement, decreased reproduction and increased mortality.

Carstensen *et al*. (2007) reported on the reaction of porpoises to the construction of the Nysted offshore wind farm in the western Baltic by monitoring their echolocation clicks. On the basis that clicks relate to density, they found substantial changes in habitat use, with the porpoises leaving the construction area. They also noted that only future monitoring will determine if the porpoise population will recover, and that their methods could be modified to look at other cetacean species. Operational farms produce broadband low frequency noise at the lower end of the threshold frequency spectra of selected representative odontocetes (these are toothed animals, rather than baleen as do animals in the other suborder of cetaceans, Mysticeti. Odontocetes include sperm whales, beaked whales, dolphins, and others. Toothed whales are active hunters, feeding on fish, squid, and, in some cases, marine mammals (Richardson *et al*., 1995). However, the zones of audibility and potential exclusion around operational marine wind farms have not been clearly defined. Notwithstanding, a small masking effect has been reported for a porpoise in an experimental study (Lucke *et al*., 2007), although this was based on the noise produced by a small turbine, the authors describe the likely masking zone as extending several tens of metres.

The nature of the foundations of wind farms will also affect the transmission of noise from the operating turbines (Ødegaard & Danneskiold – Samsøe, 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). Madsen *et al*. (2006) comment 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."

The most significant concerns relating to wind farms are currently related to noise production. Marine noise pollution has the potential to displace individuals and populations, interfere with normal behaviour and, at very high intensities, may be physically damaging (Simmonds and Dolman, 2008). The MRED construction phase, when pile-driving is typically used, apparently has the greatest potential to cause acute effects. Increased noise, potentially including operational noise from the turbines and increased boat traffic associated with the maintenance of the turbines, may cause behavioural impacts. Given the intense sound production during construction, it is not surprising that porpoise detections at Nysted and Horns Rev marine wind farms in Denmark decreased over considerable ranges during pile driving for wind farm construction (Teilmann *et al*., 2007). Noise from decommissioning of wind farms by activities such as drilling, cutting and the potential use of explosives also causes concern for the future (Prior and McMath, 2007). Thomsen *et al*. (2006) found that the noise generated by the construction of wind farms was loud enough to be audible by harbour porpoises beyond 80km from the source, could mask communication at 30-40km, and that there are behavioural reactions at 10-20km. They concluded that the construction of offshore wind farms has "the potential to affect porpoise behaviour and physiology at considerable distances and the mitigation should focus on damping of the higher frequency part of the ramming noise".

As wave and tidal power devices are relatively new, very little research has been done into their impact on the marine environment; noise levels from construction, again in particular pile-driving, and maintenance may be a significant issue, especially in areas of high marine mammal abundance.

3.1.2 Entrapment, entanglement or collision

MRED devices themselves and certain features in particular (such as submerged rotating blades) may present risks of entrapment, entanglement and harmful, perhaps even lethal collisions. The greatest hazards for some animals may be cables. Types and amounts of cable vary according to the device type, but include mooring cables, guy-lines and power cables. They may be slack, taut, vibrating, horizontal, diagonal, vertical, crossed, current-carrying and so forth, and with the potential to be hazards for cetaceans and other wildlife. Floating devices could present a collision hazard along with their supporting structures.

Carter *et al*. (2008) have modelled the likely encounter rate of marine mammals with marine energy devices. They concluded that there was a possible risk to marine mammals noting that these devices will be big (for example, the turbines of one device have a diameter of approximately 15 to 20 m) and that the developers' preferred sites for tidal stream devices will be restricted passages, for example, between islands and the mainland, or around headlands which are also favoured by marine mammals.

The risk of collisions between boats and cetaceans is significantly increased due to the increased vessel activities during exploration, construction, maintenance and decommissioning of various MRED's.

3.1.3 Contamination of the local environment

Contamination of the local environment could occur via leaks or spills of hydraulic fluid, the use of biocides to control growth of fouling organisms on submerged structures and also the dumping of wastes from structures. High levels of vessel traffic and construction work have the potential to increase the turbidity and re-suspension of polluted sediment.

3.1.4 Electrical and electromagnetic disturbance

The extensive underwater electrical cables associated with MREDs may affect wildlife. This has been highlighted as a threat to elasmobranches but other wildlife, including cetaceans, might also be affected (Gill & Taylor, 2001). The electromagnetic fields could alter feeding behaviour, migration, reproduction, or susceptibility to predation of animals near the cables and there is also risk of injuries and mortalities depending on the strength of fields (U.S Department of Energy, 2009).

3.1.5 Siting of devices:

Devices might be placed in sensitive areas, such as those used for breeding, feeding or migration. Tidal barrages, for example, have a significant negative impact on estuarine ecology such as wading birds and migrating fish. Seabirds are reported to avoid Horns Rev wind farm, and may generally avoid entering offshore wind farms where foraging habitat may be reduced and the birds may have to expend valuable energy flying around the turbines. The construction of offshore wind farms also has the potential to have a similar effect on nearby populations of cetaceans (Snyder and Kaiser, 2009)

3.1.6 Habitat degradation:

This might include damage to the sea bed, changes in vertical mixing and increased turbidity (particularly during installation and construction). Local benthic flora and fauna may be disturbed, though the effects may be short-term. Disturbance of pelagic or demersal organisms, including fish, may have negative implications for their predators.

Cable-laying from wind farms to take the electricity generated to suitable nodes to connect with national grids may require considerable marine engineering work, with associated noise pollution and physical habitat disturbance due to upheaval of the seabed.

In areas where devices are placed the currents and velocities there is the potential for alterations of currents, waves, circulation patterns and water quality, potentially having knowck-on effects for cetacean behaviour (U.S Department of Energy, 2009)

3.1.7 Displacement:

It is possible that a combination of disturbing/habitat-degrading activities, potentially including increased vessel movements for maintenance purposes, could cause displacement of cetaceans from the area where devices are deployed. (Boat disturbance has been shown to affect behaviour and displace dolphins (see for example, Lusseau, 2005)). The presence of structures (including artificial reef effects causing habitat alterations) and, potentially, changes to prey and food webs has the potential to displace cetaceans (Wahlberg and Westerberg, 2005).

Harbour porpoises were shown to occur less frequently in the area around both Nysted and Horns Rev during the construction of the wind farms; a change mainly thought to be due to the noise created during construction. At Horns Rev it seems the porpoises started to return, yet two years later, at Nysted, the porpoises are still not as numerous as they were during the baseline study (Snyder and Kaiser, 2009)

The severity of these impacts will differ at each site based on a number of variables, the type of device, location (devices can be sited at the shoreline, near-shore, offshore, deep water channels, in rivers, estuaries, on the sea bed, surface etc.), scale (single devices will have a different impact to that of an array) and so forth.

Other factors potentially affecting impacts could include:

- The type of seabed support used. For example, wind turbines with concrete foundations emit higher noise levels below 50Hz and lower levels between 50Hz and 500Hz, than those with monopole foundations; and
- The topography of the seabed and the nature of the seabed substrate.

