Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh waters

Phase 1 - Desktop Review of Marine Mammals and Risks from Underwater Marine Renewable Devices in Welsh waters

On Behalf of

The Welsh Assembly Government

Date: 28th March 2011
Our Ref: JER3688

RPS
Conrad House
Beaufort Square
Chepstow
Monmouthshire
NP16 5EP

Tel: (0)1291 621 821
Fax: (0)1291 627 827
Email: rpssw@rpsgroup.com

Quality Management

Prepared by:	Ben Wilson (SAMS)	
Prepared by:	Jonathan Gordon (Ecologic)	
Authorised by:	Nicola Simpson (RPS)	
Date:	28th March 2011	
Revision:	4	
Project Number:	JER3688	
Document Reference:	JER3688R101122BW Phase 1 - Desktop Review of Collision Risk of MM from Underwater Devices V4.doc	
Document File Path:	O:\JER3688 - Marine renewable Strategy for Wales\STAGE 2\Project File\Task 1&2 Marine Mammals Collision Risk\JER3688R101122BW Phase 1 - Desktop Review of Collision Risk of MM from Underwater Devices V4.doc	

Executive Summary

S.1 The Marine Renewable Energy Strategic Framework for Wales (MRESF) is seeking to provide for the sustainable development of marine renewable energy in Welsh waters. As one of the recommendations from the Stage 1 study, a requirement for further evaluation of potential environmental impacts on marine mammals from marine renewable devices was identified. This report summarises information on marine mammals that frequent those areas within Welsh waters with high tidal currents identified as likely candidate sites for tidal turbine installations. The types of devices that are being developed are briefly reviewed and an assessment of the range of potential hazards that these could pose for marine mammals is made. Particular emphasis is placed on collision risk, which is considered to be one of the most significant hazards. Physical, biological and behavioural factors that might affect the probability and severity of collisions are reviewed and comments are offered on the likely sensitivity of different species and regions. Potential strategies for mitigation and knowledge gaps that need to be addressed are also discussed.

S.2 The regions with strongest tidal currents and which, on this basis, are of most interest for development as tidal turbine sites are inshore waters north and west of Anglesey, west of the Lleyn Peninsular, to the west of Pembrokeshire and an area in the mouth of the Bristol Channel. Both grey seals and cetaceans can be found in all areas; however, there is some variation in species mix and relative densities. Some of these sites also include, or are very close to, protected areas for which marine mammals are qualifying features and in several areas, the commercial significance of marine mammals for tourism is substantial. Generally, we might expect the likelihood of interactions between marine mammals and turbines to be related to their relative densities in an area. Available sighting information, much of which was collected opportunistically, has recently been collated to provide a broad scale view of densities and distributions. However, several points should be stressed. The first is that marine mammals are distributed in 3D space so knowledge of their diving behaviour and the proportion of time they spend at the operating depth of the turbines is crucial information. The second important point is that these tidal rapid sites cover a very small proportion of the species range and are physically forbidding habitats in which to survey. As a consequence very little survey effort has actually been expended in these areas, especially at tidal states when currents are at their highest, which of course is the time for which data is required. These sites are also ecologically unusual, which means that one can not extrapolate animal densities or dive behaviour with any confidence from better studied habitats

outside these areas. Indeed, studies show that animal densities and behaviour are often quite different in these areas compared to adjacent ones, and they vary with tidal cycle. Thus, data at the spatial and temporal scale necessary to assess collision risk in different areas is much sparser than might be supposed.

S.3 The installation of tidal turbines in tidal rapids gives rise to a suite of general concerns. Although, as tidal turbines are such a new feature in the marine environment, and largely unstudied, current understanding of associated risk is very limited.

S.4 Some of the risks identified include:

- They may affect habitat, in particular be altering current flow, patterns of sedimentation and the dynamics of foraging in rapidly flowing waters. They may be attractive to some prey species. Some of these effects could boost prey availability, though this might also increase collision risk;
- Turbines will generate noise during operation. Marine mammals are particularly sensitive to sound underwater and may exhibit avoidance. If particularly noisy turbines designs were developed then direct effects on hearing would be possible, though this seems unlikely. However, high levels of noise with the potential to be damaging and cause long range habitat exclusion, could be generated over relatively short periods during construction if activities such as pile driving are involved; and
- Sensitivity of marine mammals to electrical fields is poorly understood. Seals at least do seem very responsive and this topic warrants further investigation.

S.5 Collision between marine mammals and moving turbine blades is believed to represent one of the most acute and serious hazards for marine mammals. Some insights can be gleaned by considering analogous anthropogenic impacts, such as ship strikes and entanglement in fishing nets in the marine environment and collisions of birds and bats with wind turbines. Indications from these are that typically the number and severity of collisions are underestimated and that interactions can occur even though the animals concerned seemed able to sense the hazard and have the capability to avoid the structures involved.

S.6 It is often useful to consider collision risk as being made up of three components:

- The probability that an animal will come into close proximity to a turbine at times when it is rotating, which is a function of fine scale distributions and densities, including depth distribution within the water column;
- The risk that proximity will result in a collision, which will be heavily dependent on an animal's ability to detect and evade a moving turbine blades; and
- The consequences of collision. These will be influenced by blade speed and the robustness of the animal may range from superficial wounds to mortalities.

S.7 Realistic models of these risks required much better information on local 3D densities, detection ranges, avoidance and evasion capability. These are likely to be affected by a range of ecological factors and the sensory capabilities of the different species involved. Turbines will be deployed in arrays and this give rise to additional concerns; for example the extent to which a field of devices might act as a barriers or trap. Existing collision risk models suggest that, typically, larger animals should be more vulnerable than smaller ones. This is because individuals are more likely to be hit if they pass through the blades while, at the population level, population size and reproductive rates tend to be lower for larger animals.

S8 From a conservation perspective risks at the population level need to be considered. In this case the size and status of the local population and the size and nature of other threats will all contribute to a population's vulnerability to additional mortality or perturbation.

S.9 Of the four regions within Welsh waters highlighted as having a substantial tidal resource, to the west of Pembrokeshire stands out as potentially being particularly sensitive from a marine mammal perspective. It has a high species diversity with offshore species, such as common dolphins and minke whales, being common. Densities of porpoise are particularly high and at least some of the tidal rapids here seem to be particularly important to porpoises at certain times of the tide. Grey seals breed and haul out in adjacent coves. Most of the high tidal energy area is within the Pembrokeshire Marine SAC and marine mammals are also an important component of local wildlife tourism operations. The Lleyn peninsular and the areas of North Anglesey both include grey seal breeding beaches and have healthy harbour porpoise populations. With its higher breeding grey seal numbers, resident Risso's dolphins and proximity to the Cardigan Bay SAC, the Lleyn peninsular might be considered the more sensitive of the two. The tidal races around the Skerries and North and South Stacks North Anglesey have substantial porpoise densities and are close to grey seal haulout sites and breeding beaches. The area in the mouth of the Bristol Channel seems to have the lowest diversity and density of marine mammals; although it should be noted that the level of dedicated monitoring in this area to date has been low.

S.10 A number of different approaches to mitigation are reviewed. At the planning stage, developments could be sited in lower density, less sensitive areas, while within sites, at a finer scale, it may be possible to locate turbines at spots where collision risks are lower. Locating turbines at depths which are less-utilised by marine mammals might be a practical option for some devices at some deep water sites. Measures may be taken to improve the visual detection by making structures more conspicuous underwater. Acoustic detectability of devices may be improved by making them a stronger echolocation target and locating them in areas with lower levels of masking background noise. Active noise sources to warn or deter animals may be useful, though these also raise concerns of habitat exclusion and habituation. It may be necessary to monitor for marine life continuously and stop or slow blades when detections are made in high risk locations to ensure compliance with the Habitats Directive.

S.11 A detailed assessment of the risks posed by tidal turbines is hampered by major knowledge gaps in all areas. A better understand of marine mammal distributions and densities in these unusual but apparently important habitats, including knowledge of diving behaviour, is important for assessing encounter probability. Better understanding of sensory and motor capabilities and behaviour is important for quantifying evasion, quantifying collision risk and devising effective mitigation strategies. Improved understanding of the biology of marine mammals in these areas and the use they make of these special habitats is necessary for assessing the biological significance of any impacts. Some research can only be undertaken when turbines are installed and operational at sea. Other work, however, could be initiated immediately. The scale of research effort and monitoring required to make these assessments in a timely manner ahead of the main phase of development should not be underestimated.

Contents

Tables and Figures

Tables

Figures

1 Introduction and Background

1.1 Purpose

1.1.1 Stage 1 of the Marine Renewable Energy Strategic Framework for Wales (MRESF) was completed in September 2008 (RPS, 2008). The Framework is intended to provide for the sustainable development of marine renewable energy in Welsh waters. The report provided an overview of the data gaps highlighted during the Stage 1 study, together with an indication of the priorities for addressing these gaps in Welsh waters. In discussion with the project Steering Group, a number of Stage 2 studies were identified. As one of the recommendations from the Stage 1 study, a requirement for further evaluation of marine mammal collision risk with wave and tidal stream energy devices was identified.

1.1.2 The aim of this report is therefore to provide an objective assessment of the potential for marine mammals to collide with wave or tidal devices based on the available literature and our current understanding, including a review of existing impact prediction and monitoring data where available.

1.2 Scope

1.2.1 The scope of the study is limited to marine renewable devices that can be classed here as either wave energy converters (WEC) or tidal stream energy converters (TEC); with specific focus on the latter in this report given that these devices tend to having moving parts and therefore greater perceived risk for collision, although many of the other associated risks are applicable to both device categories. Two other reports also produced as part of MRESF Stage 2 were commissioned to look at collision risk for fish (ABPmer, 2010) and collision risk for sea birds (RPS, 2011). These reports provide a more complete treatment of the scope and purpose of these studies and are referred to in this report where appropriate. The MRESF is focused on Welsh territorial waters, i.e. from baseline (usually mean high water spring) seawards to the 12 nm limit, although many of the aspects discussed are more generally applicable.

1.2.2 At the time of writing this report, a Strategic Environmental Assessment (SEA) was being undertaken for the Severn Tidal Energy Project. This desktop review therefore, does not include information regarding the Severn Estuary as there is not the resource for other tidal stream energy converters within the area. The decision to exclude tidal range was made by the WAG in conjunction with the Steering Group.

1.2.3 A collision in the context of this report is considered to be an interaction between a marine mammal and a marine renewable energy device that may result in a physical injury (however slight) to the organism. A collision would therefore usually involve actual physical contact between a marine mammal and device or a harmful interaction with its pressure field (Wilson *et al*., 2007).

1.2.4 It can be useful to consider collision effects as being the product of several different components. In the first place, the probability of a marine mammal coming into proximity of an operating device depends on the distribution of marine mammals and the exact overlap with the locations of devices. Because devices occupy a particular range of water depths an animal's diving behaviour is also an important consideration. The degree of collision risk is likely to vary with the rate of movement of current devices (e.g. turbine blade rotation speed), and this varies with the tidal cycle. In addition, the potential for an animal to detect a device visually may depend on levels of daylight and water clarity. Thus, temporal as well as the spatial patterns of distribution are considered to be relevant.

1.2.5 Two other behavioural factors may affect the probability of a collision. At moderate ranges an animal might detect a device and respond to it. It may show avoidance, reducing the risk of an interaction, but it is also possible that devices could be attractive. The range at which an animal can detect a device using available senses and how this might be affected by environmental conditions is highly relevant to this aspect. At very short range animals might directly respond to, and evade, the moving parts of the device itself (for example, manoeuvring to evade the rotating blades of a turbine). Animals which pass through a turbine may or may not be struck by the blades. The size of the animal, its speed of movement and the number and speed of movement of the blades in the turbine all affect this probability. Finally, the physiological consequences of any collisions will also vary with factors such as the speed of the part of the device with which the animal makes contact and the part of the body which is hit. In the review that follows we explore each of these factors individually before bringing them together to comment on likely collisions risks and consequences.

1.2.6 The subsequent sections of this document are structured in the following way: Section 2 provides an overview of marine mammals in tidal areas and specifically in Welsh waters; Section 3 provides an overview of marine tidal devices; Section 4 a general overview of risk to marine mammals posed by marine renewable developments; Section 5 gives specifics on collision risks; Section 6 an overview of the sensitivity of different species and sites in Welsh waters; Section 7 potential mitigation methods; Section 8 identifies knowledge gaps and priorities for research; and finally, Section 9 provides a brief concluding statement.

2 Marine Mammals in Tidal Areas

2.1.1 A thorough review of the hydrodynamics, geology and ecological characteristics of high tidal current areas is provided in the fish collision risk report (ABPmer, 2010). Here we review additional information on the significance of these habitats for marine mammals. Globally, there are many examples of apparent "hotspots" for cetacean (mysticete and odontocete whales and dolphins) and pinniped (seal) that coincide with areas dominated by strong tidal streams (prominent examples include the Bay of Fundy: Johnston, *et al*. 2005a, b; Moray Firth: Hastie *et al*., 2006; Ramsey Sound: Pierpoint, 2008; North Devon: Goodwin and Speedie, 2008; and NE Pacific: Zamon, 2001). The definitive reasons why these areas are favoured are less clear, but the strong flows and associated eddy features are often cited. Such features are thought to aggregate prey and/or simply make them more available to marine predators (Johnston *et al*., 2005a). In addition, the inherent bottleneck characteristics of many areas of strong tidal flow are also likely to funnel transiting marine mammals and hence concentrate their abundance even if these sites have no attractive features in themselves (Wilson *et al.,* 1999).

2.1.2 In contrast, there are also high water flow areas that appear not to be attractive to marine mammals. For example, in their analysis of the distribution of harbour porpoise over a substantial portion of the west coats of Scotland, Embling *et al*. (2009) found a negative correlation between porpoise abundance and peak tidal flow. Unsurprisingly, such examples are less common in the scientific literature, partially because unremarkable marine areas tend not to be the focus of intensive field research. However, this apparent contradiction highlights the widespread lack of information on the probably complex relationship(s) between marine mammal abundance/behaviour and tidal streams, and the spatial and temporal scales on which they might occur.

2.1.3 To date, no specific synoptic studies of marine mammal and tidal-stream associations have been carried out. It is clear, however, that areas of interest for tidal-stream energy extraction have the potential to host elevated concentrations of foraging or transiting marine mammals.

2.2 Areas in Wales likely to be of interest as sites for tidal stream generation devices

2.2.1 Many tidal stream energy devices are designed to operate in current speeds around 2.5 m/s at the peak of a spring tide (Scottish Marine Renewable SEA, 2007) however exploitable tidal-streams are likely to range either side of this flow speed. The tidal stream exploited by the SeaGen device in the Strangford Lough narrows, for example, has tidal flows at speeds up to 4 m/s and peak flows at the European Marine Energy Centre, Orkney (a test centre for device development) are similar. The development of so-called "third-generation" turbines may also reduce the lower bound to exploitable speeds to > 2 m/s (Aquascientific, 2010).

2.2.2 At present there are operational limitations on the depth of water in which tidal devices can be sited. The maximum depth noted by tidal device developers during the Scottish SEA was 70 m, with most requiring water depths of 10 to 60 m; however some device specific information cites depths of greater than 100 m, (see RPS, 2008). As has been the case with offshore wind turbines, it is likely that the operating envelope of tidal stream devices, in terms of water depth, will grow over the coming years as the technology is improved upon.

2.2.3 As part of the overall MRESF project, the potential for commercial levels of wave and tidal stream energy within Welsh waters has been investigated (RPS, 2008). This work has indicated that the main tidal stream resources in Wales are based to the north and west of Anglesey, directly west of the Lleyn Peninsula, West of Pembrokeshire and from the Gower Peninsula eastwards into the Bristol Channel (Figure 2-1). Almost the entire exploitable wave energy resource is off Pembrokeshire. Several locations in Welsh territorial waters are already proposed or in use as test sites for wave or tidal stream devices Table 2-1.

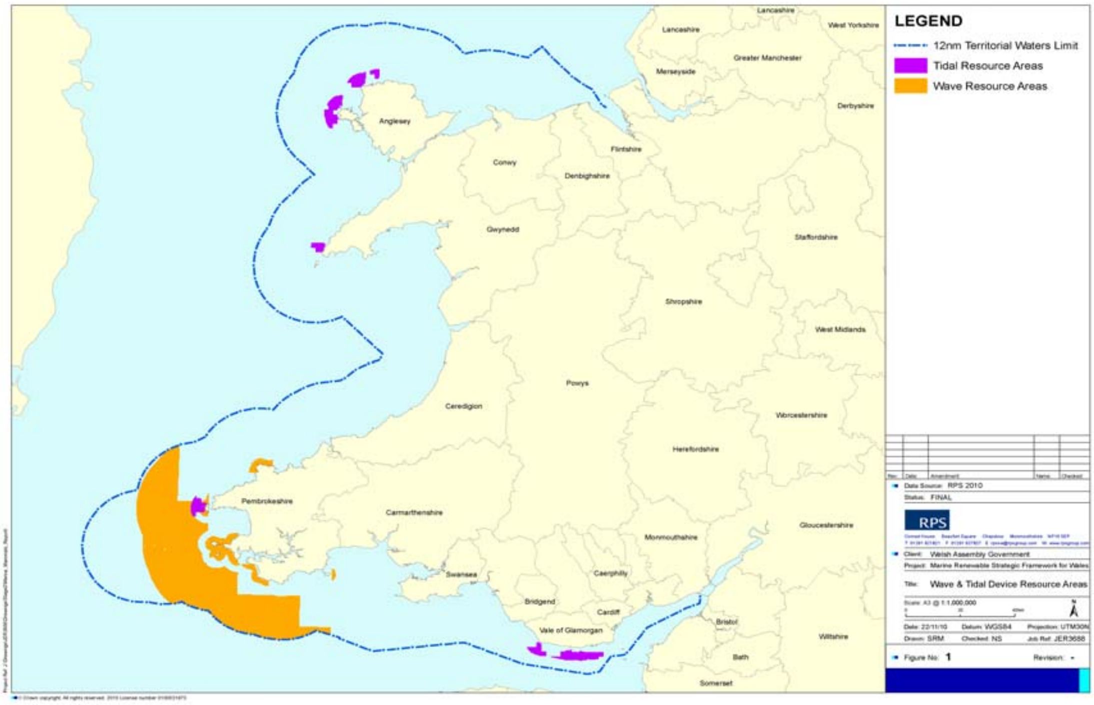

Figure 2-1 Areas identified as being suitable sites for tidal stream and wave generation as part of the MRESF project (RPS, in preparation)

Table 2-1 Identified interest in potential and actual marine renewable energy projects in Welsh waters (From ABPmer (2010), Based on information from: RPS, 2008)

Energy Group Type	Company	Location	Development Status
TEC	Lunar Energy	Ramsey Sound, St. David's, Pembrokeshire	Scoping study submitted October 2007.
	Marine Current Turbines and NPower Renewables - Skerries Tidal Stream Array	Between the Skerries and Camel Head on the Isle of Anglesey	Scoping Study submitted July 2006. Consents currently under consideration.
	Marine Current Turbines - South Stack Tidal Stream Array	2-3km from the west Anglesey Coast	Scoping Study submitted July 2006.
	Swan Turbines	River Tawe, Swansea	Tested scale model of Swan Turbine.
	Swan Turbines	Milford Haven	Investigating potential deployment in Milford Haven.

Energy Group Type	Company	Location	Development Status
	Swan Turbines	Strumble Head	Investigating potential through Feasibility Study.
	Tidal Hydraulic Generators Ltd	Tidal River Cleddau, possibly between Severn Crossings and/or Ramsey Sound, Pembrokeshire	Previous trials undertaken, recent linkage with Peter Brotherhood Ltd to install a full scale system (location unknown). Trials in Milford Haven complete.
	Unknown	Bristol Channel	Understood that data are being acquired by the Welsh Energy Research Centre for a potential tidal stream turbine site in the Bristol Channel.
	Tidal Energy Limited (TEL) - DeltaStream	Ramsey Sound	Scoping study submitted November 2008. Formal consents issued March 2011. Construction expected to commence 2012.
WEC	Wave Dragon Pre-commercial Demonstrator	1.7 km west of St Ann's Head at Long Point, Pembrokeshire	Environmental Impact Assessment (EIA) submitted April 2007.

2.3 Marine mammals in Welsh waters

2.3.1 Eighteen species of cetacean have been sighted in Welsh waters since 1990. Of these, five; the harbour porpoise *Phocoena phocoena*, bottlenose dolphin *Tursiops truncatus*, common dolphin *Delphinus delphis*, Risso's dolphin *Grampus griseus* and minke whale *Balaenoptera acutorostrata* can be considered relatively common. Others (such as killer *Orcinus orca*, and fin whales, *Balaenoptera physalus*) occur with less predictability and generally greater distance offshore, particularly the larger whales and deep diving species. One species of seal, the grey seal *Halichoerus grypus* makes regular use of Welsh waters and breeds at Welsh coastal sites. Here we provide a brief introduction to each of the most commonly encountered species before considering their populations in areas likely to be of interest for tidal turbine development in more detail.

Harbour porpoise *Phocoena phocoena*

2.3.2 The harbour porpoise is the smallest cetacean in European waters with adults ranging in size between 1.4 and 1.8 m. Females are slightly larger than males in this species. Porpoises are generally restricted to the continental shelf and are often found in shallow waters close to shore. They are generalist foragers feeding on a range of fish and cephalopods. Their broad and adaptable diet often varies regionally and temporally to exploit available resources. In many areas they are often believed to feed predominantly on the seabed. Porpoises have a relatively simple social organisation and are typically found singly or in small groups (less than five). This is the commonest small cetacean in Welsh waters, and indeed in the coastal waters of the temperate North Atlantic. It has a wide distribution being found in Eastern Atlantic shelf waters as far south as Senegal, while Iceland and Novaya Zemlya in the Barents Sea mark the northern extent. Porpoises also occur in the Baltic and sub species are common in the Pacific and Black Sea. The most recent survey in European waters, the SCANSII survey in 2005, estimated a North Western European population of 385,617 (Coefficient of Variation e.g. the length of time series of abundance estimates (CV) 0.20). Welsh waters fell within two of the SCANS survey blocks. The Irish Sea, with a population of 15,230 (CV 0.35) and density 0.335 (CV 0.35) animals per km^2; and the Celtic Sea population size 80,613 (CV 0.50) and density of 0.408 (CV 0.5) animals per km^2 (Hammond, 2006; Hammond *et al*. In Press).