Many potential impacts would be site-specific. Baseline data is required to understand the abundance and distribution of species and local habitat use, so that wave and tidal devices or wind farms are not located in sensitive areas such as breeding and feeding grounds, or on migratory routes. For example, many shallow waters in northern Europe are important calving and nursing areas for harbour porpoises. Planning should consider the entire life of the farm from exploration, construction, operation to maintenance and decommissioning, during all seasons of the year.

The acute and chronic effects of noise pollution and disturbance on cetaceans are considered further in Simmonds *et al*. (2004), Jasny (2005) and Weilgart (2007). As noted above, Jefferson *et al*. (2009) provide valuable insights into the implications for cetaceans of a range of industrial developments at sea, and how such matters might be addressed. Issues relating to marine wind farms are discussed more fully in Evans (2008) and the authors note that there are concerns that relate to the potential impacts of marine wind farms on seabirds, mainly relating to collisions with moving turbine blades. Varying configurations of energy farms/arrays have varying impacts, depending on their size, spacing, cumulative effect, the topography of the sea bed, etc. Larger arrays of devices, in particular, have the potential to cause fragmentation of habitats (Inger *et al*., 2009).

3.2 Possible positive impacts of MREDS

There are possible positive impacts for wildlife that may result from deployment of MREDs, although direct evidence for this seems negligible at this time. For example, the area around an array of devices may become in some respects a ‘protected zone’ where certain activities, such as fishing or shipping are excluded or limited. It has been suggested (Inger *et al*. 2009) that MRED 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.

Renewable developments might also exclude large fishing operations from certain waters because the boats will not be able to operate amongst the structures. Such potential benefits need to be carefully evaluated before they can be accepted.

4 Conclusions

There remain considerable uncertainties surrounding the potential impacts of MREDs on cetaceans. Arguably the pile driving process during construction offers the greatest threat. Other concerns relating to MREDs could include collisions between cetaceans and structures on the surface or in the water column, contamination of water (for example by leaks of lubricants), entanglement (for example in cables) and habitat degradation and displacement.

Effects on marine mammals can be expected to differ according to the type of MRED in question, how it works and how, and where, it is positioned. Some experience gained from other marine industries as to their impacts (such as offshore oil and gas production) may well be relevant to wind, wave and tidal projects. For example the use of pile driving and decommissioning methods may be similar.

The authors believe that the local environmental impacts of MREDs deserve further careful consideration. We support the calls from Inger (*et al*. 2009) and others to minimise potential conflicts by involving key stakeholders in the decision making process from concept, through stages of design, location, construction & operation. Involvement should include local and national conservation groups, planning authorities, the energy company, and the local fishing community.

Robust and clear guidance on marine renewable energy developments is required before large scale developments are approved including guidelines on suitable sites and the required precision of pre-, during and post- construction monitoring, monitoring of several years before and after construction will yield the most comprehensive results.

The impact on marine wildlife, not only cetaceans, should be taken into account, not only from the moment of submitting the plans, but from the point of conception. That these impacts should be implicit in the design, rather than farther down the developmental line, and that a device that has not been developed accordingly would not be given the consents to be deployed.

Because of the potential impacts of MRED's on cetaceans and the marine environment in general, the authors feel that it is most important for developers to avoid areas altogether that are considered essential habitat for cetaceans including breeding, nursing and feeding grounds.

Acknowledgements

Thanks to Sarah Dolman for her comments on an earlier draft of this paper and Deborah Wright for her help in researching this matter. Thanks also to the developers who assisted us by consulting with us on the different types of devices.

References

ASCOBANS 2006 Report of the 5th Meeting of Parties. Resolution 4. http://www.ascobans.org/index0401.html

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. http://www.ascobans.org/index0401.html

BERR 2009. UK Department for Business Innovation and Skills website. www.berr.gov.uk/energy/sources/renewables/explained/wave-tidal/wave/page17058.html

Brown, V.C., Simmonds, M.P., 2008. An Update on the Extent of Marine Renewable Energy Developments in the Northeast Atlantic. Paper submitted to the Scientific Committee of the IWC. SC/60/E6.

Brown, V.C., 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 IWC. SC/61/E7

Carter, C.J., Wilson, B. and Black, K. 2008. Marine renewable energy devices: a collision risk for marine mammals? Proceedings of the ASCOBANS/ECS workshop: offshore wind farms and marine mammals: impacts & methodologies for assessing impacts. San Sebastian, Spain, 21st April 2007. ECS special publication series no. 49 Feb 2008

Carstensen, J., Henriksen, O. D., Teilmann, J., 2006 Impacts of offshore wind farm construction on harbour porpoise. *Marine Ecology Progress Series* 321, 295-308

DECC, 2009. Energy Security: A national challenge in a changing world. Department of Energy and Climate Change. Department of Energy and Climate Change – Press Release: 5 August 09: http://www.decc.gov.uk/en/content/cms/news/pn090/pn090.aspx

EMEC 2009 European Marine Energy Center website: http://www.emec.org.uk/wave_site.asp

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, 21st April 2007. ECS special publication series no. 49 Feb 2008

Gill, A.B., Taylor H. 2001. The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon Elasmobranch Fishes Research Project for Countryside Council for Wales CCW Science Report No. 488

Hörter, A. 2002. German Offshore Wind Projects Planning and Status Quo. Report from the Conference 'Offshore Wind Energy', Cuxhaven, 7-8th March, 2002. http://www.offshore-conference.de.

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., Godley, B.J., 2009. Marine Renewable Energy: potential benefits to biodiversity? An urgent call for research. *Journal of Applied Ecology* In Press.

IWC 2009 – Report of the Scientific Committee IWC/61/Rep 1

Jasny, M., 2005. The rising toll of sonar, shipping and industrial noise in marine life. Published by Natural Resources Defence Council. 76 pages. Available at www.nrdc.org/wildlife/marine/sound/sound.pdf

Jefferson TA, SK Hung, B Würsig 2009. Protecting small cetaceans from coastal development: Impact assessment and mitigation experience in Hong Kong. *Marine Policy*: 305-311

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.

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

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:

Ødegaard & Danneskiold – Samsøe A/S 2000. *Underwater noise measurements, analysis and predictions.* Rødsand Offshore Wind farm EIA Technical Background Report: Underwater Noise, Dec 2000. Report no. 00.792 rev.1.

Prior, A., McMath, M.J., 2007. Marine Mammals and Noise from Offshore Renewable Energy Projects – UK Developments. In: 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, 21st April 2007. ECS special publication series no. 49 Feb 2008

Richardson, W.J., Greene, C.R., Malme, C.I. and Thompson, H.H. 1995. Marine Mammals and Noise. Academic Press, San Diego

ruralgateway.org.uk. 2009 Scotland: national rural network website: last visited 7/5/2010

seageneration.co.uk. 2008 Sea Generation Ltd. Website: last visited 7/5/2010

Simmonds, M.P., Dolman, S.J., 2008. All at sea: renewable energy production in the context of marine nature conservation. In: 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, 21st April 2007. ECS special publication series no. 49 Feb 2008

Simmonds, M.P., Dolman, S.J., Weilgart, L., (Eds), 2004 Oceans of Noise 2004. A WDCS Science Report Published by the Whale and Dolphin Conservation Society 169 pages.