2.3.3 One of the most significant threats to harbour porpoise populations in recent years has been from fisheries by-catch in bottom set gill nets. The authors are unaware of any fisheries with a substantial by-catch in Welsh coastal waters but in 1995 the by-catch in fisheries in the Celtic Shelf were estimated to be 1,500 per year (Donovan and Bjorge, 1995). Other threats include acoustic disturbance. Porpoises seem to be particularly sensitive to anthropogenic sound sources such as acoustic deterrent devices and pile driving, chemical pollution and vessel collision. Porpoises are predated by killer whales and in some areas they have also been harassed and killed by bottlenose dolphins.

2.3.4 Harbour porpoises are listed on Annex II of the Habitats Directive as being a species requiring designation of Special Areas of Conservation (SACs). Thus far no SACs have been designated for porpoises in UK waters but areas of Pembrokeshire have been suggested as strong candidates. Like all cetaceans, porpoises are also Annex IV, species in need of strict protection from killing, disturbance or the destruction of themselves or their habitat.

Bottlenose dolphin *Tursiops truncatus*

2.3.5 The bottlenose dolphin is a large delphinid reaching an adult body length of 2 to 4 m in UK waters. Males are larger than females. The species is very widely distributed being found in virtually all temperate and tropical seas in both inshore and offshore waters. Throughout its range it exhibits a substantial degree of variation in physical appearance and it is considered likely that several sub species will eventually be recognised. In many parts of the world, including the UK, there are distinct inshore and offshore forms. It is probably the best known and most completely studied of delphinids in the wild and also the species most often kept in captivity for research and display. Bottlenose dolphins have a well developed, complex and adaptable social organisation which has been extensively researched in various locations. Bottlenose dolphins are opportunistic feeders consuming a wide range of fish and cephalopod species. Some populations show specific foraging adaptations, often involving learned cooperative behaviours, in some cases involving cooperation with man.

2.3.6 In the North Atlantic bottlenose dolphins are found from the equator to the Faeroes and from shallow inshore lagoons and estuaries to the open ocean. The SCANS II survey, in 2005, estimated a population of 12,600 (CV 0.27) for Northern European waters. Estimates for the Irish Sea were 235 (CV 0.75) and for the Celtic Shelf 5,370 (CV 0.49). The species is widely distributed throughout coastal waters of North and West Wales with Cardigan Bay being a well known area with particular high densities. Photo identification studies provide an estimate for this inshore population centred on Cardigan Bay of 213 (95% confidence interval (CI) 182-279) (Baines *et al*. 2002) and confirm frequent movement of individuals between Cardigan Bay and North Wales as well as movements to waters off Cornwall.

2.3.7 Major threats globally include by-catch in fisheries, directed hunting, live capture for display and chemical pollution. In the northeastern Atlantic bottlenose dolphins are taken in drive fisheries in the Faeroes and pollutant loads have been shown to be high in some areas. Bottlenose dolphins are certainly vulnerable to entanglement in fishing gear but it is not yet possible to determine the cumulative rates or significance of impacts of by-catch on this species in the region.

2.3.8 Bottlenose dolphins are a cetacean species which is on both Annex II and Annex IV of the Habitats Directive. They are thus classed as both a species in need of strict protection and potentially as a qualifying interest for SAC designation. SACs for bottlenose dolphin have been established in Cardigan Bay. They are also protected from injury or disturbance under Schedule 5 of the Wildlife and Countryside Act.

Common dolphin *Delphinus delphis*

2.3.9 The common dolphin is rather smaller than *Tursiops* with a typical adult body length of 2-2.5 m. The species is widely distributed in the tropical and temperate waters of the Atlantic and Pacific Oceans with separate sub populations occurring in the Mediterranean and Black Seas. While groups can often be found close to shore the species has a more offshore distribution than bottlenose dolphins and porpoises. They are typically found in large schools with a dynamic composition, which can number in the hundreds or thousands.

2.3.10 Common dolphins feed on small schooling fish and squid and are often associated with frontal features and areas of upwelling that have high productivity. Like many oceanic delphinids, common dolphins are more vocally active at night (Goold, 2000) and probably forage more actively during the night than during the day.

2.3.11 In waters off Europe, the number of animals on the continental shelf was estimated to be 50,500 (CV 0.29) by the 2005 SCANSII survey (Hammond, 2006; Hammond *et al*. In Press). Numbers in the Irish Sea block were 825 (CV 0.78) and in the Celtic Shelf block they were 11,141 (CV 0.61). The zone from the break of the continental shelf to the 200 mile limit was surveyed during the CODA survey in 2007 and the total numbers of common dolphins off the European coasts was estimated to be 116,709 (CV 0.34) (Cañadas *et al.,* 2009).

2.3.12 Threats to the species worldwide include fisheries by-catch, substantial directed fisheries in some areas and competition with human fisheries for resources. In northern European waters common dolphin by-catch has occurred in seine nets, trawls, drift nets and bottom set gillnets. A by-catch of around 800 animals per year was estimated to be occurring in UK and French sea bass fisheries in the early part of the century, mortality in the UK fishery is now reported to have fallen considerably (Northridge, 2006). However, several other fisheries cause by-catch mortalities in these waters. We are not aware of any fisheries with particularly high by-catch rates operating in Welsh waters.

2.3.13 Common dolphins are listed on Appendix IV of the Habitats Directive, a species in need of strict protection from killing, disturbance or the destruction of themselves or their habitat. They are also protected from injury or disturbance under Schedule 5 of the Wildlife and Countryside Act.

Risso's dolphin *Grampus griseus*

2.3.14 This is a large dolphin with adults growing to 3 to 4 m in length. Males are somewhat larger than females. These dolphins have large prominent dorsal fins and unlike bottlenose and common dolphins, they have a blunt forehead and no beak. Adults are typically extensively scarred (apparently from interactions with each other) and these light coloured scars can give older animals an almost white colouration. Risso's dolphins are widely distributed throughout the tropical and temperate waters of the Atlantic, Pacific and Indian Oceans. In the North Atlantic they extend in coastal and shelf waters from the equator to Norway. However, within this range their distribution is quite patchy. Assemblages are often found associated with features such as sea mounts, island and underwater escarpments. Rissos's dolphins are specialist predators of cephalopod. They are generally believed to be deep divers and are thought to feed in deeper shelf waters down to 1000 m. In some locations, for example off Bardsey Island, North Wales, Risso's dolphins are regularly found close to shore; however, these may represent inshore resting aggregations.

2.3.15 There are no population estimates for the northeastern Atlantic and there were apparently no recorded sightings of Risso's dolphins during the SCANS or CODA surveys.

2.3.16 In some regions, Rissos's dolphins are directly hunted and may form a major component of fisheries by-catch but the species does not appear to be particularly prone to by-catch in UK waters.

2.3.17 Like all cetaceans, Risso's dolphin is on Appendix IV of the Habitats Directive and classed as a species in need of strict protection. They are also protected from injury or disturbance under Schedule 5 of the Wildlife and Countryside Act.

Minke whale *Balaenoptera acutorostrata*

2.3.18 The minke whale is the smallest of the balaenopterid (rorqual or finner whales) whales. Males reach a body length of around 9-10 m while females are slightly larger, growing to nearly 11 m in length. *B. acoustrostra* has a very extensive distribution extending from the northern and southern ice edges in the Atlantic, Pacific and Indian Oceans through the intervening tropical and temperate waters. However, as minke whales migrate their distributions will vary seasonally. They are thought to visit temperate polar waters to feed in the summer months and breed in warmer waters in the winter. Surprisingly little is known about their breeding behaviour but they are believed not to form large breeding assemblages and to spend much of the breeding season in offshore waters. Although they may be found in northern European waters minke whales are most abundant on the shelf and may be found in coastal waters and very close to shore in some places. Minke whales feed on small schooling fish and crustaceans (krill) and seem well able to adapt their diet to suit local conditions.

2.3.19 The SCANS surveys provided a population estimate for European coastal waters of 18,600 animals (CV 0.34). Estimates for the Irish Sea in SCANS II were 1,070 (CV 0.91) and for the Celtic shelf they were 1,719 (CV 0.43).

2.3.20 Minke whales are more heavily hunted than any other species of whale. Catches in the Antarctic by Japan are made under the guise of scientific whaling while in the northeast Atlantic both Norway and Iceland have continued to whale under objection with combined annual catches of around 600 animals in recent years. Other threats include fisheries interactions, including entanglement with creel lines and collision with high speed vessels.

2.3.21 Minke whales are included on Appendix IV of the Habitats Directive and classified as a species in need of strict protection within EC waters. Individuals are also protected from injury or disturbance under Schedule 5 of the Wildlife and Countryside Act. Whaling quotas are discussed at the International Whaling Commission.

Grey seal *Halichoerus grypus*

2.3.22 Grey seals are a medium sized moderately sexually dimorphic seal. Males grow to 2.5 m and weigh 300 kg or more while females are shorter at 1.8 m and weight 200 kg or less. Males start to breed at around ten years of age and can live for some 20 years. Females reach breeding age at about five years of age and can live for over 30 years.

2.3.23 The distribution of grey seals is restricted to the North Atlantic. On the western side of the Atlantic the centre of the population is in Canada and northeast USA. The majority of the population in the northeast Atlantic is in UK waters accounting for just under half of the world population and 95% of the EU population. Within the UK 90% of the population breeds in Scottish waters. In Scotland most breeding takes place on remote islands and isolated beaches from September through November. In Wales and the southwest breeding is earlier, in August and September, and often occurs in sea caves.

2.3.24 Grey seals are generalist feeders taking a variety of fish and cephalopod prey species. They are central place foragers, making foraging trips from land-based haul out sites. These trips can extend for up to 30 days, but on average last for 3 to 5 days. There is considerable inter and intra individual variability in preferred foraging areas and the lengths of foraging trips. Extended trips make take animals hundreds of kms offshore while on other occasions animals appear to repeatedly visit distinct "patches" which may we within tens of kms from the haulout site they are using. . Seal populations are normally assessed by counting the number of pups produced each year using aerial surveys. In 2008, pup production for the whole of the UK was 46,820 with the contribution from Wales being estimated at 1,650 pups.

2.3.25 Until recent times, grey seals were hunted commercially and bounties and organised culls were put in place to reduce their populations. Seals perceived to be interfering with nets are still shot by fishermen and aquaculturalist in some areas. There is also a substantial by-catch of grey seals in some fisheries. Grey seals carry a significant pollutant burden and there are concerns that this may increase their vulnerability to disease.

2.3.26 One recently recognised and possibly new hazard is worth mentioning. Seals with a characteristic suite of wounds consisting of a remarkably clean spiral cut severing the pelt and blubber have been washing up, mainly on the east coast of Scotland and off Norfolk (Thompson *et al.*, 2010). No “spiral” cut seals have been reported from Wales. The closest site with such mortalities is Strangford Lough in Northern Ireland. Common seals seem to be particularly vulnerable but substantial numbers of grey seals are included among the casualties. The mechanism leading to these lethal injuries is not fully understood but it seems very likely that they are caused by vessels with ducted propellers. There is as yet no suggestion that tidal turbines represent a similar hazard but construction, support and maintenance work is likely to involve vessels with ducted props, including dynamically positioned vessels.

2.3.27 Grey seals are listed on Annex IIof the Habitats Directive and they are classed as a potentially qualifying interest for SAC designation. Several SACs have been proposed with grey seals as the primary feature and one of these, the Pembrokeshire Marine SAC, is in Wales. Grey seals are also listed as secondary qualifying features at two additional Welsh sites, Cardigan Bay and the Lleyn Peninsula and Sarnau SAC.

2.4 Marine mammals in Welsh high tidal energy areas

2.4.1 Knowledge of the distributions and densities of marine mammals in areas that are potential sites for underwater marine renewable installations is relevant to assessing the likelihood of animals coming within close proximity to devices, which is a component of collision risk. Levels of local populations also provide a context for the implications of damage from collisions and/or disturbance and exclusion.

2.4.2 A recent publication, The Atlas of Marine Mammals of Wales (Baines and Evans, 2009) presents information on marine mammals in Welsh waters based on the analysis of data collated from a number of effort-related sighting surveys in Welsh waters which were made available by a variety of research and conservation groups. The majority of these data have come from surveys conducted using platforms of opportunity, such as ferries, and from small scale surveys carried out by a range of small research groups and NGOs. Some data collected by shore based lookouts were also included, though the spatial coverage of this is inevitably limited. The disparate nature of these data posed some methodological problems to the authors' attempts to combine datasets and not all of these were fully resolved. Even so, this timely publication provides the most-up-to date and relevant information on the distribution, abundance and seasonality of marine mammals in Welsh waters and adjacent seas, and is probably the most complete analysis of this type for any of the UK regions.

2.4.3 For the five most commonly sighted species, harbour porpoise, bottlenose dolphin, common dolphin, Risso's dolphin and minke whale, data were plotted on a spatial grid of 10' x 10' (approximately 18.5 km N/S by 11.2 km E/W) (see Figures 2-2 to 2-6). This scale is too coarse to provide a detailed perspective on cetacean densities at the sites of individual marine renewable installations. However, combining the maps in this Atlas (Baines and Evans, 2009) with those generated by the MRESF project, giving areas of potential tidal stream resource (Figure 2-1) does afford a first indication of levels of cetacean densities in these areas and an indication of the potential for interactions between marine mammals and possible sites for tidal device deployments. To be able to understand the potential risk on a finer scale, more detailed marine mammal distribution data are required. As part of Stage 2 of the MRESF, new, fine scale survey and telemetry work was conducted within two areas likely to be of particular interest as sites for tidal turbines (off the Skerries and south and North Stacks to the north and west of Anglesey and in Ramsey Sound and to the west of the Bishops and Clerks islands in Pembrokeshire). These studies aimed to provide information on the distribution and densities of marine mammals within these sites at a fine scale appropriate for assessing encounter probabilities with underwater marine renewable devices. Results of this work are fully described in Gordon *et al.* (2011). Boat based visual and acoustic surveys in July and August combined with monitoring using static acoustic detectors (PODs) provided most of the cetacean data. For grey seals, the majority of information has come from fine scale satellite telemetry of newly weaned animals which were tagged at breeding beaches at the Skerries in Anglesey and Bardsey Island off the Lleyn peninsula. As these animals moved to other areas after tagging, data from some other high tidal current areas in Wales (and elsewhere) were also collected.

2.4.4 Another substantial survey effort carried out in conjunction with a tidal turbine development has been a series of shore based visual surveys in Ramsey Sound (Barradell, 2009).

2.4.5 Here, we briefly review information on marine mammal distributions within each of the four high tidal energy areas identified above, drawing on the species summaries provided in the Atlas of Marine Mammals of Wales (Baines and Evans, 2009), as well as recent directed surveys and on other publications where appropriate.

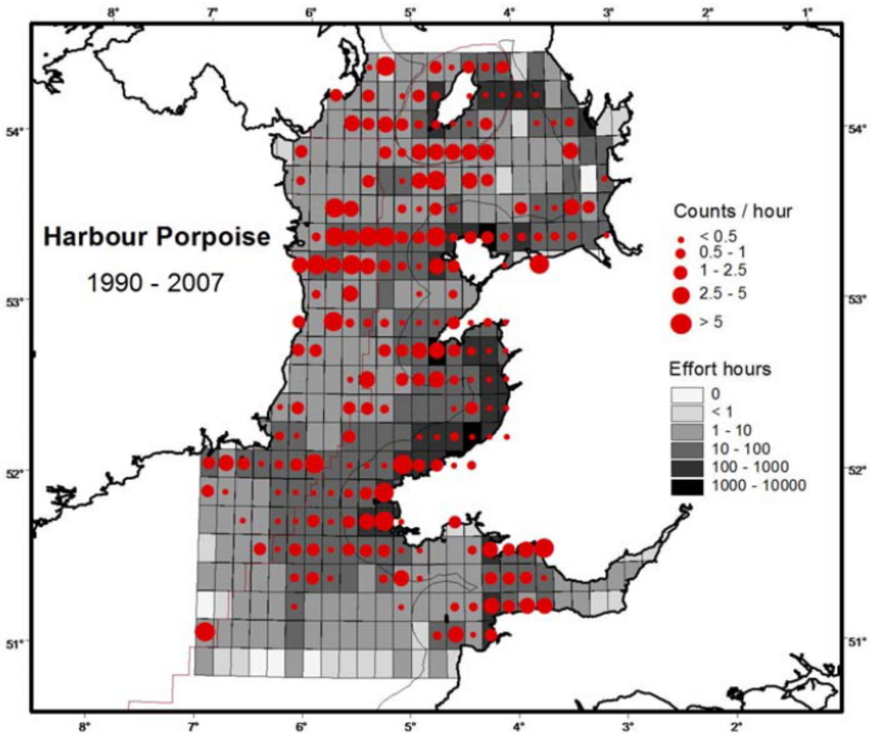

Figure 2-2 Long term interpolated sightings rates of harbour porpoise (from Baines and Evans, 2009)

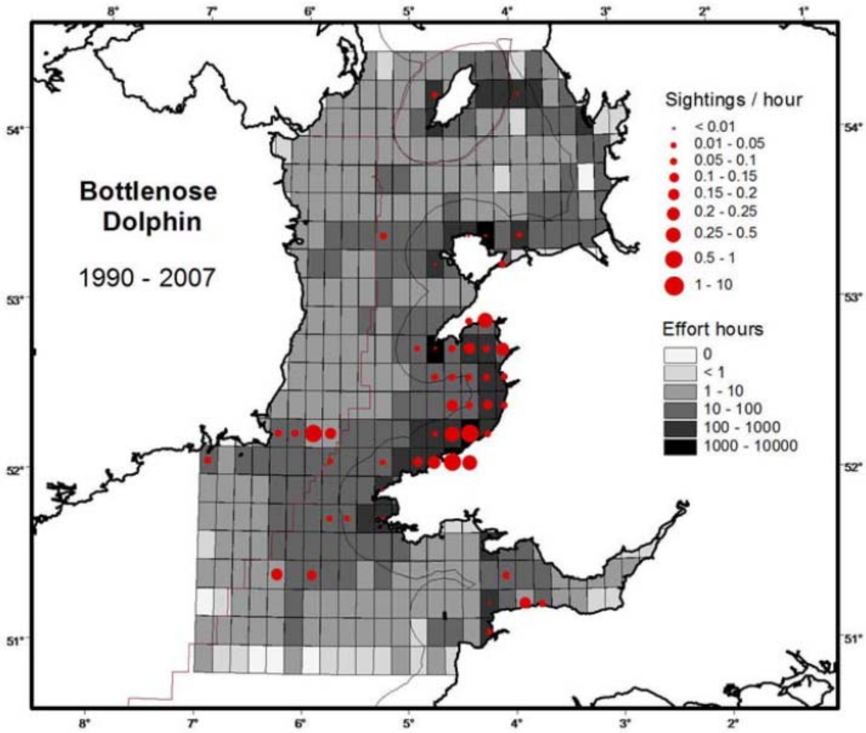

Figure 2-3 Long term interpolated sightings rates of bottlenose dolphins (from Baines and Evans, 2009)

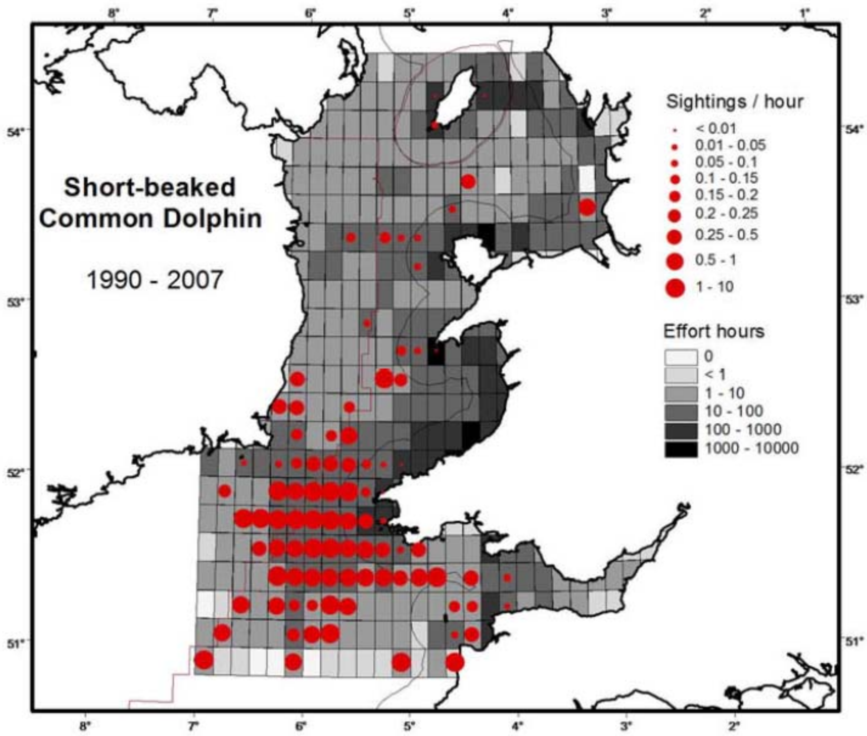

Figure 2-4 Long term interpolated sightings rates of common dolphin (from Baines and Evans, 2009)