Snyder, B., Kaiser, M. J., 2009 Ecological and economic cost – benefit analysis of offshore wind energy. *Renewable Energy* 34: 1567-1578

Teilmann, J., Tougaard, J., Carstensen, J., 2007. Effects From Offshore Wind Farms On Harbour Porpoises In Denmark. In: 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, 21st April 2007. ECS special publication series no. 49 Feb 2008

Thomsen, F., Betke, K.., Schultz-von Glahn, M., Piper, W., 2006 Noise During Offshore Wind Turbine Construction and it's effects on Harbour Porpoises (*Phocoena phocoena*) European Cetacean Society 20th Annual Conference

U.S Department of Energy. 2009. Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technolgies.

Weilgart, L.S., 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology* 85, 1091–1116.

Wahlberg, M. and Westerberg, H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. *Marine Ecology Progress Series* 288: 295-309.

Wilson, B., Batty, R.S., Daunt, F. & 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.

Wright, D., Brown, V., Simmonds, M.P. 2009. A Review of Developing Marine Renewable Technologies. Paper submitted to the Scientific Committee of the IWC. IWC/SC/61/E6.

Figure 1. Location of windfarms in Europe

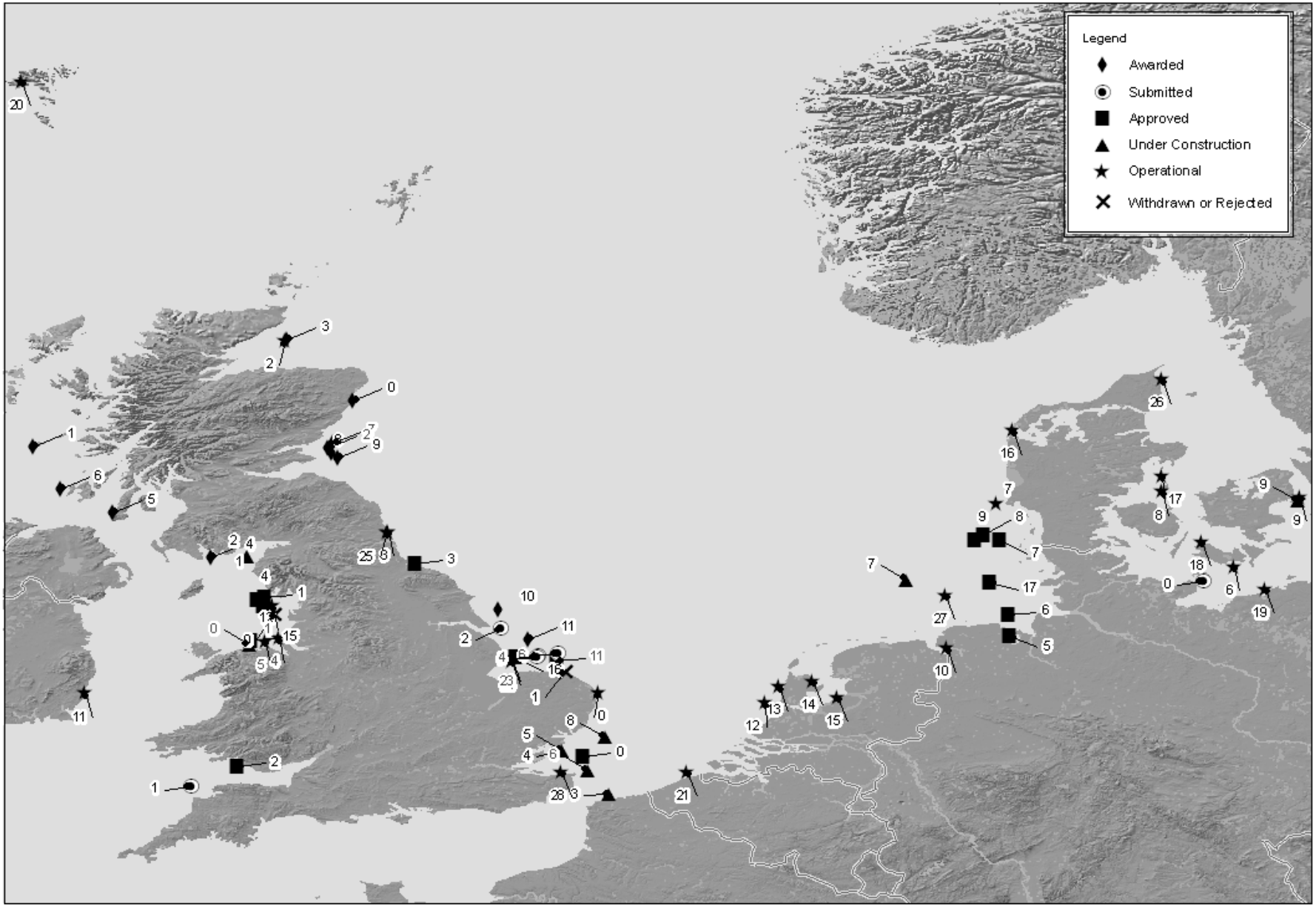


Table 1. Location of wind farms

Site No.	Name	Location	Region	Turbines	Developer	Lat Long	Country	Year	Energy Generated (MW)	Energy Capacity (MW)	Info source
Withdrawn or Rejected											
0	Cirrus Array (Shell Flats)	7km Cleveleys	North West/ Lancashire	90	Celt Power/ DONG Energy/ Shell Wind Energy	53 31 00N 03 15 00W	England	2003	0	270	BWEA website www.bwea.com/ukwed/planning.asp
1	Cromer	7km Cromer	East of England	30	EdF		England		4	108	WEA www.bwea.com/ukwed/offshore.asp
Approved											
0	Aberdeen demonstration site	Aberdeen		0	Aberdeen Renewable Energy Group (AREG)		Scotland	2009		115	www.viewsofscotland.org/ www.bwea.com/
1	Argyll Array	West of Argyll and the island of Tiree		0	Scottish Power		Scotland	2009		1800	www.scottishpower.com/PressReleases_1832.htm
2	Bell Rock Lighthouse	10km offshore		140	Airtricity		Scotland	2009		700	www.scottish-southern.co.uk/
3	Beatrice extension	Beatrice oilfield, Moray Firth		184	Scottish and Southern Energy		Scotland	2009		920	www.scottish-southern.co.uk
4	Wigtown Bay		Dumfries and Galloway	56	DONG Energy		Scotland	2009		280	www.dongenergy.co.uk/Wind_energy/
5	Kintyre	3km due west of Macrihanish		126	Scottish and Southern Energy		Scotland	2009		378	www.scottish-southern.co.uk
6	Islay	13km offshore		138	Scottish and Southern Energy		Scotland	2009		690	www.scottish-southern.co.uk
7	Inch Cape	15km offshore in outer Tay estuary		180	npower/ SeaEnergy		Scotland	2009		900	"www.npower-renewables.com
8	Neart na Gaoithe	Outer Forth estuary		0	Mainstream Renewable Power		Scotland	2009		360	www.mainstreamrp.com
9	Forth Array			0	Fred Olsen Renewables		Scotland	2009		415	www.thecrownestate.co.uk
10	Westernmost Rough	8km offshore, 25 km north of Spurn Head	Greater Wash	80	DONG Energy		England	2009		240	www.bwea.com/ukwed/offshore.asp
11	Triton Knoll	33km off the Lincolnshire Coast	Greater Wash	240	npower renewables		England	2009	5	1200	BWEA website www.bwea.com/ukwed/offshore.asp
Submitted											
0	Sky 2000			50	GEO		Germany	2004		175	Offshore Wind.de www.offshore-wind.de
1	Atlantic Array	12 miles offshore Ilfracombe, Bristol	Devon	350	Farm Energy		England	2007		1500	www.offshorecenter.dk/offshorewindfarms.asp