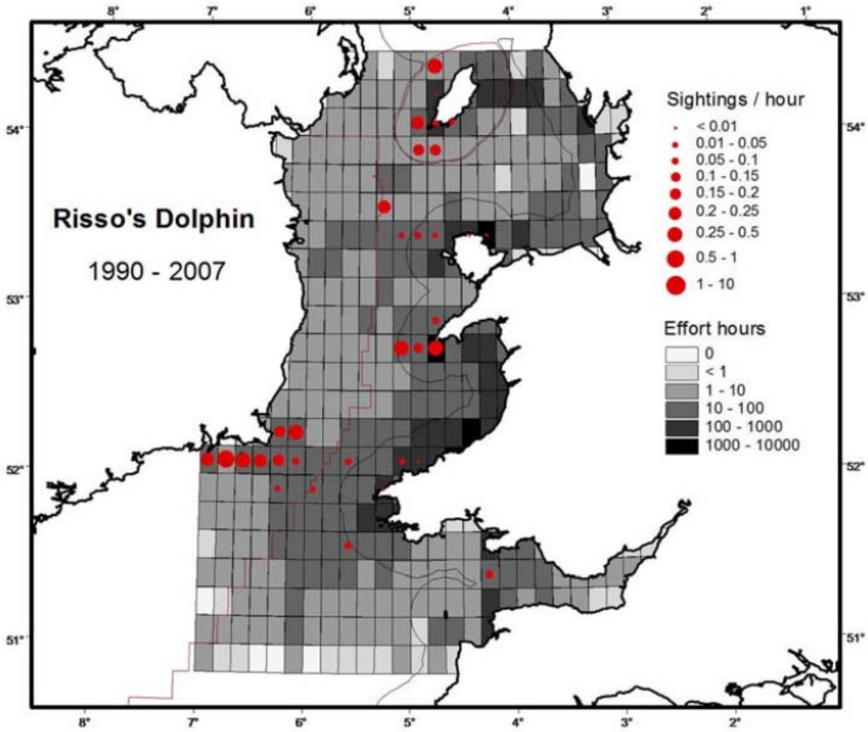

Figure 2-5 Long term interpolated sightings rates of Risso's dolphins (from Baines and Evans, 2009)

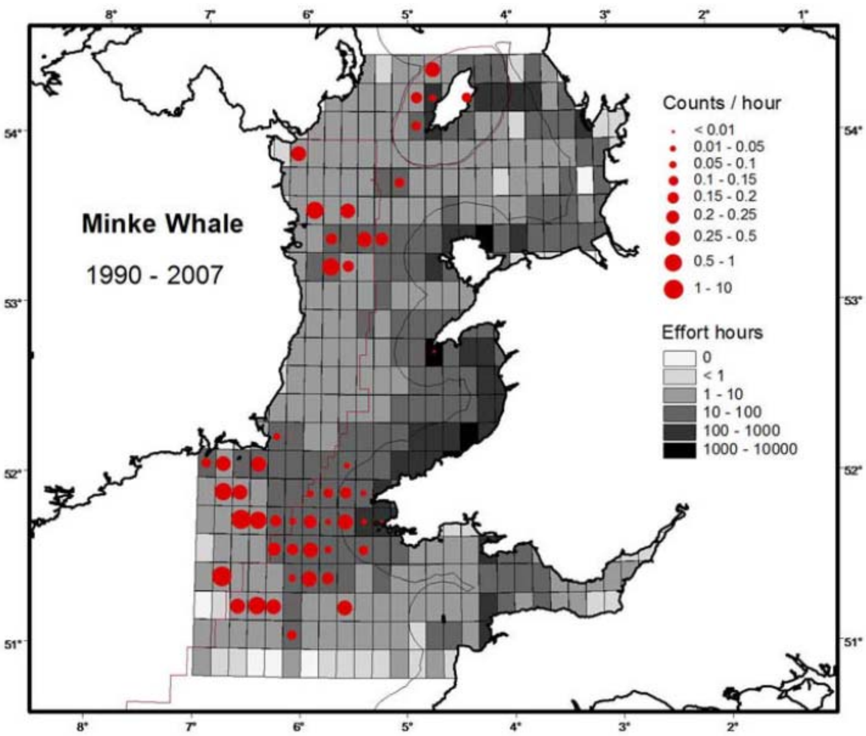

Figure 2-6 Long term interpolated sightings rates of minke whales (from Baines and Evans, 2009)

North and west of Anglesey

2.4.6 The area to the north and west of Anglesey is indicated by the Marine Mammal Atlas (Baines and Evans, 2009) as an area of moderate porpoise density with counts of between one and five animals per hour (Figure 2-2). However, high density counts have been recorded on towed hydrophone detection surveys on tidal rapid areas between the Skerries and Carmel Head and have only been exceeded by those recorded in tidal rapids off Pembrokeshire as part of the same study, and surveys conducted in the Baelt and Keil Bight in the Western Baltic. Sightings of bottlenose dolphins are relatively low in this area (<0.15 per hour) (Figure 2-3). The few sightings of common dolphins here have tended to be offshore (Figure 2-4). Risso's dolphins have rarely been sighted and no sightings of minke whales are recorded in the Atlas (Figure 2-5).

2.4.7 A series of dedicated line transect surveys covering the waters off the northern coast of Anglesey extending from the 10 m isobaths out to approximately 10 km offshore (Shucksmith *et al.,* 2009) are particularly relevant. Shucksmith *et al.,* (2009) calculated a porpoise density of 0.63 porpoises per km^2 for the area overall, assuming that g(0) was 1, i.e. all animals on the track-line were seen. However, they argue that g(0) may have been as low as 0.5 (i.e. 50% of animals on the track line were missed in which case the density would be double this value. The authors also noted that the sighting rate fell off with distance from the shore and that variance was high; perhaps indicating a high variability in density related to complex oceanographic conditions. Their survey area was divided into five blocks running along the coast. Two of which covered areas with strong tidal currents that have already attracted interest as sites for tidal turbine installations (South Stacks and Carmel Head/Skerries) which had, respectively, the second and third highest densities of 0.289 and 1.267 individuals per km^2 (assuming a g(0) of 1). This, together with the trend for sighting rates to be higher closer to the shore (noted above), suggests a substantial potential for interaction between turbines and porpoises in this area.

2.4.8 Calderan (2003) conducted a series of land based surveys at a site close to Middlemouse Island to the east of the Skerries. She found that harbour porpoise presence and apparent foraging behaviour at the site were strongly dependent on the state of tide, with the highest densities and levels of activity being during the flood phase.

2.4.9 Dedicated surveys focused on tidal rapid areas between the Skerries and Carmel Head and, to a lesser extent off the coast between North and South Stacks, were conducted over a three week period in July 2009 (Gordon *et al.*, 2011). Poor weather conditions at the time meant that the majority of detections were made using passive acoustic systems; with both towed hydrophone surveys (comprising 607 nm of track line) and monitoring using five static detectors (PODs) being undertaken. The vast majority of detections were of harbour porpoises. The towed hydrophone surveys were designed to provide a fairly even spatial and temporal coverage, with the aim being to cover all areas at all states of the tide. These surveys confirmed that porpoises make use of tidal rapid areas through all states of the tide and that local densities appear to be high (see data summarised in (Table 2 2). The towed hydrophone detection rates reported here have only been exceeded by those recorded in tidal rapids off Pembrokeshire as part of the same study, and surveys conducted in the Baelt and Keil Bight in the Western Baltic. Estimated densities were are as high as those reported from Scotland during the SCANSII surveys (Hammond, 2006; Hammond *et al.,* In Press). It should be noted that these density estimates would have been substantially higher if an allowance for g(0) had been made.

Table 2-2 Comparisons between detection rates and estimated densities measured from the two study areas during this study (Gordon et al., 2011) and those reported from other areas

Detection rate and density comparison						
Region	**n**	**Effort**	**n/100km**	**Density (assuming group size = 1.5 eshw = 186 m)**	**Survey type**	**Source**
Bishops and Clerks	82	232	35.3	1.43	Acoustic	Gordon *et al.,* 2011
Skerries	57	607	9.4	0.38	Acoustic	Gordon *et al.,* 2011
Kiel Bight	52	494	10.5		Acoustic	Gillespie *et al*., 2005
Little Belt	49	291	16.8		Acoustic	Gillespie *et al*., 2005
Southern North Sea, 2001	81	1267	6.4		Acoustic	Gillespie *et al*., 2003
Southern North Sea, 2002	9	598	1.5		Acoustic	Gillespie *et al*., 2003
English Channel 2001	9	433	2.1		Acoustic	Gillespie *et al*., 2003
SCANSII - Irish Sea				0.34	Aerial	Hammond *et al*., In Press
SCANSII - W coast of Scotland				0.39	Aerial	Hammond *et al*., In Press

Detection rate and density comparison						
Region	**n**	**Effort**	**n/100km**	**Density (assuming group size = 1.5 eshw = 186 m)**	**Survey type**	**Source**
SCANSII - English Channel				0.33	Aerial	Hammond *et al*., In Press
SCANSII – Southern North Sea				0.51	Visual ship	Hammond *et al*., In Press

2.4.10 Within the study area, densities appeared to be highest in the strongest tidal rapids area between the Skerries and Carmel head. Detection rates were significantly affected by rate of tidal flow and water depth (Gordon *et al.,* 2011).

2.4.11 Analysis of data from PODs (static acoustic monitoring devices) revealed substantial variability in detection rates between different sites that were within a few km of each other. There were also significant tidal and diurnal patterns in the data which were often quite different at different sites. There were some indications that porpoise occurrence was highest in turbulent "flushing out" areas down stream of the strongest current. The authors speculated that these data may indicate a degree of fine scale and potentially predictable variability in distributions and densities which had not been captured or explained by the towed hydrophone surveys. A better understanding of such variability could be used to help site devices to reduce encounter risk with porpoises.

2.4.12 Gordon *et al.* (2011) also report on research using a vertical hydrophone array to calculate the depth at which porpoises vocalised. This was a proof of concept study and the results were thus sparse and preliminary, but they indicated that porpoises were diving to the bottom in these areas and were thus using the whole water column.

2.4.13 Dedicated boat based surveys and shore watches directed towards bottlenose dolphins have also been conducted along the northern coast of Anglesey (Pesante *et al.,* 2008). Bottlenose dolphins were found along the length of the coast, usually very close to the shore. Photo-identification techniques were used to identify individual dolphins. Some 64 well marked individuals were identified and 91% of these had already been seen within the Cardigan Bay SAC (established for bottlenose dolphins), demonstrating a degree of connectivity between these two areas.

2.4.14 Grey seals haul out at a variety of small islands and at sheltered mainland sites along the North Anglesey coast. These are Ynysoedd y Moelrhoniaid/The Skerries, Ynys Cybi/Holy Island (comprising sites between Ynys Lawd/South Stack and the harbour at Holyhead), Trwyn y Gader/Carmel Head (consisting of sites between Cemlyn Bay and Church Bay), and islands on the east coast, Ynys Dulas and Ynys Seiriol/Puffin Island (Westcott and Stringell 2004). Haul out numbers at each site varied from day-to-day and also showed seasonal trends however, over a hundred seals might be hauled out along this coast at any one time. Pup production was assessed by Westcott and Stringell (2003). During surveys in 2003, they counted 35 pups in sea cave sites on Ynys Cybi/Holy Island (mainly along the coast between South Stack and Holyhead harbour), 15 pups on Ynysoedd y Moelrhoniaid/The Skerries and two at Trwyn y Gader/Carmel Head. Neither sightings data in the Atlas (Baines and Evans, 2009) nor modelling based on satellite tracking (Hammond *et al.,* 2005) suggest high densities of seals at sea in this area.

2.4.15 A telemetry project investigating the fine scale movements of newly weaned grey seal pups tagged in North Wales is ongoing. However, some preliminary results from five weaners tagged in October 2009, three from the Skerries, Anglesey and two from Bardsey Island, off the Lleyn peninsular are summarised in Gordon *et al.* (2011). A typical pattern was for pups to spend the first two to six weeks foraging close to their natal beaches. In all three cases foraging has been almost entirely restricted to waters within 10 km of the shore and within 30 km of haul-out sites. A common pattern was for animals to spend time in tidal rapids areas, apparently drifting to and fro with the tide and diving down close to the bottom in a pattern characteristic of foraging in grey seals. One of the Anglesey seals moved to the Lleyn Peninsular after a few weeks and established the same pattern of behaviour within the tidal rapid area there. Whether or not this clear tendency to utilise tidal rapid areas will continue as these animals mature is as yet unknown.

West of the Lleyn Peninsula

2.4.16 The Welsh Marine Mammal Atlas (Baines and Evans, 2009) indicates that this is an area that has received a high level of survey effort and also shows high porpoise detection rates (2.5-5.0 sightings per hour) (Figure 2-2). Bottlenose dolphins were also sighted during surveys in this area which is towards the northern edge of the well-documented concentration of bottlenose dolphins in Cardigan Bay (Figure 2-3). Common dolphins were reported here at rates as high as 0.14-0.20 per hour, with most sightings in more offshore waters (Figure 2-4). The waters around and to the west of Bardsey Island are highlighted in the Atlas (Baines and Evans 2009) as being the most prominent "hotspot" in Welsh waters for Risso's dolphins with sighting rates as high as 0.25-0.5 per hour (Figure 2-5). Risso's dolphins have also been regularly reported by the Bardsey Bird and Field Observatory and are the subject of a long term photo-identification study by the Whale and Dolphin Conservation Society (WDCS) and Friends of Cardigan Bay (FoCB) (De Boer, 2009). In addition, they are an important part of the island's ecotourism offering. There have been few if any sightings of minke whales in these waters (Figure 2-6).

2.4.17 The most important grey seal haul out sites in this area, and indeed in North Wales as a whole, are found on the West Hoyle sandbank, where counts of hauled out seals have exceeded 800 individuals. Seals use beaches and sea caves as both general haul out sites and for pupping. Westcott and Stringell (2003) counted 45 pups at sites on the Lleyn Peninsular in 2002 and a further 13 on Bardsey Island. Both sightings (Baines and Evans, 2009; Figure 2-7) and analysis of satellite telemetry data (Hammond *et al.,* 2005) suggest that grey seals spend time in the high tidal energy waters in this area.

2.4.18 Preliminary results from high resolution satellite telemetry of seals (Gordon *et al.,* 2011) show that two weaned pups tagged at Bardsey spent their first two weeks of life foraging close to their natal beach diving close to the bottom as if feeding. A typical pattern was for them to move to and fro in areas of high tidal current apparently drifting with the tide. One of the pups tagged at Bardsey travelled to Wexford in southern Ireland and then as far south as Brittany before returning to Cornwall where it was recaptured and taken into a rehabilitation centre on 26th December 2009.

2.4.19 The Lleyn Peninsula Sarnau SAC covers some of the inshore waters of high tidal energy at this location and also extends well to the east into Cardigan Bay. Bottlenose dolphins and grey seals are noted as Annex II species present as qualifying features of the SAC (www.jncc.gov.uk/ProtectedSites/SACselection/sac.asp?EUCode=UK0013117).

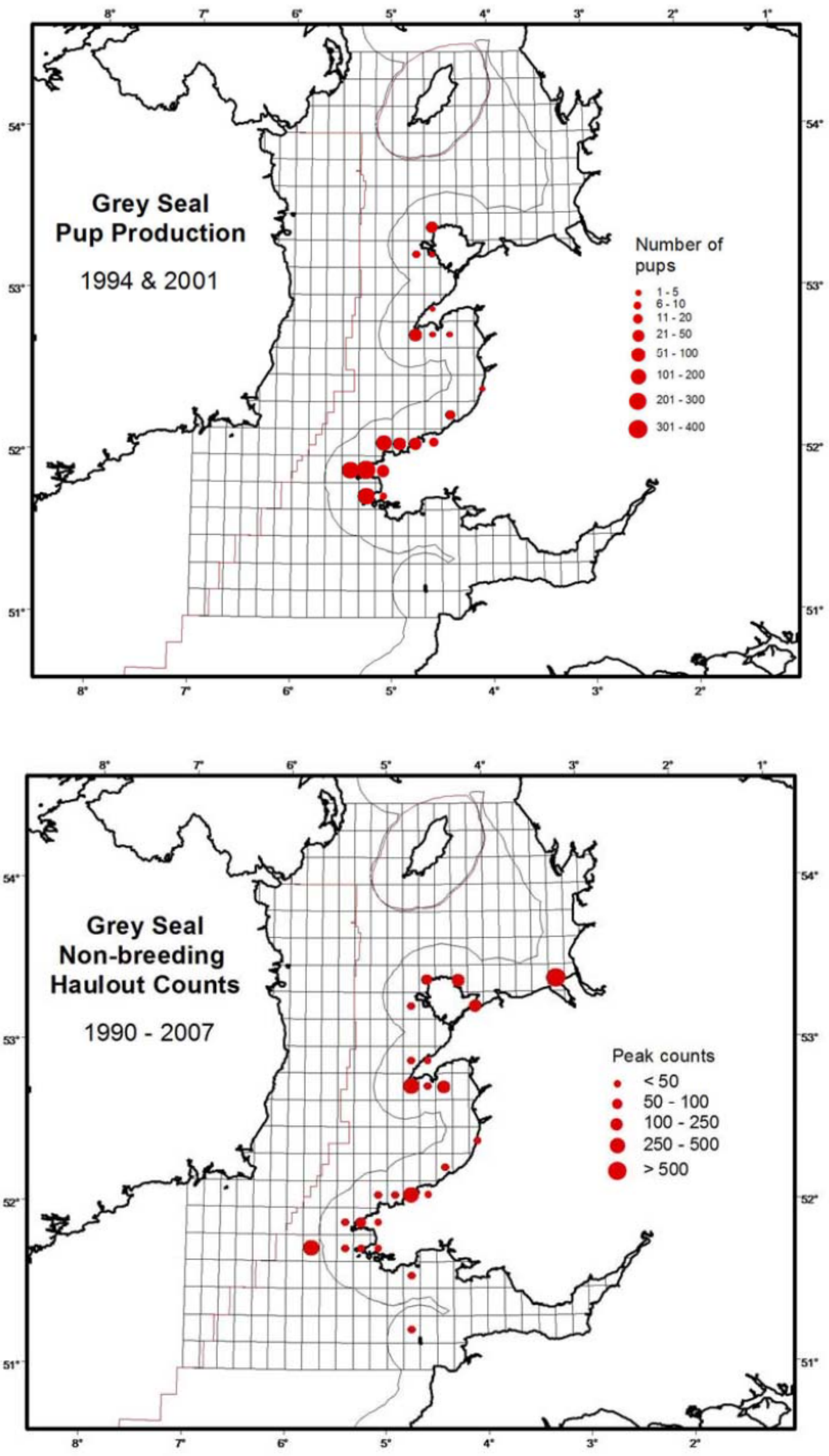

Figure 2-7 a) Grey seal pup production and b) Counts of grey seals at haul-out sites during non-breeding season (from Baines and Evans, 2009)

West of Pembrokeshire

2.4.20 Like those of the Lleyn Peninsula, the waters west of Pembrokeshire provide some of the highest levels of porpoise encounter rates found anywhere in Wales, with average count rates as high as five an hour (Figure 2-2; Baines and Evans, 2009). Bottlenose dolphins are also reported here, but encounter rates reported by Baines and Evans (2009) are low (generally less than 0.1 sightings per hour) (Figure 2-3). Common dolphins are often sighted in the summer months, with sightings rates exceeding 1 an hour in some areas. The waters off Pembrokeshire lie on the north eastern edge of a substantial concentration of common dolphins which the Marine Mammal Atlas (Baines and Evans, 2009) shows straddling the southern section of the Irish Sea over the Celtic Deep through the summer and autumn months (May-November), coinciding with the location of the Celtic Sea Front and also coming well within Welsh coastal waters (Figure 2-4). The Atlas suggests that Risso's dolphins are rarely sighted in this area although there are a number of strandings recorded for this species (Figure 2-5). The most substantial concentration of minke whales in Welsh seas is found in these waters, extending to the west into the Celtic Deep, over much the same area as the common dolphin concentration, with densities in these more offshore areas reaching 0.2 counts per hour (Figure 2-6). Seasonally, minke whale sightings extend from May through to November.

2.4.21 The waters off Pembrokeshire have been identified of being of particular importance for harbour porpoises within the UK (Evans and Wang, 2002) and this is supported by results presented in the Welsh Marine Mammal Atlas (Baines and Evans, 2009). The species is believed to breed locally (Penrose and Pierpoint, 1999); approximately 24% of schools observed in July included neonate calves.

2.4.22 Several studies have investigated the distribution and behaviour of porpoises in areas of high tidal current in this area. Pierpoint (2008) used shore-based observation to investigate the behaviour and distribution of porpoises foraging in areas of very high tidal flow in and around Ramsey Sound. He found that porpoises, which appeared to be foraging and were often accompanied by feeding seabirds, were seen almost exclusively during the south-going ebb tide in an area just to the south of the Sound above a steep-walled trench. He suggested that topographical features might concentrate prey in these areas. Similar but more extensive shore based observational effort has been continued at Ramsey Sound by Barradell (2009). His year-round surveys have shown that porpoises use the Sound on a daily basis throughout the year. Like Pierpoint (2008), he observed porpoise foraging activity to the south of the Sound during the ebb tide.

Foraging activity was also observed to the north of the Sound during the north-flowing flood tide, though for shorter periods. Observations suggested that animals moved through the Sound between foraging areas.

2.4.23 As part of focused surveys conducted as part of Stage 2 of this project, six passive acoustic detectors, PODs were deployed in with the Ramsey Sound system in August and September 2009 (see Gordon *et al.,* 2011). Analysis of acoustic detection rates for porpoises confirmed the occurrence of porpoises in the tidal rapid to the south of Ramsey Sound during ebb tide (as reported by Pierpoint, 2008) and also indicated that porpoise detections were higher during the flood tide to the north of this tidal rapid. This is consistent with the hypothesis that more turbulent waters down stream from areas of maximum flow are preferred. The data also revealed a marked diurnal pattern with detection rates being higher at night than during the day (Gordon *et al.,* 2011).