2	Humber Gateway	Channel Humberside		70	E.ON UK Renewables	53 37 00N 00 16 00E	England	2008	3	300	BWEA website www.bwea.com/ukwed/planning.asp
4	Race Bank	Greater Wash		88	Centrica Renewable Energy Ltd		England	2009		620	BWEA website www.bwea.com/ukwed/planning.asp
5	Docking Shoal	Greater Wash		0	Centrica Renewable Energy Ltd		England	2008		500	BWEA website www.bwea.com/ukwed/planning.asp
6	Dudgeon	32 km north of Norfolk, Greater Wash		168	Warwick Energy		England			560	BWEA website www.bwea.com/ukwed/offshore.asp
Approved											
0	London Array	24km off Clacton-on-Sea	Thames Estuary	271	DONG Energy/ Shell Wind Energy/ E.On Renewables	51 38 00N 01 32 00E	England	2006		1000	BWEA website www.bwea.com/ukwed/consented.asp
1	Ormonde	off Walney Island	North West/ Cumbria	30	Eclipse Energy	54 06 00N 03 25 00W	England	2007	5	150	BWEA website www.bwea.com/ukwed/consented.asp
2	Scarweather Sands	5.5km Sker Point (nr Porthcawl)	South Wales/ Bridgend	30	DONG Energy/ E.ON UK	51 28 50N 03 50 50W	Wales	2004	3.6	108	BWEA website www.bwea.com/ukwed/consented.asp
3	Teeside/ Redcar	1.5km NE Teesmouth	Yorkshire & Humber/ North Yorkshire	30	EdF	54 38 00N 01 05 00W	England	2007		90	BWEA website www.bwea.com/ukwed/consented.asp
4	Walney Island	14km Walney Island	North West	0	DONG Energy	54 04 00N 03 32 00W	England	2007	3.6	450	BWEA website www.bwea.com/ukwed/conseted.asp
5	Wilhelmshaven	550m offshore Wilhelmshaven		1	Winkra-Energie GmbH		Germany	2003	4.5	4.5	http://www.offshore-wind.de/page/index.php?id=4761
6	Offshore Windpark Nordergrunde			25	Energie-kontor AG		Germany		25	125	http://www.offshore-wind.de/page/index.php?id=4761
7	Offshore-Burger-Windpark Butendiek			80	Gmbh & Co. KG Husum		Germany			240	http://www.offshore-wind.de/page/index.php?id=4761
8	Dan Tysk			80	Gesellschaft fur Energi und Okologie mbH		Germany			400	http://www.offshore-wind.de/page/index.php?id=4761
9	Nordlicher Grund			80	GEO mbH, renergys GmbH		Germany			400	http://www.offshore-wind.de/page/index.php?id=4761
11	Sheringham Shoal	Sheringham, Greater Wash	East of England/ Norfolk	0	Scira Offshore Energy Ltd	53 07 00N 01 08 00E	England	2008		315	BWEA website www.bwea.com/ukwed/co

											nsented.asp
12	West of Duddon Sands	N. Irish Sea	North West	0	DONG Energy/ E.ON UK/ Eurus	53 58 00N 03 26 00W	England	2008		500	BWEA website www.bwea.com/ukwed/consented.asp
15	Gwynt y Mor	Liverpool Bay (13-15km offshore)	North West	200	npower renewables	53 26 00N 03 38 00W	England	2008		750	BWEA website www.bwea.com/ukwed/consented.asp
16	Lincs	8km off Skegness	Greater Wash	0	Centrica Renewable Energy Ltd	53 11 00N 00 29 00E	England	2008		250	BWEA website www.bwea.com/ukwed/consented.asp
17	Nordsee Ost	36km offshore		80	Amrumbank West GmbH		Germany			400	http://www.offshore-wind.de/page/index.php?id=4761
Operational											
0	Scroby Sands	3km NE Great Yarmouth	Norfolk	30	E.ON UK Renewables	52 38 00N 01 47 00E	England	2004	2	60	BWEA website www.bwea.com/ukwed/operational.asp
1	Barrow	7km Walney Island	North West/ Cumbria	30	DONG Energy/ Centrica Renewable Energy	53 59 00N 03 17 00W	England	2006	3	90	BWEA website www.bwwa.com/ukwed/operational.asp
2	Beatrice	Beatrice Oilfield, Moray Firth	Scotland	2	Scottish and Southern	58 06 20N 03 05 35W	Scotland	2007	5	10	BWEA website www.bwea.com/ukwed/operational.asp
3	Blyth Offshore	1km Blyth Harbour	North East/ Northumberland	2	E.ON UK Renewables	55 08 09N 01 29 25W	England	2000	2	3.8	BWEA website www.bwea.com/ukwed/operational.asp
4	Burbo Bank	5.2km Crosby	North West/ Merseyside	25	DONG Energy	53 29 00N 03 11 00W	England	2007	3.6	90	BWEA website www.bwea.com/ukwed/operational.asp
5	North Hoyle	7.5km Prestatyn and Rhyl	North Wales/ Denbighshire	30	npower renewables	53 26 00N 03 24 00W	Wales	2004	2	60	BWEA website www.bwea.com/ukwed/operational.asp
6	Nysted	10km south of Nysted on Lolland	Rodsand/ Lolland	72	DONG Energy		Denmark	2003			http://uk.nystedhavmoellepark.dk/frames.asp
7	Horns Rev	14-20km offshore from Jutland	Blavandhuk	80	DONG Energy		Denmark	2002		160	http://www.hornsrev.dk/Engelsk/default_ie.htm
8	Samso	3.5km south of the island Samso	Island of Samso	10	Locally owned		Denmark	2003	2.3	23	http://www.samsohavvind.dk/windfarm/
9	Middelgrunden	2km offshore from Copenhagen	Port of Copenhagen	20	DONG Energy		Denmark	2003	40	90TWh	http://www.windpower.org/en/pictures/offshore.htm
10	Ems-Emden	40m offshore		1	Enova		Germany	2004	4.5	4.5	Offshore-wind.de website www.offshore-wind.de
11	Arklow Bank	10km Arklow	County Wicklow/East Ireland	7	Airtricity		Ireland	2007	25.2		Offshore Wind Energy www.offshorewindenergy.org
12	Q7-WP	23km Ijuiden		60	Econcern, Energy Investments		Netherlands	2008	2	120	Offshore Wind Energy www.offshorewindenergy.