2.4.24 The same team also conducted towed hydrophone surveys in a block outside Ramsey sound to the west of the Bishops and Clerks (Gordon *et al.,* 2011). Porpoise acoustic detection rates and calculated densities were higher here than have been reported for any other locations (Table 2-2). Within the survey block there was considerable variability in densities with water depth, distance from surface tidal features and tidal phase being significant predictors in a model of relative density (Gordon *et al.,* 2011).

2.4.25 Isojunno (2008) analysed sighting data collected by dedicated observers and skippers on rigid hull inflatable vessels during ecotourism and ferry journeys around Skomer Island. She found that, in this area, porpoises preferred deeper waters. They avoid steeply sloping seabeds on flooding tides but seemed to prefer them on ebbing tides. These tide-dependent relationships may be indicative of the type of fine scale foraging patterns, exploiting flows around particular topographical features, suggested by the studies in Ramsey Sound (e.g. Pierpoint, 2008; Barradell, 2009).

2.4.26 Two publications present results from dedicated surveys for common dolphins in this area; Goold (1998) and Earl *et al.* (2004). Goold (1998) analysed detections of common dolphins made during a series of regular acoustic surveys conducted between September and December 1995 in a 100 nm^2 block in the northwestern portion of these waters (Goold, 1998). The spatial and temporal occurrence of dolphin detections corresponded well with the strength and location of the Celtic Sea Front, indicated by concurrent satellite images of sea surface temperature. Results from a series of visual surveys conducted from boats over two years (2001 to 2003), but excluding the winter months of December to February, are presented by Earl *et al.* (2004). They confirmed a seasonal peak in sightings in late summer and early autumn evident in both the Atlas (Baines and Evans, 2009) and Goold's (2008) data. Gordon *et al.* (2011) also report several encounters with common dolphin schools during surveys within a high tidal current area to the west of the Bishop and Clerks islands off the Pembrokeshire peninsular.

2.4.27 In recent years occasional but spectacular sightings of feeding groups of fin whales have been made in these waters (Anon 2005; Anon 2009). It is possible that these represent a trend towards a more frequent occurrence of large whales in this area, or increased sightings may be due to greater human activity in these areas and increased awareness.

2.4.28 Ramsey Island and beaches on the north Pembrokeshire mainland account for most of the grey seal reproductive output in Wales. In 2005, pup production was estimated to lie between 258 and 350 on Ramsey and 145 and 198 on the mainland (Strong *et al*., 2006). The Marine Mammal Atlas of Wales (Baines and Evans, 2009) shows significant numbers of sightings of seals in the immediate offshore waters and this pattern of use is also evident in the satellite tracking data summarised in Hammond *et al.,* (2005).

2.4.29 The Pembrokeshire Marine SAC (http://www.jncc.gov.uk/ProtectedSites/SACselection/sac.asp?EUCode=UK0013116) covers much of the area of high tidal energy to the west of Pembrokeshire. Grey seals are listed as an Annex II species that are a primary reason for the designation of the site.

2.4.30 Marine mammals, in particular porpoises and grey seals, are important features for boat based ecotourism trips operating in Ramsey Sound and around Skomer and they figure prominently in the promotion of tourism for this area.

Bristol Channel east of the Gower Peninsula

2.4.31 The Atlas of Marine Mammals of Wales (Baines and Evans, 2009) shows this area to be relatively poorly covered especially in its eastern sections where tidal energy is greater. It has received the lowest amount of survey attention of any of the high tidal energy areas within Welsh waters. Even so, the Atlas does indicate an area of high porpoise density in a band extending to the south from the coast between the Gower Peninsula and Cardiff across the mouth of the Bristol Channel to North Devon (Figure 2-2). This coincides with the westerly edge of the high tidal energy area in this region (Figure 2-1). There are also some sightings of bottlenose dolphins in this area, especially towards the English Coast (Figure 2-3). Neither common nor Risso's dolphins seem to extend further east than the Gower Peninsula and there have also been no recorded sightings of minke whales here (Figure 2-4, Figure 2-5 and Figure 2-6 respectively).

2.4.32 A year round project to investigate porpoise distributions in the area between Carmarthen Bay and Swansea Bay collected data using static and towed acoustics and boat and shore based visual observations is reported by Watkins and Colley (2004), with the work extended as part of the application for an offshore wind farm at Scarweather Sands. Porpoises were recorded in the area year round with several apparent hot spots being identified. There are no indications that these waters are heavily used by seals.

3 Tidal Stream Energy Devices

3.1.1 There are a wide variety of tidal-stream energy extraction devices currently in development. These vary both in their basic energy extraction concepts (e.g. lift vs. Venturi vs. drag devices) and in their specifics including water depth requirements; water column position; extent of surface piercing; methods of seabed mooring/attachment; installation techniques; extent and velocity of exposed moving parts; size and seabed footprints; noise emissions; potential pollutants used and maintenance/ decommissioning requirements (RPS, 2008; Scottish Marine Renewables SEA, 2007).

3.1.2 Although some environmental interactions such as removal of the tidal energy itself, cable runs, maintenance boat access, anchoring and fisheries exclusions are likely to be generic, it is anticipated that, given the variability between device types, the majority of issues relevant to marine mammals will vary depending on the particulars of the individual devices.

3.1.3 Tidal energy generation falls into two broad categories. Tidal range devices utilise changes in water level (include tidal barrages and lagoons) and as tidal range devices are excluded from the MRESF (see RPS, 2008) will not be considered further here. Tidal stream devices exploit the kinetic energy within the tidal flow itself. Most devices exploiting the tidal stream work much like wind turbines but are driven by flowing water rather than air. Because water is much (800x) denser than air, equivalent amounts of energy can be extracted at lower flow rates but cavitation becomes a constraint. This phenomenon occurs when flow speeds around a device exceed a critical threshold and produce transient vapour bubbles. This cavitation can lead to significant mechanical damage. Consequently, tidal-stream devices are smaller and rotor speeds are lower than conventional wind turbines (EMEC, 2010).

3.1.4 There are currently three main types of tidal stream tidal devices: horizontal axis turbines; vertical axis turbines and Venturi devices. Horizontal axis turbines are the most common technology type being progressed and most look broadly similar to wind turbines. Turbine blades rotate around a horizontal axis to drive a generator. The turbine may be shrouded increasing tidal flow through the turbine and better aligning the presentation of water to the blades. Foundation strategies vary from gravity bases through monopiles, hanging from surface barges or floating while tethered to fixed seabed anchor points. Devices may exploit alternate directions of flow (i.e. flood vs. ebb) by physically swinging around, adjusting blade angles or using paired turbines with each accepting unidirectional flow. The number of turbine blades is variable from two to many; with three currently the most common. There are many variants on these themes including devices with sets of counter-rotating blades mounted one in front of the other or blades supported by a doughnut-shaped structure with an open centre.

3.1.5 There are fewer vertical axis turbines in development than horizontal axis turbines and generally these are in more basic stages of development. Mounting options, the number of blades and the configuration of the blades also vary between devices.

3.1.6 Venturi devices are horn-shaped tubes through which water is directed to flow. In passing through the constriction the water speeds up creating reduced pressure which sucks air from the surface through a turbine to drive a generator.

3.1.7 In addition, several other concepts have been introduced including horizontal but transverse to flow rotation turbines combining both lift and drag energy extraction (e.g. the Aquascientific marine turbine), oscillatory motion hydroplanes (EMEC, 2010) and so on. The majority of devices are currently in the prototype stage but eventual commercial scale machines are expected to have generating capacities ranging from 40 kW to around 2 MW per device. Depth requirements also vary between device types, and though all marine mammals in Welsh coastal waters will be capable of reaching the entire water column of interest to tidal-energy extraction, the vertical extent of devices is likely to have implications for how marine mammals actually interact with them. Bottom-mounted devices can operate in depths of 40 to 50 m or deeper, and have the capacity for no surface expression. Thus marine mammals will be able to pass directly over the top of these. Conversely, devices hung from surface barges will have their clearance below them. Surface-piercing piled devices will occupy the entire water column with economic deployment depths currently in the 20 to 50 m depth range. Most devices could be scaled to shallower water depths and some devices are being specifically developed to operate in waters too shallow for conventional shipping. In such cases, bottom or surface mounted devices may have insufficient clearance to allow animals to pass above or below them and hence act as if they were surface-piercing bottom mounted devices. Though relatively minor compared to the devices themselves, all will require some infrastructure (navigation buoys etc) to inform other water users of the installations.

3.1.8 Various anchoring options are available and will be dictated by the device requirements, the receiving environment (including need for slack water and seabed characteristics), environmental impact considerations and also infrastructure availability. Likely methods include piling, drilling, gravity structures (including caissons), anchors, weights and reverse hydrofoils.

3.1.9 In many devices the rotors are the only moving parts during energy production but in the case of the oscillating hydrofoil the foil is swung vertically through the water on an arm. Venturi devices do not have moving parts exposed to the water. Other than energy gathering, most devices have no other exposed moving parts but some swing on a mooring or pivot at the turn of each tide.

3.1.10 Rotor blades on commercial scale horizontal-axis turbines will vary in their dimensions by device and site characteristics, being in the region of 2 to 20 m in diameter. Rotation speeds are likely to be up to 30 revolutions per minute with an upper tip-speed of 10 to 12.5 $m.s^{-1}$ (RPS, 2008; EMEC, 2010). Blades may be exposed or shrouded within an open ended tube. By funnelling and accelerating the water through the turbines, shrouding can make devices more efficient, but may also have an effect on the potential risk of submerged animals being struck by blades. Any shrouding will act to increase the visibility (visual or acoustic) of the entire devices and better indicate the arc of blade sweep but once entering the tube, the shroud itself creates a physical barrier reducing the manoeuvring options of the marine mammal and altering the chance of an enforced passage through/between the blades of the turbine. Vertical axis turbines turbine diameters are likely to be in the regions of 3 m to approximately 6 m in diameter and up to 6 m in height.

3.1.11 Biological fouling of tidal devices is inevitable and is most likely to have critical impacts on the efficiency of moving parts. There is less clarity on potential antifouling strategies that companies will use than other aspects of device design though it is expected that the majority of developers will seek to use non-toxic antifouling materials should they be available. Similarly most steel devices will require the use sacrificial anodes (cathodic protection) to protect them against corrosion. Most devices will also contain hydraulic fluids but these are likely to be relatively small in quantity with respect to marine mammal concerns and specifics of their potential toxicity and resilience in the environment can be addressed at device level EIA investigations.

3.1.12 As with other post-concept testing issues, maintenance schedules are less clear. The limited working windows present at tidal sites will provide a strong incentive for developers to seek strategies that involve minimal maintenance. However the techniques used – raising and lowering on a pile; complete uplift, partial uplift etc – will potentially make a substantial difference to the vessel traffic associated with maintenance of a tidal array. Decommissioning is likely to involve similar processes to the construction phases.

3.1.13 At present the bulk of the tidal-stream energy industry is focused on the deployment and improvement of single demonstrator devices but to deliver useful electricity the industry will have to move into the next phase: the placement of multiple full scale devices. Considerations of the appropriate geometry and spacing of such arrays from an optimal energy extraction point of view is still at an early stage and so it is difficult to extract generalities in terms of potential environmental impacts from such scale-ups. However, current discussions suggest that arrays will be composed of identical devices duplicated across discrete patches of the seabed.

3.1.14 It should not be overlooked that marine renewable energy extraction industries are in their infancy. Consequently, there are many unknowns with respect to how these devices will function let alone how they will interact with the receiving environment. Accordingly, some development of the industry needs to occur in order for interactions with the environment to be fully understood – the so-called “deploy and monitor” approach. The operating restrictions on the Strangford Lough SeaGen device are a case in point where licence conditions have included restrictions on operation when marine mammals come within a certain distance of the turbine and are detected visually or with Sonar (MCT 2010). However to fully understand whether collisions are a real factor these restrictions would need to be relaxed experimentally with appropriate monitoring and adaptive management.

4 Overview of Risks in Relation to Marine Mammals

4.1 Introduction

4.1.1 The ultimate implications of marine mammal relevant risks and concerns are likely to vary principally between those that are short lived (acute) and those that occur over longer periods (chronic). Most issues associated with construction, decommissioning and some major maintenance components will take place over discrete, usually short, time periods (days to months), while the operation of tidal-stream devices, together with day to day maintenance activities, will extend over much longer periods (years). It should be noted that some of the concerns and potential issues associated specifically with tidal stream devices during operation are theoretical, as insufficient field data are currently available to quantify the actual risk.

4.1.2 The primary concerns are likely to fall into the following areas: contaminants; habitat changes and exclusion; ship/boat strikes; noise pollution, sensitivity to electrical fields; entanglement; entrapment and injurious collisions. These are treated individually below.

4.2 Contaminants

4.2.1 As described in the previous chapter, tidal energy devices are likely to use a variety of lubricants and antifouling compounds. Given the extreme water flow around tidal devices, passive dispersion of small spills or gradual erosion is likely to be quickly dispersed to levels unlikely to impact marine mammals. Exceptions to this may occur where spills impact neighbouring shores that include haul-out sites or if other marine vessels with larger chemical loads (e.g. a ship) collide with tidal device(s). Issues connected to potential contaminants would be expected to be addressed at the site specific level by adherence to best practice and construction/decommissioning environmental management plans etc.

4.3 Habitat changes

4.3.1 By their very nature, tidal-stream devices will add additional structure to the waters in which they are placed. A component of this is likely to be the loss of a relatively small area of the existing benthos within the footprint of a device and additional topography. There may also be downstream changes in sedimentation or benthic communities as a result of disruptions as flow is disturbed around the supporting structures and from the energy extracted by the turbine itself. A more significant indirect effect here in a marine mammal context, will be the addition of significant structures in the water column itself. These will have the potential to attract fouling organisms and larger species such as reef loving fish, although such fouling is likely to be controlled on parts of devices to ensure device efficiency is not limited, with the degree of fouling dependant on what cleaning regimes/chemicals are adopted. Again, while there are concerns that these additional structures may offer the potential for accelerated spread of alien fouling species (Brodin and Andersson, 2009), current invasive species are unlikely to directly impact marine mammals. More significant would be if these structures attract prey species, particularly fish in a similar fashion to artificial reefs and the Fish Aggregating Devices (FADs) used in offshore fisheries (Buckley *et al.,* 1989). These may provide additional foraging opportunities for marine mammals but will also bring them into closer proximity to the devices themselves. ABPmer (2010) included a review of FAD characteristics of wave and tidal stream devices, drawing on knowledge gained from existing FADs in the wider literature, concluding that the potential for a device to act as a FAD is likely to be linked to the size of the device, i.e. the larger a device the more likely it is that it would attract fish. Similar concerns would apply if seals use surfaces exposed to the air for hauling out. Such opportunities will depend on device design and have already been flagged as a potential concern for wave devices (Hagerman, 2004). It is also likely that there will be disturbances to the flow field downstream of tidal devices. There has been little research yet on how (indeed if) such changes might affect marine mammals.

4.3.2 The following are four potential scenarios: (1) improving foraging opportunities by providing eddies or flow-shadows that allow animals to maintain station near strong flow without significant energy expenditure (2) removing energy from the system and reducing overall productivity (3) altering any structuring in the water column such as eddy features or further increasing water column destratification with implications for foraging tactics or prey distribution and (4) adding additional turbulence that might degrade the hydrodynamic sense used by seals to detect the wakes from pelagic fish (Dehnhardt *et al.,* 2001). Other than during construction, impacts on sedimentary processes such as in water turbidity are likely to be slight on account of the generally highly scoured nature of existing tidal-energy sites.

4.4 Attraction/avoidance

4.4.1 The presence of structures in the water column is likely to affect different marine mammal species in varying ways. Inquisitive species, such as the seals and bottlenose dolphins, are typically attracted to novel structures and may behave similarly with tidal-stream devices. Conversely, species such as harbour porpoises, which are typically shy of man-made structures, may show avoidance responses. However, our knowledge of these potential responses is very limited. Parallels can be drawn from other anthropogenic activities but to date few have been placed in similarly high energy environments and are generally rigid structures (like oil platforms and piers) rather than ones with moving parts. At this point, experimental studies in laboratory settings could be performed (on captive seals for example) but these could offer few insights as they cannot reflect the complexities of wild animal exploratory behaviour or the magnitude of scale of functional tidal devices. Accordingly, a greater understanding of this issue will require focused monitoring around pioneer devices if lessons are to be available for other areas and the expansion of the industry (the so called "deploy and monitor" approach). However, these studies will be relevant to the sites and device around which they were conducted and care must be taken when extrapolating to these situations. This will be particularly problematic in respect to the wide variety of devices/concepts currently being progressed (>70) and the increasingly open water nature of the sector. To help generalise therefore more experimental approaches (sound playbacks, test rigs etc.) should be considered so that extrapolations of animal-device interactions can be more widely applied.

4.5 Displacement/exclusion

4.5.1 As described previously, devices currently in operation are primarily single or twin structures. Thus, attraction or displacement of animals will be relative to a point source. Unless this is in a very restricted environment any impacts will be accordingly localised. However, the development of the industry will require larger installations of multiple devices. If marine mammals do respond spatially to devices then the placement of arrays relative to each other and local topography may have more profound implications. Most basic would be barrier effects. For example, if devices were placed line abreast across a narrow channel then downstream habitat exclusion or entrapment is conceivable. More complicated scenarios are also possible. For example, animals avoiding one device might be channelled into the path of another.

4.5.2 It is almost certain that tidal-energy arrays will entail some degree of fisheries exclusion. This would result in inadvertent no-take zones for some fisheries in the immediate vicinity of a tidal array and its associated infrastructure. While this may have local environmental benefits (e.g. benthic recovery) ecosystem impacts may be more complex as fishing pressure is likely to be displaced elsewhere rather than entirely removed.

4.6 Entanglement/entrapped

4.6.1 Marine mammals are well known to become entangled or entrapped in a wide variety of man-made structures. By-catch in fishing nets is the most common form (Read *et al.,* 2006), though marine mammals as large as the baleen whales frequently become ensnared by structures as simple as vertical lobster creel lines. Because of the strong flows, opportunities to become fouled by floating debris, mooring lines, narrow gauge chains and other fixings are likely to be less frequently associated with tidal energy structures than fishing equipment, fish farm infrastructure and so on. Nevertheless, strong currents can increase the initial approach speeds of animals to static gear (and reduce the time to detect/avoid) and thus accentuate the consequences of animals becoming entangled by reducing their chances of reaching the surface to breathe once ensnared.

4.7 Ship/boat strikes

4.7.1 Like by-catch, collisions with ships or boats are a common source of marine mammal morbidity and mortality (Laist *et al.,* 2001). Harmful interactions of marine mammals with tidal-stream industry through the ship-strike route will have direct parallels with other marine heavy industry (oil industry) and maintenance (fish farming) however the occurrence of strong tidal flows in constricted water ways will add an additional level of complexity to interactions and require a further interpretation for a marine mammal to adopt in a close encounter situation. For example, a vessel (using dynamic positioning or simply motoring) to hold station in a tidal stream will effectively be moving rapidly with respect to the water but simultaneously be stationary with respect to the bottom. Since ship/boat strikes are a relatively common cause of anthropogenic marine mammal mortality, the additional complexity of shipping operating in strong tidal currents can be assumed to pose some greater risk of harmful strikes. But again, the level of this risk is currently unclear.

4.8 Noise

4.8.1 Like other industries, tidal-stream developments will introduce noise into the marine environment. This will come from a variety of sources such as site surveying, site preparation, construction, cable laying, maintenance vessels, operation and decommissioning. The noise produced by operating devices will be unique to the industry while others will be common to other activities.

4.8.2 Dependant on the methods planned, during construction and installation the key sources of noise will be geophysical survey, shipping and machinery, pile driving, drilling, rock placement and trenching. Noise associated with decommissioning is likely to be similar, and construction and decommissioning noise will depend heavily on the device concept and site specific requirements. Nevertheless, construction noise is likely to be far greater than operational noise (Richards *et al.,* 2007) and is likely to involve processes that are common to many other marine industries. Pile driving, for example, has been comparatively well studied with respect to offshore wind developments, and has the potential to pose a significant risk to marine mammals and fish (Nedwell and Brooker, 2008; Madsen *et al.,* 2006; Gordon *et al.,* 2007; Tougaard *et al.,* 2009; Southall *et al.,* 2007) while pin pile drilling, as used to secure the SeaGen tidal turbine in Strangford Lough, is considerably quieter with outputs comparable to small vessel noise (Nedwell and Brooker, 2008). It should be noted that there are a number of mitigation measures that can be applied during such noisy activities, for example recent guidance published by the JNCC related to seismic activities (JNCC, 2010) though the efficacy of these in the case of pile driving has been questioned (Gordon *et al.,* 2007).

4.8.3 Operational noise of tidal energy devices is a comparative unknown at present. Modelling studies and information from a limited number of scale devices suggests that their output will be low and quickly reach background levels (Richards *et al.,* 2007). The noise sources associated with these devices are likely to be from rotating machinery, moving water, structural noise and mooring noise (Richards *et al.,* 2007). System designers will generally seek to minimise radiated noise because it is often associated with ineffective machinery and a loss of energy, but because these devices are to be deployed in very hostile environments they will inevitably develop wear and faults. Under these conditions, the noise output is likely to rise (Richards *et al.,* 2007). While operating tidal energy devices appear unlikely to be a significant noise source, the question arises over whether the devices will have enough acoustic output to be audible at ranges sufficient to allow submerged marine mammals to detect them and take appropriate avoiding action. Results from early-stage modelling work suggest that this may be only partially the case with detection distances of likely acoustic outputs varying from thousands to only a few tens of metres depending on the specifics of the level of acoustic output, background noise levels and auditory abilities of the particular marine mammal species (Carter, 2008). There are currently few data on turbine acoustic outputs but interestingly, because ambient noise in these areas is typically well above marine mammal hearing thresholds, it is the interplay between device outputs and ambient noise that actually determine their audibility rather than the auditory sensitivity of the animals themselves (Carter, 2008).