					Holding, ENECO Energy						org
13	Egmond aan Zee	10km offshore from Egmond aan Zee		36	NoordzeeWind (Shell/NUON)		Netherlands	2007	3	108	Offshore Wind Energy www.offshorewindenergy.org
14	Lely	750m offshore		4			Netherlands	1994	500 KW	2	Offshore Wind Energy www.offshorewindenergy.org
15	Irene Vorrink	20m offshore	Dronten - Ijsselmeer	28			Netherlands	1996	600 KW	16.8	Offshore Wind Energy www.offshorewindenergy.org
16	Ronland	Lim fjord	NW Jutland	8			Denmark	2003	2.3	17.2	Offshore Wind Energy www.offshorewindenergy.org
17	Tuno Knob	Inland Sea 6km from shore		10			Denmark	1995	500 KW	5	Offshore Wind Energy www.offshorewindenergy.org
18	Vindeby	1.5km from shore		11			Denmark	1991	450 KW	4.95	Offshore Wind Energy www.offshorewindenergy.org
19	Brietling	500m offshore	Nr Rostock	1	Wind-projekt GmbH		Germany	2006	2.5	2.3	Offshore Wind Energy www.offshorewindenergy.org
20	Vestmanna			3	Rokt		Faroe Islands		1.98		www.thewindpower.net/
21	Thorntonbank	30 km from Zeebrugge		60	REpower		Belgium	2008	300	690 GW.h	http://www.repower5m.com/index_flash_uk.htm
23	Inner Dowsing	5.2km Ingoldmells	East Midlands/ Lincolnshire	27	Centrica Renewable Energy Ltd	53 11 00N 00 26 00E	England	2008	3.6	81	BWEA website www.bwea.com/ukwed/operational.asp
24	Lynn	5.2km Skegness	East Midlands/ Lincolnshire	30	Centrica Renewable Energy Ltd	53 07 39N 00 26 10E	England	2008	3	81	BWEA website www.bwea.com/ukwed/operational.asp
25	Blyth Harbour		Northumberland	9	AMEC Wind	55 07 20N 01 29 25W	England	1993	0.3	2.7	BWEA website www.bwea.com/ukwed/operational.asp
26	Frederikshavn			4	Elsam essential energy		Denmark	2008		10.6	Offshore Wind Energy www.offshorewindenergy.org
27	Alpha Ventus	45km north of Borkum		12	E.ON Energy, EWE, Vattenval		Germany	2009		60	http://www.alpha-ventus.de/index.php?id=80
28	Kentish Flats		Kent	30	Vattenfall		England	2005	3	90	http://www.bwea.com/ukwed/operational.asp
Under Construction											
0	Rhyl Flats	8km Abergele	North Wales/ Conwy	25	npower renewables	53 22 00N 03 39 00W	Wales	2007	3.6	90	BWEA website www.bwea.com/ukwed/co

											nstruction.asp
1	Solway Firth/ Robin Rigg B	9.5km Maryport/ 8.5km off Rock Cliffe	Scotland/ Dumfries and Galloway	30	E.ON UK Renewables	54 45 00N 03 41 00W	Scotland	2006	3	90	BWEA website www.bwea.com/ukwed/construction.asp
2	Solway Firth/ Robin Rigg A	9.5km Maryport/ 8.5km off Rock Cliffe	Scotland/ Dumfries and Galloway	30	E.ON UK Renewables	54 45 00N 03 41 00W	Scotland	2006	3	90	BWEA website www.bwea.com/ukwed/construction.asp
3	Breedt/ Mardyck Bench			0	Nord-Pas-de-Calais/Shell/TFE/Jeumont		France	2003		8	Offshore Wind Energy www.offshorewindenergy.org
4	Gunfleet Sands I	7km Clacton-on-Sea	East of England/ Essex	30	DONG Energy	51 43 00N 01 12 50E	England	2008	3.6	108	BWEA website www.bwea.com/ukwed/construction.asp
5	Gunfleet Sands II		East of England/ Essex	18	DONG Energy	51 43 00N 01 12 50E	England	2008	3.6	64	BWEA website www.bwea.com/ukwed/construction.asp
6	Thanet	11-13km Foreness Point, Margate	Thames Estuary	0	Warwick Energy		England	2008		300	BWEA website www.bwea.com/ukwed/construction.asp
7	Bard Offshore 1	100 km north of the isle Borkum		80	Bard Engineering GmbH		Germany	2009		400	http://www.bard-offshore.de/proj_bard_offshore_1-e
8	Greater Gabbard	26km off Orford	Norfolk, Thames Estuary	0	Airtricity		England	2007		500	BWEA website www.bwea.com/ukwed/construction.asp
9	Lillgrund Bank	10km offshore, just south of Oresund Bridge	Oresund, near Malmo	48	Vattenfall		Sweden	2008		110	www.offshorewindenergy.org; www.vattenfall.com