4.8.4 In summary, the noise associated with tidal-stream devices will vary considerably with the phase of development. Short term issues associated with construction or decommissioning are likely to have the highest acoustic impacts and include levels capable of injury and disturbance (akin to other major offshore construction work) while operational noise is likely to be far lower unless the machinery develops faults or significant maintenance takes place.

4.9 Sensitivity to electrical fields

4.9.1 Recent observations have shown that seals are extremely and unexpectedly sensitive to electric fields and this is being exploited as a means of deterring seals from predating on fish (Forrest *et al.,* 2009; Forrest *et al.,* 2008). Forrest *et al.* (2008) showed that seals were deterred from swimming though a 200 microsecond pulse length electrical field with gradient of between 0.1 -.032 V (volts) cm^{-1}. These levels did not seem to affect the behaviour of salmonid fish and Forrest *et al.* (2009) showed that catch rates of salmon were higher at nets protected by an electric field. Why seals are so sensitive to electrical fields, whether they have specially adapted electrically sensitive organs and whether this is of any biological significance to them is not known. Estimates of the electrical fields that will be generated in seawater from buried power cables bringing power ashore from marine renewable devices are orders of magnitude lower. The maximum electrical field in the sea for buried power cables was estimated to be 0.9µV cm^{-1} (CMACS, 2003) and even lower, between 0.015-0.025 µ V m^{-1} in a later study (Gill *et al.,* 2005). It would seem therefore that there is no basis for expecting the strong exclusion effects demonstrated by Forrest *et al.* (2008; 2009). However two caveats should be born in mind. The first is that the seal exclusion trials used short pulse length electrical fields and it was shown that seal sensitivity increased as pulses lengthened. Seals might thus be more sensitive to a continuous electrical field. The second caveat is that seal sensitivity and responsiveness to lower level electrical fields have not been studied and there may be effects at levels below those tested. A final consideration is that electrical currents will induce magnetic fields around cables and it's possible that marine mammals will be sensitive to these. The risk that electromagnetic fields from power cables could affect seal behaviour must therefore remain as a potential concern and should be more fully explored.

4.9.2 The authors are unaware of any attempts to test for sensitivity to electrical fields in cetaceans. Given the unexpected finding of high sensitivity in pinnipeds and the lack of any understanding of the function (if any) of this sense, it would be unwise to assume a low sensitivity in cetaceans until this has been specifically tested for the main species involved.

4.10 Collision

4.10.1 An area of concern for marine mammals that is particular to marine renewable energy devices, unlike other offshore industries, is the potential for animals to collide with devices with the risks of significant animal injury and device damage. This issue has been frequently flagged by many forums as an area of particular concern given the lack of understanding (Scottish Marine Renewables SEA 2007; EMEC Regulators and Developers workshop, 2008; Linley *et al*., 2009 etc) and will is therefore the focus of this report and more fully discussed in Section 5.

4.11 Cumulative effects

4.11.1 In addition to the potential effects of the development itself, it will be important to consider that any single tidal energy development occurs in concert with other marine activities including other marine renewable energy projects. The drive to reach energy targets and the advancing front of the industry itself is likely to result in multiple developments occurring simultaneously or in quick succession. This is contrary to the incremental "deploy and monitor" approach often discussed but a somewhat inevitable consequence of the current energy climate concerns. As a result, potentially significant issues such as habitat loss, barrier or large area exclusion effects, and displacement of other activities such as fisheries need consideration.

5 Collision Risks to Marine Mammals

5.1 Introduction

5.1.1 As described in Section 4, the potential for marine vertebrate-tidal energy device collisions have been identified as a unique issue of particular concern in many underwater marine renewables forums (Scottish Marine Renewables SEA 2007; EMEC Regulators and Developers workshop 2008; RPS, 2008; Linley *et al.,* 2009). Given the early stage of development of tidal devices there is little precedent to draw on for this issue and being at the forefront of the industry the UK is also likely to lead the way in building a comprehensive understanding of this issue. It should be noted here that the potential for a collision risk to exist between marine mammals and tidal stream devices remains theoretical.

5.1.2 For the purposes of this report, a collision is considered to be an interaction between a marine vertebrate and a marine renewable energy device that may result in a physical injury (however slight) to the organism. A collision may therefore involve actual physical contact between the organism and device or an interaction with its pressure field.

5.2 Insights from existing marine collision risks

5.2.1 Given our limited knowledge of how marine mammals and tidal devices are likely to physically interact it is helpful to consider other threats in the marine environment with potential parallels. The most obvious is shipping because of the comparatively recent acknowledgement of the magnitude and widespread nature of collisions between ships and large whales. Also considered here are other anthropogenic activities that cause physical harm to large vertebrates, namely marine-mammal fisheries entanglements and bird collisions with wind turbines.

Ship strikes

5.2.2 Ship strikes are a known cause of mortality for both whales and dolphins worldwide (Pace, 2006). Strikes appear to be common but the majority are likely to go unnoticed or unreported (David, 2006). This global problem has been highlighted by focused work in the USA (Northern right whale) and in the Mediterranean (fin whale). Actual numbers of strikes are poorly known (Laist *et al.,* 2001) and statistics on strike rates are likely to be underestimates as incidents may often go unnoticed or unreported onboard ships, stranded carcases may show no obvious sign of a strike, and only a proportion of carcases actually wash up onto shore. Where in-depth studies have been undertaken, the strike rates are often substantial, accounting for between 12 and 47% of carcases recovered (Laist *et al.,* 2001; Notarbartolo-di-Sciara *et al.,* 2003; Ward-Geiger *et al.*, 2005; Panigada *et al.*, 2006).

5.2.3 Resultant injuries tend to fall into two categories, lacerations from propellers, and blunt traumas from impact with the hull. Four main drivers that are thought to influence the number and severity of ship strikes are: vessel type and speed; underwater noise; weather conditions and marine mammal behaviour. Additional factors such as distraction by other events (foraging or social interaction) are likely to play a part (IWC 2006). Most lethal and serious injuries to whales are thought to have been caused by relatively large vessels or those travelling at 14 knots (~7 $m.s^{-1}$) or faster, including relatively quiet sailing vessels (Laist *et al.,* 2001).

5.2.4 Concerns for the high incidence of ship-strikes has received sufficient political recognition in the US to warrant legislative measures including the introduction of geographical or seasonal restrictions on passage routing, habitat designations, ship speed limits and minimum approach distances (e.g. www.nmfs.noaa.gov/pr/shipstrike).

Fishing entanglements

5.2.5 By-catch of marine mammals is a significant issue worldwide and has been reported as a likely cause of the imminent extinction of several species (Zollett and Rosenberg, 2005). A global by-catch assessment estimated that hundreds of thousands of marine mammals are incidentally captured annually (Read *et al.,* 2006). Marine mammal by-catch has been recorded for nearly every type of fishing gear. While gillnets are most common, other problem net types such as pair trawls, have more direct parallels to the potential trapping properties of marine renewable devices (i.e. funnel shaped traps moving at speed relative to the water column). That said, large species such as whales, can even get entangled in fixed structures as simple as the lines used to mark traps or pots (Read *et al.,* 2006).

5.2.6 Our understanding of why by-catch events actually occur remains limited. It is clear however that marine-mammals forage around or interact with nets regularly and only occasionally become fatally entangled in them (Cox *et al.,* 2003).

5.2.7 It often seems that animals can detect nets in test conditions but fail to do so at sea (Au and Jones, 1991). One issue associated with echolocating mammals (odontocetes) is that if the animal is actively chasing prey with its sonar is often "locked on" to the prey or seabed, fainter echoes at a different range, from the net for example, may not be perceived or attended to (Goodson, 1996). As with ship-strikes, cetaceans may not always act “logically”. Large numbers of spinner and several other dolphin species, for example, have died over recent decades in the Eastern Tropical Pacific after being encircled by tuna nets. These dolphins will not jump over the surface float line despite being perfectly capable of doing so and end up being severely injured or asphyxiated as a result (Hall,1998).

Wind turbines

5.2.8 While marine mammals and wind turbines have little physical interaction, the collision risks for marine and terrestrial birds has been the subject of research in recent years (De Lucas Janss and Ferrer 2005; Desholm *et al.,* 2006, Desholm and Kahlert 2005; Drewitt and Langston 2006; Fox *et al.,* 2006; Garthe and Huppop, 2004; Greenwood 2005; Oxley, 2006; Smales, 2006; Richardson, undated). Birds in flight and swimming marine mammals have many parallels. Models have been developed that quantify collision risk for flying birds based on the structure and operation of turbines, number and size of blades, rotation speed and bird characteristics including size, flying mode, flight speed and avoidance behaviour (Band *et al.,* 2005; Chamberlain *et al.,* 2006). The collision risk of marine birds is expected to be higher at night than during the day, but overall is deemed to be low because of their high visibility even in poor light conditions. In contrast, however, underwater visibility is considerably less (usually less than 10s of metres in the best conditions) so any interactions are more likely to be facilitated through other cues such as acoustic ones.

Lessons learnt from existing collision risks

5.2.9 The cryptic nature of marine vertebrates means that identification of negative physical interactions with existing marine technologies is severely limited. The events typically become well studied when they are sufficiently common to be a significant concern for either the human activity or the species at risk. It is clear however, that in the majority of circumstances, documented cases of physical interaction are considered to be underestimates of the true number that actually occur. Other lessons include that collision threats are often more diverse than generally thought (e.g. ships bows and static mooring lines as threats); that marine mammals though agile and equipped with sophisticated senses, are frequently struck or entangled despite obvious acoustic signatures, predictable occurrence and prior experience; that marine mammals can behave apparently illogically when faced with novel circumstances (e.g. buoyant ascents by right whales and dolphins unwillingness to leap nets (Nowacek *et al.,* 2001; Hall, 1998); that details make a difference (e.g. vessel behaviour, net material, weather, ambient noise levels); and that a variety of warning devices and gear adaptations have been developed in recognition of underwater collision issues.

5.3 Structures of concern

5.3.1 As discussed in Section 3 a wide variety of device designs have been proposed for coastal water tidal energy extraction. Here the specific brands or mechanics of operation are of less relevance than the type and movement of the physical structures that marine mammals may encounter. Thus it is helpful when evaluating collision risks to consider marine renewable devices from the standpoint of their component parts, motions and likely placement (Figure 5-1). The following section outlines the generalities of a variety of potential devices.

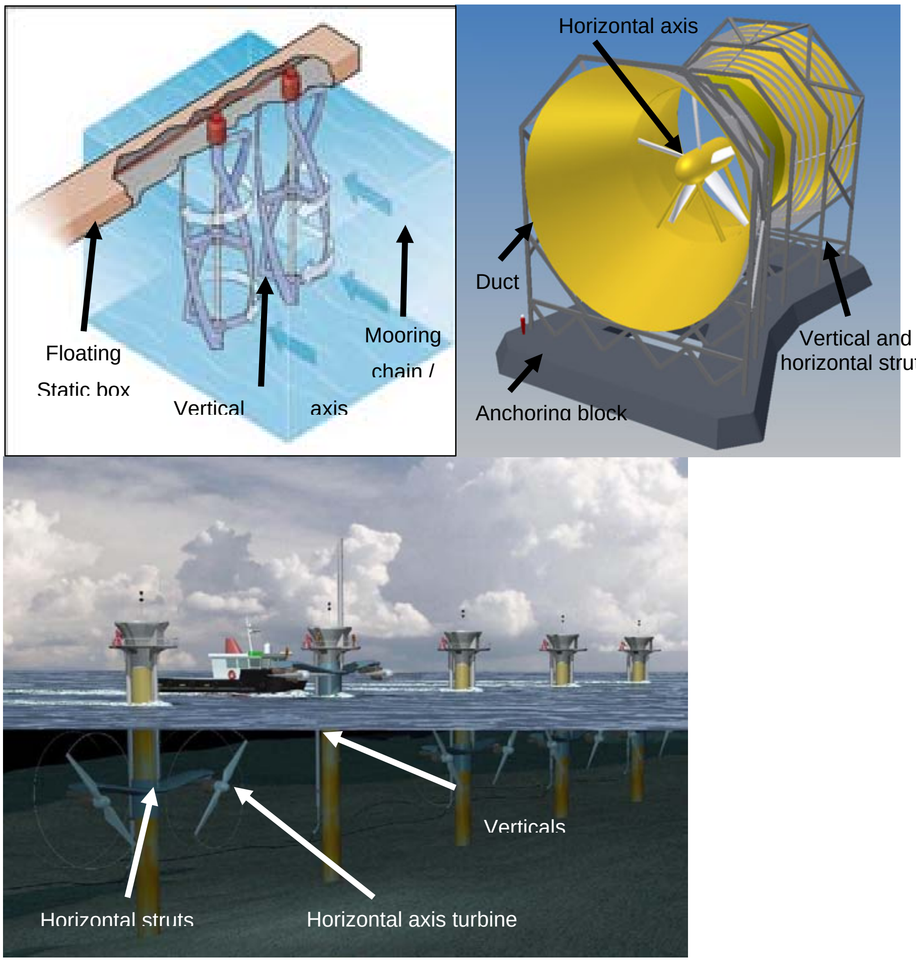

Figure 5-1 Three examples of marine renewable devices to illustrate how each combines several features that pose potential collision threats a) Gorlov helical axis turbine, b) Lunar Energy horizontal axis turbine, c) MCT SeaGen (redrawn from Wilson et al., 2007)

Fixed submerged structures

5.3.2 A variety of tidal generators utilise fixed structures submerged in the water column. Probably most common will be vertical support piles or gravity bases for machinery attachment. These structures resemble established supports often used for bridges, oil platforms etc and are most likely to pose collision risks (if at all) in areas of strong water movement. Information on collisions with such assemblies is limited probably because of their present rarity in areas of strong flow that are used by marine mammals.

Mooring equipment

5.3.3 A wide variety of device designs, especially surface floating devices will require substantial mooring equipment. Seabed standing anchor blocks or plinths are likely to function like other natural or artificial seabed structures and hence pose little novel risks for vertebrates in the water column. Cables and chains extending up through the water column will have direct parallels with mooring devices used in other offshore industrial applications as well as static fishing gear but, by the nature of the industry, will be placed in more energetic sites than most other existing marine activities. As they extend up through the water column, they will have some parallels in terms of collision risk with vertical support piles, but having a smaller cross-section will not disrupt the water flow to the same extent.

Surface structures

5.3.4 Some of the devices proposed will have significant surface components. These may either be fixed to the seabed and then pierce the surface or be anchored and float on the surface. In collision terms, species most at risk are those that frequently cross the air-water interface, i.e. diving birds and marine mammals. Nearest equivalent natural structures are floating logs and sea ice while industrial structures include fish-farm cages, oil related floating storage and offloading structures and logging industry log-booms/rafts. As with these other industrial applications, semi-aquatic species are likely to use surface floating marine renewable devices as landing/roosting or haul-out sites and risks of injury may be associated with getting onto/off the structures. While cetaceans do not haul-out, they do regularly surface for air. Species that live in ice-bound areas typically do not have dorsal fins suggesting that it is likely that collision with surface floating objects was a sufficient problem for cetaceans in ice bound areas to have evolved smaller fins. However, little is currently known about the ability of cetaceans to detect passive floating objects and the nature of injuries should contact occur. Collisions could either occur with cetaceans swimming into the structures during surfacing manoeuvres or the surface structures pitching down onto them in heavy seas. Given the scale of current designs (and unlike log-booms), it is unlikely that structures will be so large as to actually hinder marine birds or mammals from reaching the surface for air, provided the ascending animals are aware of the presence of the structures.

Turbines

5.3.5 Intuitively, the rotating or oscillating blades seem the most likely structures associated with tidal-stream energy devices to pose collision risks with marine vertebrates. This is because these components move relative to both the seabed and to the water column and there is the potential therefore to draw some parallels with wind turbine bird strikes as well as ship-cetacean strikes. However, it must be stressed that unlike ship propellers these devices take energy from the medium around them rather than putting energy in and so their rate of movement is slower relative to the ambient flow than is the case for active propulsion propellers. Furthermore, because they are turned or oscillated by the moving flow, the motion of the rotors is either that of a spiral or an undulation with the blades travelling at angles shallower than 90˚ to objects passing through their area of sweep. This means that the passing blade tips are as much pushing along the tube of water within which they are rotating (stream tube) as they are cutting through it. Open and ducted turbines also differ in the relative exposure of their blade tips to any animals in their vicinity and the angles of approaches that animals are likely to make.

5.3.6 Because turbine blades are solid structures the blade tip is the fastest moving part of the turbine and will move faster than the water flow but at or below speeds of around 12.5 $m.s^{-1}$ (23 knots). Speeds greater than this are avoided because they lead to water cavitation with associated mechanical damage and efficiency losses. Thus, tidal turbines have fundamental differences from wind turbines which are not speed limited by cavitation and from ship propellers which are smaller but introduce energy into the flow rather than extract it. Other than the rotation component, the velocity of rotor blades and especially their tips are therefore, in collision terms, more analogous to the approach speeds of ships' bows or the keels of racing yachts.

5.3.7 The majority of proposed designs have relatively narrow blades compared to the area that they sweep, however, there are some devices (e.g. Openhydro) that has a higher ratio of blade to inter-blade space. Designs of this kind are likely to give different cues to approaching marine mammals and may elicit different avoidance/evasion responses as well as escape options. Another concept is twin turbines with two sets of blades mounted one behind the other and rotating in opposite directions to one another. While having a more continuous presence in the water compared to a similarly bladed single turbine the perceived movement of the parts is likely to be considerably more complex.

Traps

5.3.8 The structures described above are generally discrete objects that marine mammals may either collide with or avoid; however, the combination of several structures raises the possibility of traps being created. While marine mammals are highly manoeuvrable, combined structures that restrict movement options are likely to lead to higher risk of collisions occurring. Such structures include ducts/shrouds, Venturi devices and combinations of turbines. The placement of such devices in areas of water flow rates that are significant relative to the swimming speeds of the species of concern will accentuate any problems. Nearest industrial parallels include fish entrapment into cooling water intakes for power plants and the mouths of fishing nets. In both of these situations, animals may enter such a trap either aware or unaware of the structure around them but begin to take counter-measures too late and experience an enforced passage through the aperture containing the turbine. Venturi devices and turbines housed in ducts are of particular concern in these circumstances.

5.4 Close encounter probabilities

5.4.1 Concern over collisions is a justifiable issue from an animal welfare and device survival viewpoint. It becomes particularly ecologically relevant if encounters occur frequently enough to make a difference to any particular species at the level of local populations. The legislative significance, however, is rather more complex, particularly around the Habitats Regulations and European Protected Species. To provide an indication of how frequently encounters might occur for the Scottish Marine Renewables SEA, Wilson *et al.,* (2007) developed an encounter risk model. The model considered two Scottish (also species that occur in Welsh waters) vertebrate species (herring and harbour porpoises) as examples and determined how often these species would share the same space and time as a fictional development of 100 tidal turbines operating in Scottish coastal waters. The model made several assumptions, principally that the fish/porpoises did not respond to the turbines by either being attracted to or avoiding them and that the animals were distributed randomly at densities provided over broad scales from ICES and SCANS datasets. Parameters of the turbine type were design neutral and intended to reflect a “typical” turbine, if such a thing exists (16 m diameter turbine rotating around 10 rpm in peak current flow with an upper blade tip velocity of 12.5 $m.s^{-1,}$ mounted in 50 m of water with an upper tip extending to 10 m below the surface).

5.4.2 The model estimated that 2% of the herring and 3.6 to 10.7% of the porpoise population would risk encountering a turbine each year. The variance in the porpoise statistics depend on the size of area considered because Scottish porpoises are not a discrete population. However, whichever area is used, the model output translates to an encounter rate of 13 porpoises per year per turbine. It should be noted that encounter rate is not synonymous with collision rate; an encounter represents the opportunity for a collision to occur. Animals may detect at long range and opt to avoid the area around turbines or respond at close range and take evasive action when in the immediate vicinity of the structures. As the model assumes that the porpoises are swimming but otherwise passive to other objects in the water, avoidance and evasion behaviour have not been included and could be expected to reduce the rates described above. For example, in wind turbine collision risk modelling, avoidance/evasion rates in birds of up to 99% occur (Whitfield and Madders, 2006). However the behavioural response(s) of harbour porpoises (and other marine mammals) to marine renewable devices is currently unknown and clearly requires targeted research to better understand and quantify.

5.4.3 Encounter risk also depends on the population density in the location of the turbines. The models described above used population density estimates derived from single broad scale surveys covering a large area and a variety of habitats. Turbines will of course all be sited in locations with high tidal current. Strong currents are likely to be of significance to marine mammals (see Section 2) and densities and behaviour in these relatively small but unusual habitats may be quite different from that over the rest of the population's range (Pierpoint 2008; and Table 2-1). Marine mammals live in three dimensions. They spend a significant amount of time underwater and the interaction between the amount of time they spend, and how they behave at different depths and the water depths swept by turbine blades will also affect collision risk. While we have some information on the dive behaviour of some of the marine mammals species most likely to encounter tidal turbines in Welsh waters, little if any will have been collected in areas of extreme tidal current and, as was the case with distribution and density data, it would be unwise to use data from elsewhere to extrapolate dive behaviour in these highly unusual habitats. Work undertaken by Gordon *et al.* (2011) as part of the MRESF project has, however collected data on dive behaviour in tidal rapids areas using two approaches. A drifting vertical array of hydrophones was used to determine the depth of vocalising porpoises to provide information on their dive behaviour. As this part of the study was a proof of concept for a new method only a small amount of data were collected but these indicate that porpoises were using the entire water column. For seals, GSM phone tags were used to measure the dive behaviour and movements of newly weaned grey seal pups that spent considerable time in tidal rapid areas. Data showed the animals diving to the seabed.

5.4.4 A further consideration is that collision risk will likely be higher, and the consequences of collision more severe, at times when tidal currents are running at their highest rates and blades are moving more quickly. Marine mammal densities in these areas often vary on a tidal cycle (Section 2.4) and it is likely that their behaviour and dive patterns also vary tidally. Thus, what is required is an understanding of distribution, densities and underwater behaviour in tidal rapids day and night and during different stages of the tide.

5.4.5 The model described above also predicted that larger animals are at much greater risk of encounter with turbine blades than smaller animals. This scale effect is on account of larger animals both swimming faster to cover more water-space and actually occupying more volume at any single moment. Although larger species tend to be less frequent in Welsh waters (i.e. whales to porpoises or seals) and so population encounter rates are likely to be lower, the risk rate per individual will be higher, and thus the ecological significance of this relationship will depend on relative species status.

5.5 Consequences of a collision

5.5.1 Should a collision between a marine mammals and a device occur, it could have a variety of outcomes. Acute effects could range from minor injuries such as abrasions through to temporary or permanent debilitation (internal injuries, surface wounds or damage to delicate organs such as eyes or mandibles) to more significant injuries (major cuts, amputations or internal trauma). Depending on severity and bodily location, these injuries may result in recoverable injury, long-term debilitation, delayed or instant mortality. Clearly, debilitation or deaths are significant concerns (see section 6.3.1) but their manifestation may vary considerably. Marine mammals that die rapidly after a collision event may strand or appear in the vicinity of the devices and therefore there is a possibility of linking the injuries to the cause (Jensen and Silber, 2003). The probability that an animal dying at sea actually washes up and is discovered depends on a host of factors, including local hydrography, weather, the characteristics of local shore line and the level of directed and opportunistic surveillance of it. In many cases, the probability of an at sea mortality being discovered as a stranded animal will be low. Animals that sustain severe injuries that are not instantly fatal may travel considerable distances before succumbing or die of complications (infection, starvation etc) rather than from the original collision. These types of injuries are likely to be more common than those causing instant mortality but detecting them and establishing causality would be very much more challenging.

5.5.2 Of most obvious concern are impacts from turbine blades. Marine mammals are relatively robust to potential strikes as they have a thick sub-dermal layer of blubber that would potentially cushion their vital organs from the worst of any blows. However, the coverage of this tissue is not even and the head is poorly covered and particularly vulnerable. Furthermore, evidence from ship-strikes suggests that for impacts with large objects, a blubber layer is insufficient protection (Laist *et al.,* 2001). It is not known what forces are required to fatally injure marine mammals but road-traffic research on large terrestrial vertebrates may provide some useful information that, with care, could be applied. Studies of seals killed by blows from killer whales and also the fatal strikes on harbour porpoises by bottlenose dolphins could be also informative (Ross and Wilson, 1996). In terms of minor collisions, seal fur and epidermis is considerably more resistant to abrasion than the skin of cetaceans (authors' personal observations).

5.5.3 Auditory damage from a very close approach (rather than an actual collision) to an operating turbine is also another potential source of physical harm. As a result of concerns over damage to human divers and marine mammals from proximity to naval activities, much is known about this topic (e.g. Ketten, 1995). Relatively little is yet known about the operational acoustic output associated with tidal-stream devices so it is difficult to determine the significance of injurious noise. However, given the balance of energy extraction to introduction it is more likely that construction rather than operation activities would pose the greater risks in this regard. Another potential source of injury would be the rapid pressure changes associated with very close pass to a blade tip. Since air is more compressible than water/tissue there is a potential to damage organs surrounding air spaces such as lungs and sinuses. This issue has been largely unexplored in the renewables context and is unlikely to impinge on marine mammals which routinely experience massive pressure changes associated with diving. This problem is probably more relevant to fish because their swim bladders will be inflated to match the ambient pressure prior to approaching a turbine and the associated pressure fluxes.

5.6 Ecological factors influencing collision risks

5.6.1 There are a number of ecological factors that may influence the risk of collision. These are identified and discussed separately below.

Depth

5.6.2 All marine mammal species found around the coasts of Wales are capable of diving to all likely operating depths of marine renewable devices (<200 m). Our extent of knowledge on the vertical distribution of different marine mammal species differs markedly, with most information known about the seals, then porpoises then the other cetaceans (Westgate *et al.,* 1995; Eguchi and Harvey 2005; Klatsky *et al.,* 2007). However, with the exception of the work undertaken by Gordon *et al.* (2011) as part of the MRESF project, very few if any measurements have been made in tidal rapid habitats and it is not clear how reliably data from other areas can be extrapolated to these physically unusual sites. Most species divide the majority of their time between foraging at depth and breathing at the surface. Species, such as the seals that forage at or near the seabed will therefore spend least time in the water column itself while pelagic feeders, such as common dolphins, will spend the majority of their time in the water column, i.e. between the surface and the bottom. The collision risk for marine mammals will therefore depend on the species of concern, the depth of the device and its relative position within the water column.

Time of day

5.6.3 All marine mammal species in Welsh waters occur at sea throughout the diel (day/night) cycle. Like birds, pinnipeds have the capacity to haul-out (i.e. exit the marine environment) but both seal species forage in bouts lasting several days and have haul-out regimes influenced by weather and by site availability tidally (Grellier *et al.,* 1996). Thus, they can be assumed to be at risk of collision with devices at sea throughout the diel cycle. Little is known about cetacean behaviour at night. Passive acoustic monitoring using PODs has shown that porpoises are more acoustically active at night both in the North Sea (Todd *et al*., 2009) and in high tidal current areas in Wales (Gordon *et al.,* 2011). Goold (2000) found that common dolphins off the Welsh coast were more acoustically active at night and dolphins which forage at night and rest during the day have quite different distributions at night than during the day (Benoit-Bird *et al.,* 2001; Elwen *et al.,* 2006). The largest impacts of time of day on collision risk are likely to concern the abilities of animals to detect devices in darkness, on which there is no firm data, and any influences of day/night changes in prey availability which may affect whether and how marine mammals forage in areas of risk. ABPmer (2010) found that reduced levels of light at night represent a medium level of contribution to collision risk with tidal stream devices, based on studies on fish entrapment in intakes, which is generally higher at night.

5.6.4 While they do have other senses, both pinnipeds and cetaceans use vision for navigation and prey capture and so it is logical to infer that collision risks will be increased during periods of low light intensity. However, as light does not travel well through water, and water clarity off Wales is usually in the range of tens of metres or less, changes in light intensity are likely to influence the close-range evasion abilities of animals rather than their long-range avoidance capabilities, where upon other cues such as acoustics will be more relevant.

5.6.5 Diel influences on foraging are likely to occur in two ways. Firstly, changes in prey distribution with light regimes will influence the foraging behaviour of marine mammals and hence their abundance or transit through areas of concern. Secondly, marine mammals and their prey have different sensory abilities with fish relying on vision for mid-range predator detection and marine mammals using vision, hearing and mechano-reception (Axenrot *et al.,* 2004; Wartzok and Ketten, 1999). Thus the relative predator-prey dynamic between these species varies between night and day and with it the foraging behaviour of marine mammals. These foraging relationships are likely to be species and area specific and therefore outside the realms of this overview report but will require consideration at the EIA level.

Season

5.6.6 Marine mammal abundance and behaviour varies seasonally. Some species such as the baleen whales and warm water dolphins (especially common and striped) typically increase in abundance in Welsh waters in summer and autumn. Most other species are resident and show only local changes in distribution. Of these, the most notable are the breeding and moulting seasons for seals with the abundance of seals at sea declining during these times. Grey seal pups leave their breeding beaches in autumn.

5.6.7 Marine mammals are seasonal breeders and it is likely that the limited swimming abilities and the naivety of calves/pups will put them at greater risk of collisions with renewable devices. Information on cetacean calf production is limited but generally positively correlated with water temperature (i.e. occurs in summer).

Water quality

5.6.8 The primary feature of water quality relevant to collision risk is turbidity. Evasion at close range is likely to be mediated for many marine mammal species by the visual cues provided by submerged devices. In other words, low turbidity (high visibility) environments are likely to give marine mammals more warning of an impending collision risk and allow them more options for escape. As well as vision, odontocete cetaceans use echolocation to sense the environment and while this sense is not significantly reduced by suspended matter in the water it is likely to be disrupted by air bubbles in the water column (Madsen *et al.*, 2006). Therefore, the “visibility” in acoustic terms of marine renewable devices is likely to be reduced in areas where tidal mixing or surface waves are sufficient to entrain air bubbles into the water column.

Flow characteristics and tidal state

5.6.9 As described above, marine mammals, in some circumstances, appear to be attracted to areas of high tidal flow to forage. This may be because of higher prey density but also because of the energetic advantages set up by local discontinuities of flow rates.

Renewable devices within these tidal streams may create greater discontinuities, disrupt existing ones or set up turbulence. The greatest consideration in terms of collision, however, is the reduction in manoeuvring options that result from moving within a tidal stream. These effects will vary with the tidal flow rate and direction and therefore will vary cyclically with the state of the tide and in intensity across springs and neaps.

Proximity to other devices

5.6.10 The placement of several devices in proximity will complicate marine vertebrate collision risks in several ways. When the animals are at long range, they will provide a larger target and more cues for animals to avoid (1) but also produce a larger combined area that will need to be avoided (2) at close animal-device range, multiple devices will produce a more complex and potentially confusing set of cues for approaching animals (3) and increase the number of collision risks (4) with some potential configurations creating traps (5) or ricochet affects (6) - where the avoidance/evasion tactics used to escape one device could guide an animal into the danger area of another.

5.6.11 In summary, multiple devices may produce greater cues at long range and have potential to reduce the number of animals getting into proximity. But, at close range they may present a more complex super-device to avoid with associated elevated collision risk.

5.6.12 The exact configuration of devices relative to one another is likely to make a considerable difference to their additive effects. This topic however has not received any targeted research. In homogenous environments, simple proximity will be the primary issue but in areas constrained by topography or polarised by tidal flow, relative orientation will also be important. Tidal-device array design is a rapidly developing field but it is not yet sufficiently formulated to allow a detailed analysis of the implications to marine mammals and their movement paths of configurations other than the simple ones outlined above.

Topography

5.6.13 Device placements in homogeneous environments (i.e. open waters or off distant headlands) provide animals with the most options for avoidance and will therefore, with all else being equal, incur the lowest collision risk. The impacts of devices on marine mammal habitat exclusion are likely to be localised to the area of placement. Tidal water masses associated with topographic constrictions (narrows, sounds etc) are often used by marine mammals as transit corridors and because they are similarly used by fish their bottleneck properties may be attractive to some marine mammal species for foraging. If placement in these areas leads to avoidance then such installations may have significant impacts on the downstream area use as well as potentially lost foraging opportunities. However, because some of these areas may hold particular transit and foraging value, animals may be particularly resistant to avoidance and therefore place themselves at higher collision risk. Entrances to blind ending waterways (estuaries etc) are likely to be similar to those for straits but because they are blind ended they will only have the potential to impact on local rather than transiting species.

5.7 Underwater sensory cues

Sight

5.7.1 All UK marine mammals use vision to navigate in their environment, avoid obstacles and forage. However, unlike many birds, marine mammals forage throughout the diel cycle and in very turbid waters and therefore they are able to function as predators in very low light levels including at night (Wartzok and Ketten, 1999). Vision is a primary sense for seals, whose large eyes face forward giving them binocular vision. Cetacean eyes are placed on the sides of the head and so give a more panoramic view. The visual fields do overlap but binocular vision has not yet been demonstrated. Colour vision in cetaceans and pinnipeds is limited and skewed to the blue-green region of the spectrum (Wartzok and Ketten, 1999). The underwater coloration of marine renewable devices may therefore appear different (more or less obvious) to these species than to ourselves.

Sound

5.7.2 Marine mammals are known to have acute hearing capabilities (Richardson *et al.*, 1995). These senses are both passive (pinnipeds (seals, sea lions etc.), odontocetes (toothed whales) and mysticetes (baleen/filter feeding whales), meaning that they listen to sounds already in the environment and active (primarily odontocetes), meaning that they produce their own sounds and interpret the returning echoes. The peak energy in echolocation signals are typically at high frequencies giving these animals good fine scale discrimination abilities (i.e. able to resolve individual small fish from background). However, unlike vision, the information derived from echolocation is limited by the repetition rate of the sound pulses and hence their perception of objects has a stroboscopic nature. It is unknown how echolocating animals will therefore perceive rotating objects such as turbines. In addition, update rates are limited by the travel time of sound. Detection of distant objects requires use of a longer inter-pulse interval than close objects and thus a slower information update rate. In many cases small odontocetes are known to attempt to minimise their inter-pulse intervals when foraging. A consequence of this is that their active echolocation is "locked to target" with a repetition rate which is continuously "tuned" to the distance of interest but with the sacrifice of being less or unable to detect closer or more distant objects. Thus, while these animals may be capable of detecting distant objects (a turbine for example) they may be effectively blind to them when foraging on nearby prey (Au, 1993). The hearing sensitivities of seals and mysticetes differ significantly from that of the odontocetes; mysticetes are thought to have good sensitivity at low frequencies, odontocetes are high frequency specialists with best sensitivity in the ultrasonic, while seals hear a broad range of frequencies in between.

5.7.3 Noise masks acoustic signals that are similar in frequency (are within a critical band) and coincide in time. Masking will affect an animal's ability to hear sounds produced by the devices themselves to hear the signals of any sound generators that might be utilised for mitigation (see Section 5.9) and to detect echolocation echoes. Thus levels of background noise are likely to have a profound effect on animals’ ability to detect devices using both active and passive acoustic sensing. During towed hydrophone surveys in area of high tidal energy in Welsh waters, Gordon *et al.* (2011) made continuous recordings and high frequency click detections. Above 20 kHz there was little contribution to background noise from the tow vessel's machinery. In this ultrasonic band they noted that background noise levels climbed steeply once the predicted current speed increased above ~1.2 $m.s^{-1}$. In some areas well defined patches of very intense noise were noted. The locations of these patches was often consistent between days and Gordon *et al.* (2011) hypothesised that these were due to patches of moving hard sediments such as gravel beds. Noise levels within these patches were often so intense that acoustic detection of porpoise echolocation clicks by click detectors within the Rainbow click program (Gillespie *et al.* in review) was effectively impossible. It is very likely therefore, that marine mammals' acoustic sensing capabilities would be severely compromised within such high noise areas. If the location of such high noise level patches are quite confined and predictable as Gordon *et al.* (2011) suggest then their occurrence could be taken into account when siting individual devices.

Mechano-reception

5.7.4 Because of logistical difficulties in measuring the stimuli that might be used by marine mammals for mechano-reception, little is known about this sense. Our best information concerns seals, which have been shown to use their vibrissae (whiskers) to sense small-scale hydrodynamic vibrations and flow vortices in the water column. They are thought to use this sense to track the wake of prey organisms swimming through the water column (Dehnhardt *et al.,* 2001). Its use for navigation or detecting larger objects is unknown. The existence of a similar sense in cetaceans is unknown.

Electro-magnetism

5.7.5 Recent observations have shown that seals are sensitive to electric fields (Forrest *et al.,* 2008; 2009). How they might use this sense to navigate and whether signals emanating from energy devices would be large enough to alter their movement decisions are unknown. The occurrence of this sense in cetaceans is unknown. There is equivocal evidence that mass cetacean stranding sites are linked with particular geomagnetic features but the definitive use of this sense has yet to be established.

5.8 Responses and escape options

5.8.1 Responses by animals to sensory cues may occur at a variety of scales but responses can be placed into either of two categories depending upon the perceived threat: avoidance or evasion. In general, avoidance occurs on a larger scale relative to the size of the responding animal. In the context of predator/prey interactions, avoidance responses are intended to reduce encounters by minimising contact with the predator. For interaction with marine renewable energy generating devices the response would be to avoid the area close to the device. By excluding themselves from the vicinity of the device “encounters” do not occur. In contrast to avoidance responses, evasion is defined as a direct response to an attack or perceived attack. Fish, and also many invertebrates, perform escape responses to sensory cues, often mediated neurologically as reflex responses. ABPmer (2010) considered acoustics to be the main cue at distance for fish, with close range evasion generally being dependant on vision. In the context of marine renewable energy devices such responses in marine mammals would occur during a close encounter with a moving part such as a turbine blade and probably result in a bout of maximum speed swimming away from the stimulus direction (as would be the case for a predatory attack (Dill, 1974).

5.8.2 Being highly mobile underwater, marine mammals have the capacity to both avoid and evade marine renewable devices provided they have the ability to detect the objects, perceive them as a threat and then take appropriate action at long or short range. However, there are several factors that have the potential to compromise this ideal scenario.

Detection failure

5.8.3 The broad acoustic, visual and hydrographic signatures of marine renewable devices are at present poorly understood. Other than the visual appearance of devices, the need for efficient energy conversion will encourage the development of devices that produce as little extraneous energy signatures as possible, reducing the size of potential warning stimuli for animals at risk. Both the stimulus output from the devices and perceptual acuity of the animals at risk will influence the distances over which animals perceive, and hence can take avoiding/evasive action. Environmental circumstances such as darkness, turbid water, background noise from rough weather or ship noise may all impact perception distances and hence escape options.

Diving constraints

5.8.4 Marine mammals are accomplished divers and typically dive close to aerobic dive limitations (Costa *et al.,* 2001). This means that animals do not have unlimited time and manoeuvrability underwater and may have few options other than swimming upwards to the surface towards the end of dives. In addition to this, buoyancy varies among marine mammals from negative to neutral to positively buoyant (bottlenose dolphins-right whales respectively). Irrepressible positive buoyancy is a particular problem for whales such as right whales when surfacing from depth and therefore constrains manoeuvring options.

Attraction

5.8.5 It is quite possible that marine renewable devices will not be perceived as a threat but instead attract marine mammals perhaps as a result of devices acting as FADs or artificial reefs. However, robust studies on associations between UK marine mammals and such structures have not yet been carried out. It is also possible that species such as seals and small delphinids will be attracted to renewable devices should they injure or disorientate their prey.

Confusion

5.8.6 We do not yet know how marine mammals will respond to perceiving a marine renewable device, especially one with moving parts. It is quite possible that they will simply swim around it but it is also possible that they will respond in an inappropriate way. This is particularly likely for devices with gaps that move relative to the animal's trajectory such as ducted turbines. Alternatively, in arrays, an escape response from one device may put the animal into a collision path with another, – the so-called “Ricochet effect”.

Distraction

5.8.7 Marine mammals undertake a variety of activities underwater from simple transits, social interactions to complex foraging tactics. It is likely that during some of these the animals' awareness of objects in the water column will be compromised. A particular example is the range detection problem encountered by echolocating cetaceans. When acoustically locked onto prey they reduce the inter click intervals of their echolocation clicks such that they become acoustically "blind" to objects at greater distance than their intended prey (Au, 1993). Therefore cetaceans such as harbour porpoises and bottlenose dolphins feeding around submerged devices run an enhanced risk of close encounters without active acoustic detection.

Illogical behaviour

5.8.8 It is commonly believed that marine mammals have a high capacity for intelligent behaviour and as such would act adaptively when faced with a threat. However, there are many examples where this is not the case. The reticence of dolphins to leap the head line of tuna nets (Section 5.2) is a prime and ecologically significant example.

6 Overview of Sensitivity of Species and Sites in Welsh waters

6.1 Introduction

6.1.1 In this section we comment on the likely relative vulnerability of different species and types of marine mammals based largely on knowledge of their biology. However, we stress that without empirical data on how individuals of different species, ages and gender respond to particular devices this remains largely speculation.

6.1.2 We consider sensitivity at three different levels.

- Sensitivity of individuals;
- Biological sensitivity on local population viability; and
- Public profile /political, sensitivity related to likely extent of public response to any incidents.

6.1.3 In addition, sensitivity for different sites in Welsh waters is also briefly commented upon in this section.

6.2 Sensitivity of individuals

6.2.1 Sensitivity at this level is related to their propensity to encounter, and ability to detect, avoid and evade devices and the likely consequences in terms of injury or mortality if a collision were to occur.

6.2.2 The likelihood of an animal coming close to an operating device will depend on their patterns of movement and underwater behaviour within high tidal current areas. Because collision risk is likely to be higher and of greater consequence when currents are higher, tidal and diurnal patterns in this behaviour is important. The aggregate of the movement patterns of many individuals is the fine scale distribution and density of animals within an area, and for cetaceans at least, it is this which is most likely to be measured by surveys in the field. As we have already stated (Section 2.4) understanding of distributions and densities at a sufficiently fine spatial scale is almost entirely lacking for all marine mammals. A program of surveys, such as those undertaken by Gordon *et al.* (2011) as part of the MRESF project, but on a much larger spatial and temporal scale, will be required. The proportion of time animals spend at different depths is also relevant to assessing encounter risk. All marine mammals encountered in Welsh waters are quite capable of reaching any depths at which tidal turbines are likely to be sited. What is virtually unknown is the underwater behaviour of any marine mammals within tidal rapids. Again, a substantial amount of focused dedicated research, along the lines of that undertaken by Gordon *et al.* (2011), is needed to provide this type of information. It is possible that marine mammals make more or less use of tidal rapids at different stages of their lives. For example, preliminary telemetry results from Anglesey suggest that newly weaned seals, spend a lot of their time in these areas especially in the first few weeks after they leave their natal haulouts (Gordon *et al.,* 2011), a pattern which is not generally evident in telemetry data for adults (Hammond *et al.,* 2005)

6.2.3 Avoidance depends on an animal's ability to detect the device and on being motivated to avoid it. Given the shortcomings of visual detection in turbid inshore tidal waters, detection is most likely to involve acoustic sensing. All marine mammals have good acoustic sensitivity and audiograms exist for all the species commonly found in Welsh waters, with the exception of the baleen whales. Odontocetes are high frequency specialists; seals have better hearing at mid and lower frequencies while baleen whales are believed to have best sensitivity at lowest frequencies. Detection range will often be determined by masking by background noise. The process of masking is quite well understood and is relatively consistent between mammalian species, and the effects of different levels of noise on detection range can be modelled, under a range of assumptions, with some confidence. Thus, given acoustic signatures for particular devices it will be possible (for those species for which there are reliable audiogram data) to calculate a range of distances at which the signal will be detectable in a range of different propagation and background noise conditions. All the odontocetes (porpoise, dolphins, pilot and killer whales) have a well-developed echolocation system and this provides an additional means of detecting devices which will be affected by the acoustic reflective characteristics of devices rather than their noise output. Enough is understood about odontocete echolocation capabilities to be able to model likely detection distances in a range of propagation and noise conditions.