Figure 2. Location of Tidal Power plants in Europe

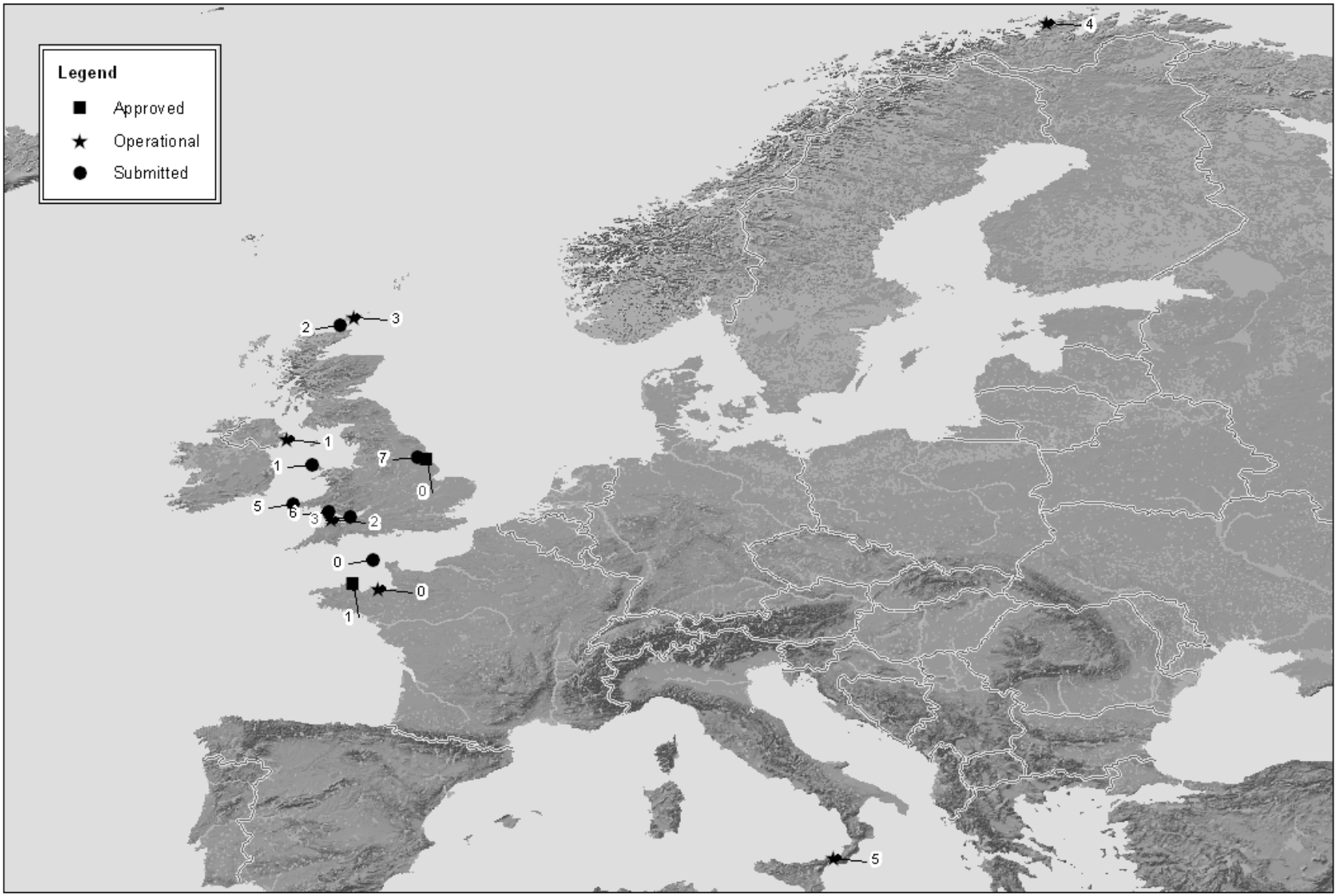


Table 2. Locations of Tidal power plants

Site No.	Name	Location	Region	Developer	Country	Year	Device	Energy Generated	Energy Capacity	Information Source
Operational										
0	Rance Power Station	Rance River	Bretagne	EDF	France	1966	24 bulb type turbine generators	68MW	240MW	www.edfenergy.com
1	Sea Gen	Stangford Lough	Co Down	Marine Turbines Ltd	Northern Ireland	2008	tidal energy convertor	1.2MW		www.marineturbines.com/18/projects/19/seagen/
2	Sea Flow	2km offshore Foreland Point, Lynmouth	Devon	Marine Turbines Ltd	England	2003	1 tidal turbine	300kW		www.marineturbines.com/6/background/14/seaflow/
3	Fall of Warness Test Site	Eday	Orkney Islands	European Marine Energy Centre	Scotland					www.emec.org.uk/tidal_site.asp
4	Kvalsund Sound	Kvalsundet	Finnmark	Hammerfest Stroem	Norway	2003				http://www.hammerfeststrom.com/content/view/45/72/
5	Enermar	Straits of Messina	Sicily	Ponte di Archimede	Italy	2001				http://www.pontediarchimede.com
Approved										
0	Humber Estuary	Upper Burcom near Stallingborough	Lincolnshire	Pulse Tidal Ltd	England	2008	Pulse generator		0.15MW	www.pulsetidal.com
1	Paimpol-Brehat	Offshore from Paimpol	Brittany	EDF	France	2008	4-10 tidal turbines		4MW	http://press.edf.com/
Submitted										
0	Alderney	Alderney Island	Channel Islands	Alderney Energy Renewable Ltd	England	2007	Tidal turbines			www.reuk.co.uk/Alderney-Tidal-and-Wave-Power.htm
1	Anglesey Skerries Tidal Stream Array	The Skerries	Angelsey Island	Marine Current Turbines and npower renewables	Wales	2008	Seven 1.5MW SeaGen turbines		10.5MW	www.marineturbines.com
2	Pentland Firth Tidal Energy Park	Caithness/ Orkney Islands	North Scotland	Tocardo	Scotland	2007	Turbines		10MW	http://www.tocardo.com/?Projects:Master_Plan_P.Fir
3	Severn Barrage	Bristol Channel	Somerset/ Glamorgan	Severn Tidal Power Group	England/ Wales	2005	214 40MW turbines		17 billion kWh	http://www.reuk.co.uk/Severn-Barrage-Tidal-Power.h
5	DeltaStream Demonstration	Ramsey Sound	Pembrokeshire	Tidal Energy Limited	Wales	2008	1 DeltaStream Unit			www.tidalenergyltd.com
6	Swansea Bay	I mile off coast from Swansea	Swansea	http://www.tidalelectric.com/Projects%20UK.htm	Wales	2007	hydro-electric turbines		60MW	http://www.cprw.org.uk/pdfs/spring05_tidalenergy.p
7	Humber St Andrews	North Ferriby	Yorkshire and the Humber	Neptune Renewable Energy	England	2009	Tidal turbines	1,000 MWhr/year		http://news.bbc.co.uk/1/hi/england/humber/7932388.