6.2.4 Thus, in very broad terms, there might be some basis for predicting that seals and baleen whales will be more likely to detect devices making predominantly low frequency noise and odontocetes more likely to detect devices with a strong high frequency component to their acoustic output. In addition, because they have an echolocation capability, odontocetes may have an enhanced detection capability (though see discussion in Section 5.7 on potential shortcomings of echolocation for detection in these circumstances).

6.2.5 What is unknown however, is how different species and individuals will respond to devices when they detect them. We might expect smaller more frequently predated marine mammals such as seals and porpoises, to be more timid and likely to avoid a novel stimulus. Seals however, often seem to be curious about objects that are not perceived as a threat. What is certain is that as soon as animals are exposed to devices they will start to learn about them, and the way that they respond will adapt as a consequence. In the absence of negative reinforcement, it is likely that animals will habituate to or at least come to tolerate signals from devices. This will lead to reduced avoidance and an increased risk of collision. Alternatively, animals may learn to co-exist with devices and behave in ways that reduce collision risk. The potential for animals to habituate to, or learn about devices, will be higher if they show a higher degree of site fidelity and therefore likely to repeatedly encounter them. Information on site fidelity is somewhat limited. Satellite telemetry shows that grey seals can alternate between periods predictably using the same haul out sites and foraging locations and periods of wandering over large areas. Seals may return seasonally to the same beaches to breed. Photo-identification studies of well marked species such as bottlenose dolphins and Risso's dolphins show that at least some individuals in Welsh populations show a degree of site fidelity (De Boer, 2009). There is an intriguing suggestion in Barradell (2009), based on identifications of individuals made by eye, that porpoises using a tidal rapids habitat in Ramsey Sound show site fidelity.

6.2.6 The effectiveness of evasion at short range in avoiding collisions will depend on several factors. In addition to being able to detect the device and respond "appropriately", manoeuvrability and swim speed will be important considerations. The probability that an animal swimming straight through a turbine will be struck by a blade will depend on the animal's body length and swim speed, the rotation rate and the number of blades. Animals whose net speed is less than a body length divided by the rate of rotation times the number of blades will always be hit. Thus, larger animals, such as baleen whales, will be less likely to be able to swim through a turbine without collision. To avoid a turbine, animals may have to swim against the current. All marine mammals are capable of swimming at speeds greater than tidal currents, provided they have sufficient time to respond. Larger animals with greater inertia may have lower initial acceleration. Manoeuvrability will also be important for short range evasion. Generally, smaller animals will be more manoeuvrable. Seals may have an additional advantage in that their bodies seem more flexible and, unlike cetaceans, they can swim backwards if necessary.

6.2.7 The consequences of any collision for individual animals will depend on the speed of the blade at the place on the blade where contact occurs. For horizontal turbines, blade speed increases linearly with distance from the central axis of the turbine. It is worth bearing in mind that the turbine hub, which may be the site of the axle and gears may be the most acoustically conspicuous part of a turbine both as a source of noise production and as a large and consistent sonar target. Lateral movements to avoid this will take animals towards the periphery where blades will be rotating more quickly.

6.2.8 Blows to different parts of the body will probably vary in the likelihood of inflicting serious injury. We might expect larger animals to be more resilient to collision at any particular speed, thus smaller animals, such as porpoises and seals, might be most easily injured.

6.3 Biological sensitivity

6.3.1 From a conservation and management perspective, it might be argued that the primary concern is whether the injury, mortality or disturbance caused by collision has an effect on the viability of populations. Population size, reproductive rate, age at sexual maturity, longevity and other sources of mortality or reduced viability, including anthropogenic impacts will be key considerations in determining the biological significance of any effects from underwater marine renewable devices. A crucial factor in any such calculation will likely be the size of the unit that managers decide to designate as the management population. Information on movements, genetic and cultural variability allied with management objectives will be important factors in making this decision. From a conservation perspective, the level of legal protection offered to individual mammals and populations will also have an influence on the conservation and management significance of any impacts.

6.4 Political sensitivity

6.4.1 Marine mammals are highly developed, charismatic mammals and the public respond to them on a variety of levels, in addition to concerns related to conservation. These include concerns for their welfare and emotional and aesthetic considerations. In addition, in some areas, marine mammals can be considered to have tangible financial value. They may be important for tourism for example, either as the primary targets of wildlife watching activities, or more generally as icons and ambassadors and part of a region's public profile.

6.4.2 All cetaceans are European Protected Species and it is an offence to injure or disturb them wherever they occur. In addition seals and cetaceans that can be shown to use a protected area, such as an SAC are also often afforded a special status even when they are outside the SAC itself. Grey seals are cited as an Annex II species that were a primary reason for site selection for the Pembrokeshire Marine SAC and bottlenose dolphins are cited as the species that is the primary reason for the site selection on the Cardigan Bay SAC. Telemetry and photo identification studies have shown that seals and dolphins that "use" these sites travel widely throughout Welsh waters (and beyond) including spending time in tidal rapid areas.

6.4.3 All marine mammals are likely to tug at the public's heart strings, but the profiles of bottlenose dolphins and seals are particularly high. It is also likely the public will be particularly concerned about the fate of young animals. Animals which are known as individuals through photo-identification studies, some of which may actually have been "adopted" by members of the public, are likely to have a higher profile than others. There have been substantial photo-identification projects on bottlenose dolphins and Risso's dolphins in Wales, as well as photo-id research with seals.

6.4.4 Marine mammals are a specific target for wildlife tourism in several locations. Of the high tidal current areas porpoises and seals are particular attractions off Skomer and Ramsey sound in Pembrokeshire. Seals and cetaceans are also part of the tourist offering of the Lleyn Peninsular while seals are a feature of trips to Puffin Island of Anglesey. In all areas there is a high level of public awareness of marine mammals and locally-based volunteer research groups routinely watch and collect data from them.

6.5 Relative sensitivity of different sites in Welsh waters

6.5.1 The likelihood of collisions occurring will depend on many factors, and as we have seen in this review, most of these are as yet very poorly understood. However, densities of animals in tidal rapids during tidal states when currents are sufficiently high to drive turbines will be one important predictor of collision risk. All four Welsh sites have significant marine mammal populations and potential impacts on these charismatic animals and their populations will be an important consideration for regulators and developers. It is likely that at all sites porpoises are the most abundant marine mammal.

6.5.2 Of the four primary sites of interest in Wales, the Bristol Channel region seems to have the lowest densities of marine mammals, although it is also the least well studied and monitored of areas. The Pembrokeshire sites have particularly high densities of marine mammals and a diverse species mix. Gordon *et al.* (2011) found higher acoustic detection rates for porpoises here than have been reported for any other region in Europe and common dolphins are also abundant. Tidal rapids here are close to areas where minke whales are often sighted and fin whales are also seen regularly. The area is close to the Cardigan Bay SAC for bottlenose dolphins and individuals of this species are sighted here. Tidal rapids areas are within the Pembrokeshire Marine SAC for which grey seals are cited as an Annex II species which are a primary reason for selection. Of the remaining two sites, the Lleyn peninsular may be considered to have a more significant and diverse marine mammal population than North Anglesey. In addition to high porpoise densities the local, apparently resident, population of Risso's dolphins are an important consideration. The Lleyn Peninsula SAC includes and abuts tidal rapids. Both grey seals, which breed in the SAC and bottlenose dolphins, are cited as Annex II species that are qualifying features but not the primary reason for selection.

6.5.3 The Countryside Council for Wales have undertaken some work recently to assess the <u>relative</u> levels of risk for negative impacts on marine mammals from tidal stream devices in Welsh waters (Smith *et al.*, 2011). Simple vulnerability models were developed to incorporate information on species' distribution, life history traits, population status and conservation status factors in order to assess the relative sensitivity of marine mammals in different areas around Wales. The outputs from this work included GIS based evidence layers which were incorporated into Stage 3 of the MRESF.

7 Potential for Mitigation

7.1.1 At this stage in the tidal-stream energy industries' development several potential mitigation measures to reduce the potential for and severity of collisions can be suggested (Table 7-1). These are likely to become more sophisticated as more becomes known about the nature and extent of issues once devices are *in situ.* The applicability of the measures suggested here will depend heavily on the device design, location and species at risk. Clearly some of those (e.g. padding on leading edge of rotor or seasonal shutdowns etc will have significant implications for the viability (economic/functionality) of the renewable energy device(s). It is also important to note that mitigation is only required if the potential impact is considered to be significant particularly as defined by environmental legislation.

7.1.2 Mitigation measures that increase the options for avoidance are desirable (ie provide sufficient information to approaching animals so that they can take appropriate choices) as they will reduce the number of device-animal close encounters. However, they also have to be considered in relation to their potential to cause habitat exclusion and other unintended consequences. For example, underwater acoustic alarms may give marine mammals or fish good warning of renewable devices but if too loud they may exclude the animals from valuable habitat or steer animals into adjacent structures. An additional consideration is that when startled, odontocetes may cease vocalising, perhaps to reduce the probability of detection by a predator (Richardson *et al.,* 1995). If this means they can no longer vocalise then their capacity to detect devices by active echolocation will be removed.

7.1.3 In order to comply with environmental legislation it maybe necessary to monitor in real time for the presence of marine mammals in device proximity and slow down or stop moving blades if there is an approach and associated perceived risk of collision. Restrictions of this type have been required in Strangford Lough (MCT 2010) as a condition of consent. A key consideration here will be the reliability with which animals can be detected and localised in time for mitigation action to be taken. The rough sea conditions typical in these waters, when tidal currents are running and the turbines blades are moving , make visual monitoring problematic , even when wind speeds are low. Sighting conditions will deteriorate further as wind speeds increase, there is fog or rain, and be impossible at night. Active sonar is one method of detecting animals underwater and high frequency scanning devices can provide images of objects within the unit's beam. Such an approach has the added advantage of being able to detect animals while they are in a submerged phase (when presumably they are at most risk of interacting with moving parts). One shortcoming with many existing sonar systems is that while a broad horizontal swath can be achieved by scanning the units narrow transmit and receive beams. The vertical extent of the detection beam is very limited so that it may be difficult to cover the full depth swept by turbine blades at close range. We are unaware of any work that shows the true operational detection efficiency of active sonar for detecting the species of interest/risk. However, these devices have been used, apparently with some success at Strangford Lough (MCT 2010), and there are efforts to develop systems with features optimised for these applications, including automated detection, tracking and classification of appropriate targets.

7.1.4 Alternatively, the orientating/hunting vocalisations made by odontocetes are high frequency and can be detected using hydrophone arrays. It is perhaps relevant to note that Gordon *et al,* (2011) found that simple passive acoustic methods provided a higher detection rate than a three man visual team during surveys for porpoises in high tidal current areas in Wales. Arrays of hydrophones can provide location data and tracks. For example, Gordon *et al*. (2011) used a vertical array of hydrophones to determine range and depth of vocalising porpoises in high tidal current areas. Extending this work, they have had recent success using a 3D array to localise and track porpoises (Gordon, *pers, comm.)*. A system of fixed hydrophones on or close to turbine supports could potentially be useful in measuring avoidance and/or in providing mitigation. Not all marine mammals vocalise as obligingly as porpoises however and it’s likely that for a detection system to achieve both a high detection probability and a low false alarm rate, a combination of detection systems will be required. Ultimately, to know how much mitigation will eventually be necessary, some quantification will be needed of whether the potential concerns described in this report actually translate into real injurious collisions. These events could either be measured at the device at the time of impact (using rotor-mounted strain gauges, video or acoustic cameras etc). Or the resulting injured animals or carcases examined through surveys for beach-cast strandings or observation of injured animals on haul-outs etc. Both of these approaches (collision detection/spotting victims) are relatively desirable as they provide definitive evidence of acute negative impacts. However neither approach has been fully explored, either for their statistical power to properly identify impacts if they occur nor to determine that impacts have not actually occurred. Notably the distinguishing signs of injury we should expect on a carcase or live animal resulting from contact with an operating turbine are as yet undetermined.

Table 7-1 Potential mitigation measures

Aim	Mitigation	Comments	Potential Feasibility and Considerations
Reduce encounter risk	Location of device relative to the bathymetry.	Ensure space is left around the device.	Devices will be spaced apart, but by how much is currently uncertain and likely to be variable between device and site. The spacing required to benefit marine mammals cannot be determined at present given the current state of knowledge.
	Device design choice.	Scale of device appropriate for area and species present. Certain devices designs may be easier to detect than others.	Potential impacts would need to be assessed on a case by case basis.
	Location choice.	To avoid priority areas *e.g.* significant breeding, migration or feeding grounds.	Likely requirement for additional baseline data to determine these, although designated sites and existing broadscale datasets are a starting point.
	Closed seasons.	To protect areas at vulnerable seasons *e.g.* seal pup first foraging trips.	Would be likely to have significant implications for developers if devices were required to be shut down for long periods of time. Would need additional understanding on vulnerable seasons and potential benefit of the approach.
	Depth.	Site device at depths at which animals spend least time.	Would need better understanding of how marine mammals use the water column. Likely to be site and species specific.
Raise device(s) conspicuousness	Device visibility.	Blade colour or lighting (but may act as an attractant).	Colours used may be included in Maritime and Coastguard Agency requirements. Visual acuity of target species needs consideration and study.
	Addition of acoustic deterrents/warning/alerting devices (e.g. pingers/seal scarers).	Must be directed at the relevant hearing abilities.	Potential for negative impacts, habitat exclusion and habituation will also need to be considered.

Aim	Mitigation	Comments	Potential Feasibility and Considerations
			Startling noises, which may result in panicked flight and/or reduced echolocation should be avoided.
	Avoid locating devices in areas with high background noise levels which will compromise animal's ability to hear devices or to detect them through echolocation and affect detection of alerting signals.		Extensive field testing required.
Protect against close encounter	Protective netting or grids.	May be collision or entanglement hazards themselves.	Are likely to become fouled and have negative effect on energy generation potential of device.
Soften collision	Shock absorption on structures of concern.	e.g. faired padding on rotor leading edge.	Benefits uncertain and potential to have negative effect on energy generation potential of device.
	Reduce sharp edges.	Particularly in areas likely to receive a glancing blow or be used for hauling out.	Benefits uncertain and potential to have negative effect on energy generation potential of device.
Slow blades	Shut down on marine mammal approach/detection.	Use visual observers, passive acoustic monitoring and active sonar; very probably in combination.	Approach used in Strangford Lough as a precaution and it is still unclear if this is necessary. Method has considerable financial implications.

8 Knowledge Gaps and Priority Research

8.1.1 Key knowledge gaps have been set out in Table 8-1. As well as a general improvement in our understanding of the basic biology of species in the areas of concern, there is also a need (and opportunity) to ask more targeted questions of existing datasets. Also, while there are several approaches to better understanding the nature of marine mammal – tidal device interactions, no single approach will answer all questions. So it is likely that a combination of approaches will allow the industry to move forward without substantial deleterious impacts on local marine mammal populations.

8.1.2 Modelling encounter/collision risk provides one assessment method and potentially the important capacity to compare between device types, concepts and specific design features. However, detailed parameterisation will prove too challenging to provide absolute estimates of collision rate because the nature of marine mammal behaviour, including habituation, sensitisation and learning, are not known. It will therefore be particularly important to conduct targeted research on existing and forthcoming turbines in parallel to any modelling exercises.

8.1.3 Thus, hand-in-hand with modelling should give better parameterisation of key features such as how animals use these tidal features; what precisely is being targeted by them; how animals behave in these areas (including their diving behaviour and any, diel, tidal cycles and seasonal cycles) and what their responses to encountering devices are likely to be. An example of the type of studies that should, in time, be able to provide this type of data is provided by the WAG funded surveys being undertaken as part of the MRESF project, reported in Gordon *et al.,* (2011).

8.1.4 In addition, there are a variety of opportunities to better equip future research initiatives and installations. Developments of marine mammal detecting active sonar and passive acoustic monitoring are ongoing elsewhere (e.g. SMRU, SMRU Ltd. Pers. Comm..) but are equally applicable to Welsh waters. However, survey techniques developed for the open sea, face significant logistical/methodological issues when applied in fast flowing water and restricted sites and refinements and rethinking of these is required. A number of these issues were addressed as part of the MRESF project reported in Gordon *et al.* (2011). Methods to better understand and refine the cues that marine mammals receive from turbines will be extremely helpful in giving the animals themselves more information with which to respond appropriately (e.g. acoustic output). Finally, there are many opportunities to improve the design of tidal-stream energy developments to reduce conflict with marine mammals. These range from specifics of device design (colour, blade thickness, tip speed etc) to array spacing and placement to construction, maintenance and decommissioning methods.

Table 8-1 Some Key Knowledge Gaps

Distribution and abundance			
	Aspect	**Known**	**Unknown**
Seals.	Distribution.	Good data on haul-out distribution. Some data and predictive models of at-sea distribution at a broad scale.	Fine-scale at-sea distribution over most areas and particularly in areas of high tidal current. Likely to be conducted on a site by site basis.
	Abundance and population trends.	Comparatively good data from breeding counts.	
Cetaceans.	Distribution.	Species present. Broad brush distribution. High-resolution information in some areas.	Fine-scale distribution in most areas but especial knowledge of distributions areas with high tidal current over tidal and circadian cycles. Likely to be conducted on a site by site basis. Winter distribution. Nocturnal distribution. Tidal influences on distribution. Seasonal movements.
	Abundance	Broad brush density estimates (porpoises), population estimates (bottlenose dolphins)	Population trends of any species. Abundance, densities, in areas of high tidal current. Project such as the MRESF (see Gordon *et al.,* 2011) have increased the knowledge base, but additional site specific data will be required.
Sensory capability and use in feeding and predator evasion			
	Aspect	**Known**	**Unknown**
Seals and cetaceans.		Capacity of key senses in seals and small cetaceans.	Mysticete hearing unknown. No audiogram for grey seal. How all species use their senses to detect and catch prey. Whether outputs from devices will mask

Distribution and abundance			
	Aspect	**Known**	**Unknown**
			biologically relevant cues. How much warning information devices will produce and how these will be perceived. Esp. how moving structures (e.g. turbines) will be perceived by echolocating species.
	Sensitivity to EMF	Unexpectedly high sensitivity to electrical fields reported in pinnipeds	Sensitivity in cetaceans to EMF Extent to which pinniped and cetaceans may be affected by EMF from generation units and transmission cables. Extent to which this sensitivity is indicative of a sensory function, and whether this could be useful in these contexts.
Behaviour			
	Aspect	**Known**	**Unknown**
Seals and cetaceans.	Responses to devices.	Information available on responses to analogous structures. Manoeuvring abilities.	Reaction distances to devices. Precise responses on detection of devices (attraction/avoidance/evasion etc). Sonar monitoring such as that underway at Strangford Lough could provide some insight here.
	Affinity for tidal streams.	Areas of high tidal flow selected by many species.	Why these areas are so favoured. 3 dimensional use of these areas, building on the work undertaken by the MRESF (see Gordon *et al.*, 2011).
Encounter rates (for a model similar to Wilson *et al.*, 2007) – note: Model constructed to consider the magnitude of potential interactions between marine species and a commercial scale development of 100 tidal turbines. It calculates encounter risk not the number of collisions.			
	Aspect	**Known**	**Unknown**
Marine mammals.	Harbour porpoises.	Population size, body size and average swimming speed.	Population distribution relative to device placement – especially areas of strong tidal flow, building on the work undertaken by the MRESF (see Gordon *et al.*, 2011). Depth distribution in waters of high tidal energy and proportion of time moving vertically within the water column, building

Distribution and abundance			
	Aspect	**Known**	**Unknown**
			on the work undertaken by the MRESF (see Gordon *et al.*, 2011). Responses once submerged when devices are detected. Implications of social and foraging behaviour on avoidance/evasion.
	Other species.	Equivalent information available for several other species, especially seals and minke whales. Information on vertical distribution potentially best for seals.	Information gaps as above.
Range of potential responses (avoidance/evasion)			
	Aspect	**Known**	**Unknown**
Seals and cetaceans.	Detection.	Sensitivity to visual and acoustic underwater cues generally known for seals and small cetaceans.	Sensory abilities of large whales Impact of environmental circumstances (e.g. darkness, turbid water, background noise) on perception distances and hence escape options.
	Evasion.	Swimming/turning abilities generally known.	Behavioural and locomotory responses of animals once devices detected. Use of the sonar monitoring at Strangford Lough could provide some insight here.
	Diving constraints.	Diving performance for many species. Proportion of time at different depths for some species, especially in areas of high tidal current.	Surfacing options when animals at or past their aerobic diving limits. Impacts of buoyancy constraints on vertical manoeuvring options.
	Attraction.	Attraction likely for seals and small cetaceans.	How foraging compromises abilities to perceive and avoid underwater structures.
	Confusion.		Interactions between multiple devices and effects on avoidance/evasion options. Will rely on further device specific research on array distribution/ device spacing.
	Distraction.	Collisions with nets	Severity of sensory abilities (esp.