Figure 3. Location of Wave Power plants in Europe

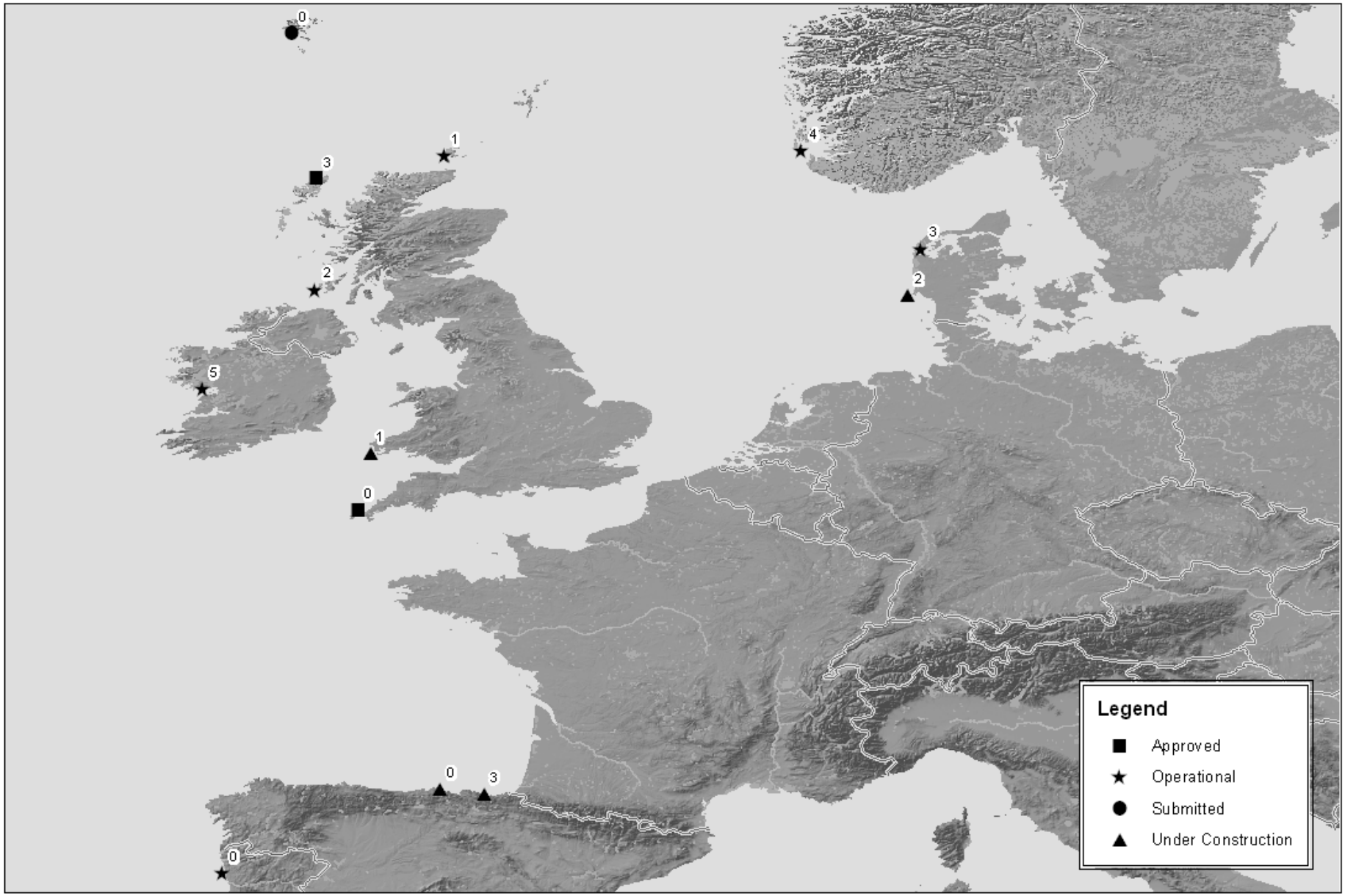
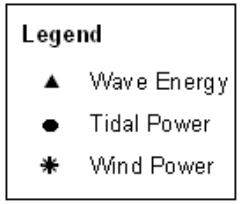


Table 3. Location of Wave power plants

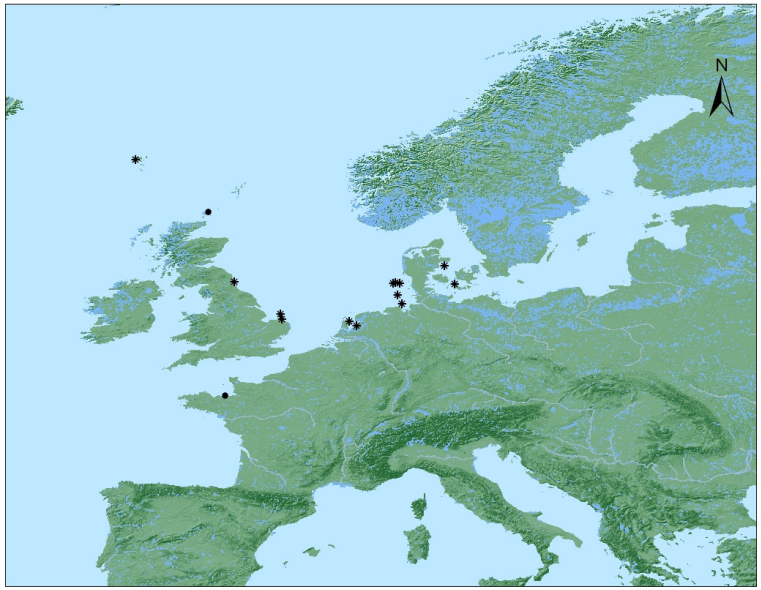
Site No.	Name	Location	Region	Developer	Country	Year	Device	Energy Generated	Energy Capacity	Information Source
Operational										
0	Aguçadoura	5km offshore from Agucaduora		Energias de Portugal	Portugal	2006	3 Pelamis P-750 machines	2.25MW	22.5MW	www.power-technology.com/projects/pelamis/
1	Billia Croo Test Site	2km offshore from Billia Croo	Orkney Islands	European Marine Energy Centre (EMEC)	Scotland	2003				www.emec.org.uk/wave_site.asp
2	Limpet 500	Portnahaven	Isle of Islay	Wavegen	Scotland	2000	Inclined oscillating water column	500KW		www.wavegen.co.uk/what_we_offer_limpet_islay.htm
3	Nissum Bredning	Nissum Bredning Fijord		Wave Star Energy	Denmark	2006	20 floats	5.5KW		www.wavestarenergy.com/
4	Kvitsoy Pilot Project	Kvitsoy	Rogaland	Wave Energy	Norway	2007	SSG wave energy converter		200KW	www.wavessg.com/WAVESSGProject.htm
5	Galway Bay Wave Energy Test Site	N side Galway Bay, 1 mile East of An Spideal	Co. Galway	Mairine Institute and Sustainable Energy Ireland	Ireland	2006				www.marine.ie/
Under Construction										
0	Santoña	4km offshore from Santona	Cantabria	IBERDROLA RENOVABLES	Spain	2008	10 PowerBuoy devices		1.39MW	www.iberdrolarenovables.es/
1	Wave Dragon Pembrokeshire	5km offshore from St. Anne's Head	Pembrokeshire	Wave Dragon	Wales	2008	Wave Energy Converter		70MW	www.wavedragon.net/
2	Horn's Rev	14km offshore		Wave Star Energy	Denmark	2007	20+ floats		500kW	www.investindk.com/visNyhed.asp?artikelID=18099
3	Mutriku	Mutriku Harbour	Pais Vasco	Wavegen	Spain	2008	Oscillating Water Column		300KW	www.wavegen.co.uk/news_mutriku.htm
Approved										
0	Wave Hub test site - Hayle	16km offshore from Hayle	Cornwall	South West Regional Development Agancy	England	2007				http://download.southwestrda.org.uk/
3	Siadar Wave Energy Project	350m offshore in Siadar Bay	Isle of Lewis	npower/ Wavegen	Scotland	2009	Oscillating Water Column	4MW	4MW	www.npower-renewables.com/siadar/index.asp
Submitted										
0	Faroes		Faroe Islands	Wavegen	Danish Kingdom	2007	Oscillating water column			www.wavegen.co.uk/what_we_offer_limpet_faroes.htm

Figure 4. The growth of marine renewables in Europe

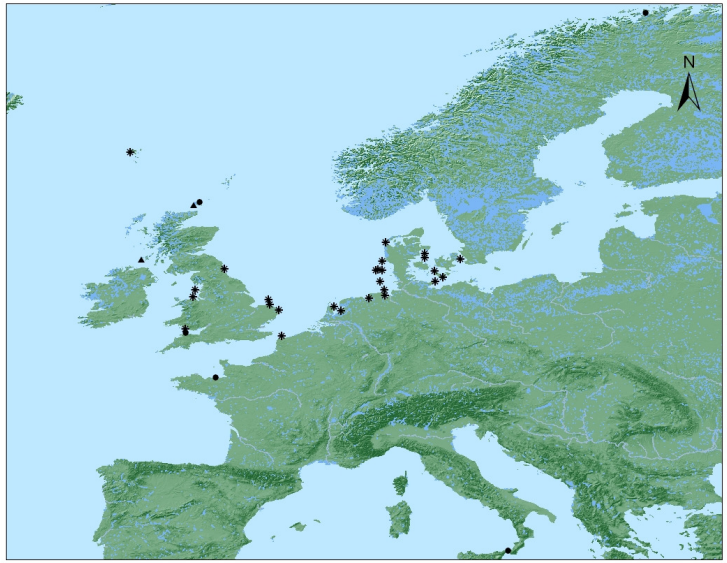
These maps include all awarded, withdrawn or rejected, operational, under construction, approved and submitted MREDs.



Marine Renewable Developments in Northern Europe pre 2000



Marine Renewable Developments in Northern Europe 2000-2004



Marine Renewable Developments in Northern Europe 2005-2009

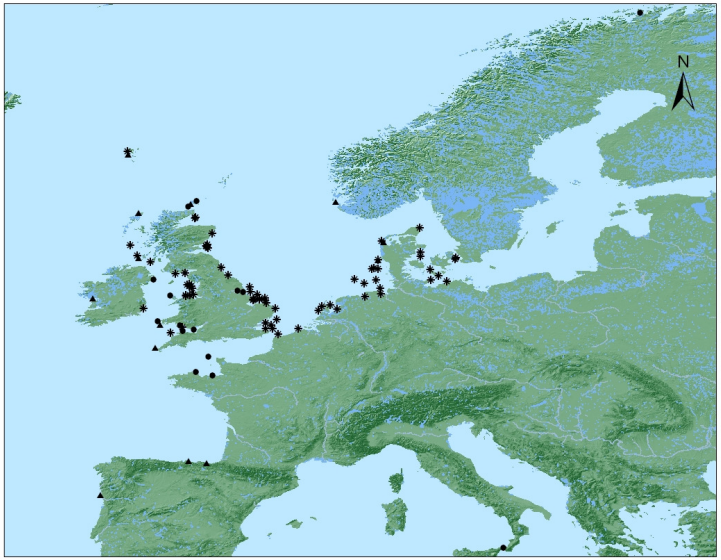
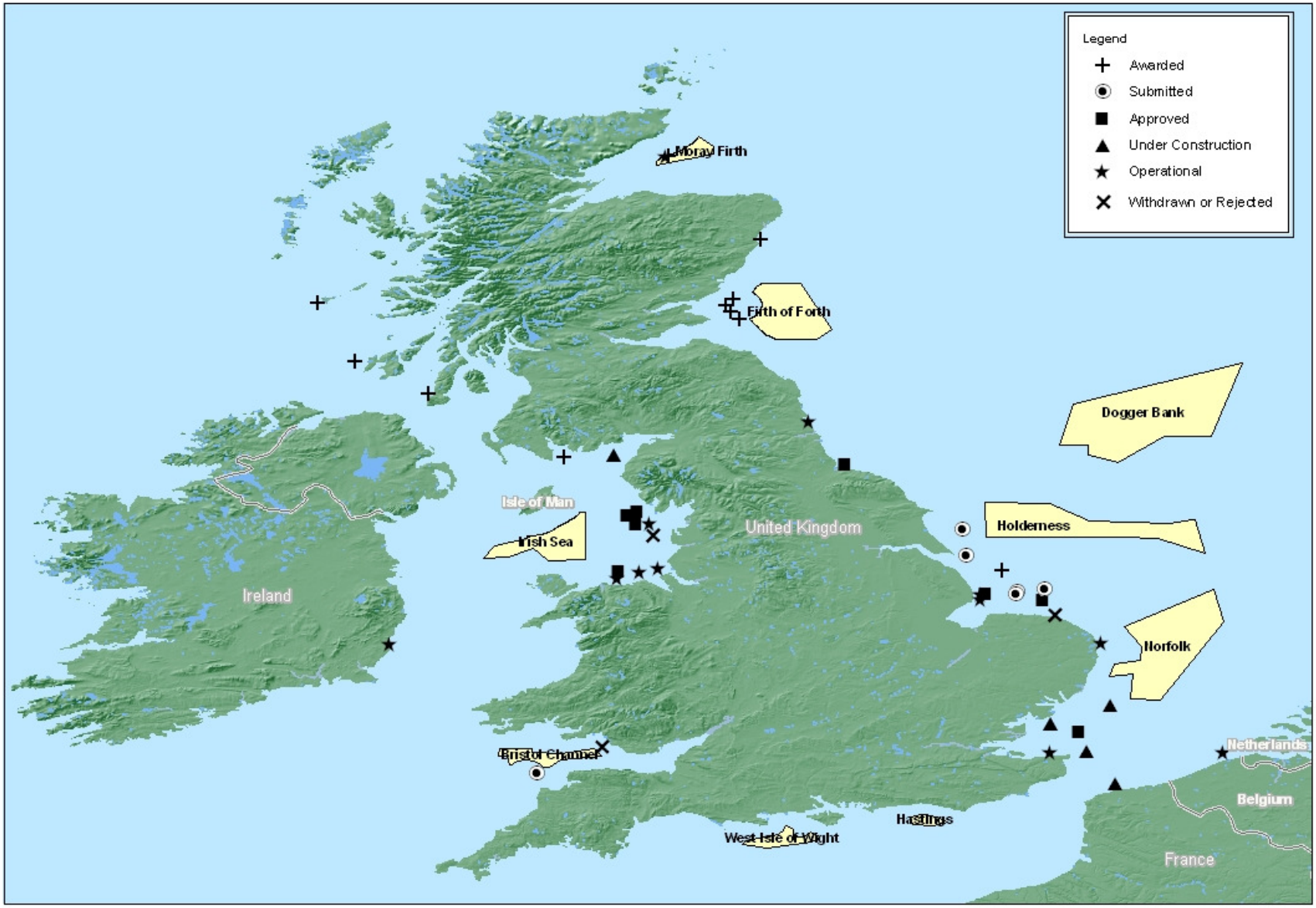



Figure 5. Location of Round 3 Zones in the UK and current wind farms