Distribution and abundance			
	Aspect	**Known**	**Unknown**
		suggest confusion/distraction occurs.	echolocation) being compromised by other activities (foraging, social interaction etc).
	Illogical behaviour.	Examples from fisheries interactions.	How marine mammals will perceive then respond to novel structures in the marine environment. Use of the sonar monitoring at Strangford Lough could provide some insight here.
Potential effects of collision risks			
	Aspect	**Known**	**Unknown**
Seals and Cetaceans.	Disturbance/ avoidance.	Avoidance likely in several species.	Implications for habitat exclusion. Will require greater knowledge of habitat use, building on broadscale studies of cetacean distribution such as Baines and Evans (2009). Long-term impacts of short-term behavioural responses.
	Injury.	Range of outcomes – minor injuries, temporary or permanent debilitation, death. Instant death less likely than other injuries but easier to detect and attribute to cause.	Magnitude of collisions required to cause significant injuries, relative vulnerabilities of different parts of the body in different species and post-mortem signs in/on carcases following injury. Study of strandings may provide some information here. Signature of any non-lethal signs in living animals following collisions.
	Exploitation.	Seals and small delphinids likely to exploit any increased foraging opportunities around devices.	Potential benefit of foraging opportunities against cost of higher collision risk.

9 Conclusions

9.1.1 Wales is fortunate in having both significant tidal energy resources and healthy and relatively abundant marine mammal populations. However, this raises a concern that exploiting the former to provide a renewable source of electricity could have deleterious impacts on the latter. Because current driven tidal turbines are such new features in the marine environment there is virtually no direct information on the effects that they could have on marine mammals. However, a detailed review shows that some risks do raise potential concerns, because of their potential to impact both charismatic protected species and marine mammal-based tourism activities. The possibility of collision between marine mammals and rotating turbine blades is believed to be potentially the most serious of these risks, although a variety of mitigation measures may be effective in reducing impacts. Substantial uncertainties exist in all areas necessary to properly understand these risks and it is important that these are addressed as soon as possible. Some of this work can be initiated immediately. Other research can only be undertaken when the first test devices come into operation. It is important that an appropriate level of effort is expended to allow a timely assessment of risk, and the development of any necessary mitigation measures, to take place before the main phase of commercial turbine installation gets underway.

References

ABPmer (2004) Atlas of UK Marine Renewable Energy Resources: Technical Report. ABP Marine Environmental Research Ltd, Report No. R 1106.

ABPmer (2010) Collision Risk of Fish with Wave and Tidal Devices: report commissioned by RPS Group plc on behalf of the Welsh Assembly Government. ABPmer Report 1516.

Anon (2005) Giant whales spotted off Wales.

Anon (2009) Sea Trust spots pod of fin whales off Pembrokeshire coast. Western Telegraph.

Aquascientific (2010) Turning the tide on alternative energy. Technology www.aquascientific.com/#/technology/4518299356.

Au, W. L. (1993) The sonar of dolphins. New York: Springer-Verlag.

Au, W. W. L. and L. Jones (1991) Acoustic Reflectivity of Nets – implications concerning incidental take of Dolphins. Marine Mammal Science, 7, 258.

Axenrot, T., T. Didrikas, C. Danielsson and S. Hansson (2004) Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer. Ices Journal of Marine Science, 61, 1100.

Baines, M. E. and P. G. H. Evans, (2009) Atlas of the Marine Mammals of Wales. . In: CCW Monitoring Report No. 68. Countryside Council for Wales.

Baines, M. E., M. Reichelt, P. G. H. Evans and B. Shepherd, (2002) Bottlenose dolphin studies in Cardigan Bay, West Wales. Final Report to EU INTERREG and the Countryside Council for Wales. 18pp. Sea Watch Foundation.

Band, W., M. Madders and D. P. Whitfield, (2005) Developing field and analytical methods to assess avian collision risk at wind farms. In: Birds and wind power. M. De Lucas, G. Janss and M. Ferrer (Eds.). Lynx Editions, Barcelona.

Barradell, M. G., (2009) Fine scale use of Ramsey Sound, Pembrokeshire, West Wales, by harbour porpoise (*Phocoena phocoena*). 45. Pembrokeshire College, Haverfordwest.

Benoit-Bird, K. J., W. W. L. Au, R. E. Brainard and M. O. Lammers (2001) Diel horizontal migration of the Hawaiian mesopelagic boundary community observed acoustically. Marine Ecology-Progress Series, 217, 1.

Brodin, Y. and M. H. Andersson (2009) The marine splash midge *Telmatogon japonicus* (Diptera; Chironomidae)-extreme and alien? Biological Invasions, 11, 1311.

Buckley, R. M., D. G. Itano and T. W. Buckley (1989) Fish Aggregation Device (Fad) Enhancement of Offshore Fisheries in American-Samoa. Bulletin of Marine Science, 44, 942.

Calderan, S. V., (2003) Fine-scale temporal distribution by harbour porpoise (*Phocoena phocoena*) in North Wales: acoustic and visual survey techniques. In: School of Biological Sciences. University of Wales, Bangor.

Cañadas, A., L. Burt, K. MacLeod, E. Rogan, B. Santos, A. Uriarte, O. Van Canneyt, J. A. Vázquez and H. P.S. (2009) Abundance and distribution of common dolphins in the offshore NE Atlantic Reports of the International Whaling Commission Scientific Committee Working Paper SC-61-SM6, 15.

Carter, C. (2008) Marine renewable energy devices: a collision risk for marine mammals? MSc thesis, University of Aberdeen / UHI Millennium Institute. .

Chamberlain, D. E., M. R. Rehfisch, A. D. Fox, M. Desholm and S. J. Anthony (2006) The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models. Ibis, 148, 198.

CMACS (2003) A baseline assessment of electromagnetic fields generated by offshore wind farm cables. Rep. No. COWRIE EMF-01-2002 66. Centre for Marine and Coastal Studies.

Costa, D. P., N. J. Gales and M. E. Goebel (2001) Aerobic dive limit: how often does it occur in nature? Comparative Biochemistry and Physiology a-Molecular and Integrative Physiology, 129, 771.

Cox T.M., Read A.J., Swanner D., Urian K. and Waples D. (2003) Behavioural responses of bottlenose dolphins, *Tursiops truncatus* to gillnets and acoustic alarms. Biological Conservation, 115, 203.

David, L. (2006) Risks of collision for fin whales in the north-western Mediterranean Sea in Summer. Fins, 16.

De Boer, M., (2009) Risso's dolpphins off Bardsey Island. 4. Whale and Dolphin Conservation Society.

De Lucas, M., G. Janss and M. Ferrer, (2005) Birds and wind power. Lynx Editions, Barcelona.

Dehnhardt, G., B. Mauck, W. Hanke and H. Bleckmann (2001) Hydrodynamic trail-following in harbor seals (Phoca vitulina). Science, 293, 102.

Desholm, M., A. D. Fox, P. D. L. Beasley and J. Kahlert (2006) Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. Ibis, 148, 76.

Desholm, M. and J. Kahlert (2005) Avian collision risk at an offshore wind farm. Biology Letters, 1, 296.

Dill, L. M. (1974) Escape Response of Zebra Danio (Brachydanio-Rerio) .1. Stimulus For Escape. Animal Behaviour, 22, 711.

Donovan, G. P. and A. Bjorge (1995) Harbour porpoises in the North Atlantic: Report of the IWC Scientific Committee, Dublin 1995. Reports of the International Whaling Commission 16, 3.

Drewitt, A. L. and R. H. W. Langston (2006) Assessing the impacts of wind farms on birds. Ibis, 148, 29.

Earl, S., E. Sheen and C. Benson, (2004) The short-beaked common dolphin *Delphinus delphis* and other cetaceans in Pembrokeshire waters and the southern Irish Sea 43. Countryside Council for Wales.

Eguchi, T. and J. T. Harvey (2005) Diving behavior of the Pacific harbor seal (*Phoca vitulina richardii*) in Monterey Bay, California. Marine Mammal Science, 21, 283.

Elwen, S., M. A. Meyer, P. B. Best, P. G. H. Kotze, M. Thornton and S. Swanson (2006) Range and movements of female Heaviside's dolphins (*Cephalorhynchus heavisidii*), as determined by satellite-linked telemetry. Journal of Mammalogy, 87, 866.

Embling, C. B., P. A. Gillibrand, J. Gordon, J. Shrimpton, P. T. Stevick and P. S. Hammond (2009) Using habitat models to identify suitable sites for marine protected areas for harbour porpoises (*Phocoena phocoena*). Biological Conservation, 143, 267.

EMEC, (2010) www.emec.org.uk/tidal_devices.asp.

Evans, P. G. H. and J. Wang, (2002) Re-examination of Distribution Data for the Harbour Porpoise around Wales and the UK with a view to site selection for this species. Report to the Countryside Council for Wales. 100. Sea Watch Foundation, Oxford.

Forrest, K. W., J. D. Cave, C. G. J. Michielsens, M. Haulena and D. V. Smith (2009) Evaluation of an Electric Gradient to Deter Seal Predation on Salmon Caught in Gill-Net Test Fisheries. North American Journal of Fisheries Management, 29, 885.

Forrest, K. W., J. D. Cave, D. V. Smith, L. Harlan, C. Burger, L. Carstensen, K. Smith, C. Beggs, B. Munro and M. Haulena., (2008) Evaluation of the use of an Electrical Gradient as a Seal Deterrent Report to the Southern Fund Committee. 19.

Fox, A. D., M. Desholm, J. Kahlert, T. Kjaer Christensen and I. B. Krag Petersen (2006) Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis, 148, 129.

Garthe, S. and O. Huppop (2004) Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. Journal of Applied Ecology, 41, 724.

Gill, A. B., I. Gloyne-Phillips, K. J. Neal and J. A. Kimber, (2005) The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms – a review. Report for COWRIE. 128. CMACS.

Gillespie, D., R. Swift, M. Caillat, J. Gordon and K. Macleod (In review) Acoustic detection and tracking of harbor porpoise on line transect surveys. Journal of the Acoustical Society of America.

Goodson A.D., (1996) Sonar characteristics of the harbour porpoise (*Phocoena phocoena*): source levels and spectrum. ICES Journal of Marine Science, 53, 465.

Goodwin, L. and C. Speedie (2008) Relative abundance, density and distribution of the harbour porpoise (*Phocoena phocoena*) along the west coast of the UK. Journal of the Marine Biological Association of the United Kingdom, 88, 1221.

Goold, J. C. (1998) Acoustic assessment of populations of common dolphin off the West Wales Coast, with perspectives from satellite infrared imagery. Journal of the Marine Biological Association of the United Kingdom, 78, 1353.

Goold, J. C. (2000) A diel pattern in vocal activity of short-beaked common dolphins, *Delphinus delphis*. Marine Mammal Science, 16, 240.

Gordon, J., D. Thompson, S. Gillespie, M. Lonergan, S. Calderan, B. Jaffey and V. Todd, (2007) Assessment of the potential for acoustic deterrents to mitigate the impact on marine mammals of underwater noise arising from the construction of offshore windfarms. 71. Sea Mammal Research Unit, for Cowrie Ltd, St Andrews.

Gordon, J., D. Thompson, R. Leaper, D. Gillespie, C. Pierpoint, S. Calderan, J. Macauley and T. Gordon, (2011) Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh Waters. Phase 2 - Studies of Marine Mammals in Welsh High Tidal Energy Waters. Doc Ref. JER3688R091109JG Version 4. Report to the Welsh Assembly Government. EcologicUK.

Greenwood, J. J. D. (2005) Wind, fire and water: renewable energy and birds. A report on the BOU's annual conference held at the University of Leicester, 1-3 April 2005. Ibis, 147, 865.

Grellier, K., P. M. Thompson and H. M. Corpe (1996) The effect of weather conditions on harbour seal (*Phoca vitulina*) haulout behaviour in the Moray Firth, northeast Scotland. Canadian Journal of Zoology-Revue Canadienne De Zoologie, 74, 1806.

Hagerman, G. (2004) Offshore wave power in the US: Environmental Issues. E2I Global EPRI-007-US report. .

Hall, M. A. (1998) An ecological view of the tuna-dolphin problem: impacts and trade-offs. Reviews in Fish Biology and Fisheries, 8, 1.

Hammond, P. S., (2006) Small Cetaceans in the European Atlantic and North Sea (SCANSII). LIFE4NAT/GB/000245 Final Report.

Hammond, P. S., K. Macleod, P. Berggren, D. Borchers, L. Burt, A. Cañadas, G. Desportes, G. Donovan, A. Gilles, D. Gillespie, J. Gordon, S. Hedley, L. Hiby, I. Kuklik, R. Leaper, K. Lehnert, M. Leopold, P. Lovell, N. Øien, C. Paxton, C. Ridoux, E. Rogan, F. Samarra, M. Sequeira, U. Seibert, H. Skove, R. Swift, M. Tasker, J. Teilmann, O. Van Canneyt and J. A. Vazquez (In Press) Distribution and abundance of harbour porpoise and other cetaceans in European Atlantic shelf waters (submitted to the Journal of Applied Ecology, June 2009).

Hammond, P. S., S. P. Northridge, D. Thompson, J. Gordon, A. J. Hall, G. Aarts and J. Matthiopoulos, (2005) Background information on marine mammals for Strategic Environmental Assessment 6. 73. Sea Mammal Research Unit, St Andrews.

Hastie, G. D., B. Wilson and P. M. Thompson (2006) Diving deep in a foraging hotspot: acoustic insights into bottlenose dolphin dive depths and feeding behaviour. Marine Biology, 148, 1181.

Isojunno, S., (2008) Non-linear interactions predict harbour porpoise (*Phocoena phocoena*) occurrence in strongly tidal habitat. 40. University of St Andrews, St Andrews.

IWC, (2006) 58th Annual Meeting of the International Whaling Commission. Ship strikes working group. First Progress report to the conservation committee.: 22.

Jensen, A. S. and G. K. Silber., (2003) Large Whale Ship Strike Database. 37 pp. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-OPR- 25

JNCC, (2010) JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys.

Johnston, D. W., L. H. Thorne and A. J. Read (2005) Fin whales *Balaenoptera physalus* and minke whales *Balaenoptera acutorostrata* exploit a tidally driven island wake ecosystem in the Bay of Fundy. Marine Ecology Progress Series, 305, 287.

Johnston, D. W., A. J. Westgate and A. J. Read (2005) Effects of fine-scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. Marine Ecology-Progress Series, 295, 279.

Ketten, D.R. 1995 Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In Sensory Systems of Aquatic Mammals. R.A. Kastelein, J.A. Thomas and P.E. Nachtigall (editors) De Spil Publishers, Woerden, The Netherlands.

Klatsky, L. J., R. S. Wells and J. C. Sweeney (2007) Offshore bottlenose dolphins (*Tursiops truncatus*): Movement and dive behavior near the Bermuda Pedestal. Journal of Mammalogy, 88, 59.

Laist, D. W., Knowlton, J. G. Mead, A. S. Collet and M. Podesta (2001) Collisions between ships and whales. Marine Mammal Science, 17, 35.

Linley, A., K. Laffont, B. Wilson, M. Elliot, R. Perez-Dominguez and D. Burdon, (2009) Offshore and coastal renewable energy: Potential ecological benefits and impacts of large scale offshore and coastal renewable energy projects. NERC Marine Renewables Scoping Study Final Report.

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

MCT (2010) SeaGen Environmental Monitoring Porgramme: Biannual Update. Version 1- SeaGen Biannual Environmental monitoring July 2009-Jan 2010. 21st April 2010 9S8562 www.seageneration.co.uk/downloads/

Nedwell, J. R. and A. G. Brooker, (2008) Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford Lough. Subacoustech Report No. 724R0120 to COWRIE Ltd. ISBN: 978-0-9557501-9-9.

Northridge, S., (2006) Dolphin Bycatch: Observations and Mitigation Work in the UK Bass Pair Trawl Fishery 2005-2006 Season. Occasional Report to DEFRA October 2006. DEFRA, London.

Notarbartolo-di-Sciara, G., M. Zanardelli, M. Jahoda, S. Panigada and S. Airoldi (2003) The fin whale *Balaenoptera physalus* (L. 1758) in the Mediterranean Sea. 33, 105.

Nowacek, D. P., M. P. Johnson, P. L. Tyack, K. A. Shorter, W. A. McLellan and D. A. Pabst (2001) Buoyant balaenids: the ups and downs of buoyancy in right whales. Proceedings of the Royal Society of London Series B-Biological Sciences, 268, 1811.

Oxley, R. (2006) An overview of marine renewables in the UK: a synopsis of Michael Hay's presentation. Ibis, 148, 203.

Pace D.S., M. A., and Mussi B., (2006) Vessels and dolphins: scars that tell stories. In: Fins: 19.

Panigada S., Pesante G., Zanardelli M., Capoulade F., Gannier A. and Weinrich M.T. (2006) Mediterranean fin whales at risk from fatal ship strikes. Marine Pollution Bulletin, 52, 1287.

Penrose, R. and C. Pierpoint, (1999) The use of Welsh coastal habitats as calving and nursery grounds for the Harbour porpoise (*Phocoena phocoena*). Contract Report No. 378. 22. Countryside Council for Wales, Bangor.

Pesante, G., P. G. H. Evans, P. Anderwald, D. Powell and M. McMath, (2008) Connectivity of Bottlenose Dolphins in Wales: North Wales Photo-Monitoring Interim Report. . In: CCW Marine Monitoring Report No: 62. : 42.

Pierpoint, C. (2008) Harbour porpoise (*Phocoena phocoena*) foraging strategy at a high energy, near-shore site in south-west Wales, UK. Journal of the Marine Biological Association of the United Kingdom, 88, 1167.

Read A.J., Drinker P. and Northridge S. (2006) By-catch of marine mammals in U.S. and global fisheries. Report to IWC SC/55/BC, 20, 163.

Richards, S. D., E. J. Harland and S. A. S. Jones, (2007) Underwater Noise Study Supporting Scottish Executive Strategic Environmental Assessment for Marine Renewables. QinetiQ Ltd., Farnborough, Hampshire.

Richardson, W. J., (undated) Bird migration and wind turbines: migration timing, flight behaviour and collision risk. In: National Avian - wind power planning meeting III. nationalwind.org.

Richardson, W. J., C. R. J. Greene, C. I. Malme and D. H. Thomson (1995) Marine mammals and noise. San Diego, CA: Academic Press, Inc.

Ross, H. M. and B. Wilson (1996) Violent interactions between bottlenose dolphins and harbour porpoises. Proceedings of the Royal Society B-Biological Sciences, 263, 283.

RPS (2008) Marine Renewable Energy Strategic Framework for Wales Stage 1 Report. A report to the Welsh Assembly Government.

RPS (2011) Assessment of Risk to Diving Birds from Underwater Renewable Devices in Welsh Waters. Phase 1 - Desktop Review of Birds in Welsh Waters and Preliminary Risk Assessment.

Scottish Marine Renewables Strategic Environmental Assessment (SEA) Environmental report. (2007). Report Prepared for the Scottish Executive by: Faber Maunsell and Metoc PLC.

Shucksmith, R., N. H. Jones, G. W. Stoyle, A. Davies and E. F. Dicks (2009) Abundance and distribution of the harbour porpoise (*Phocoena phocoena*) on the north coast of Anglesey, Wales, UK. Journal of the Marine Biological Association of the United Kingdom, 89, 1051.

Smales, I., (2006) Wind farm collision risk for birds: cumulative risks for threatened and migratory species. Biosis Research Pty Ltd, Melbourne.

Smith K, Briggs J, Hamer J, Hill A & Walker P (2011). Natural heritage evidence to support strategic planning for marine renewable energy. Countryside Council for Wales Policy Research Report No. 11/3.

Southall, B. L., A. E. Bowles, W. T. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene, Jr., D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas and P. L. Tyack (2007) Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals, 33, I.

Strong, P. G., J. Lerwill, S. R. Morris and T. B. Stringell, (2006) Pembrokeshire marine SAC grey seal monitoring 2005. In: CCW Marine Monitoring Report No: 26: 51. Countryside Council for Wales.

Thompson, D, Bexton, S, Brownlow, A, Wood, D, Patterson T., Pye K, Lonergan, M, Milne, R. 2010. Report on the recent seal mortalities in UK waters caused by extensive lacerations. http://www.smru.st-and.ac.uk/documents/366.pdf

Todd, V. L. G., W. D. Pearse, N. C. Tregenza, P. A. Lepper and I. B. Todd (2009) Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. Ices Journal of Marine Science, 66, 734.

Tougaard, J., J. Carstensen, J. Teilmann, H. Skov and P. Rasmussen (2009) Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). Journal of the Acoustical Society of America, 126, 11.

Ward-Geiger, L. I., G. K. Silber, R. D. Baumstark and T. L. Pulfer (2005) Characterization of ship traffic in right whale critical habitat. Coastal Management, 33, 263.

Wartzok, D. and Ketten, D.R., (1999) Marine mammal sensory systems. In: Biology of Marine Mammals: 117. R. A. Rommel (Ed.). Smithsonian Institution Press, Washington, D.C.

Watkins, H. and R. Colley, (2004) Harbour Porpoise *Phocoena phocoena* Occurrence Carmarthen Bay - Gower Penninsula - Swansea Bay December 2002 - February 2004. 98. Gower Marine Mammal Project.

Westcott, S. M. and T. B. Stringell, (2003) Grey seal pup production for North Wales, 2002. Marine Monitoring Report No: 5. 55. Countryside Council for Wales, Bangor.

Westcott, S. M. and T. B. Stringell, (2004) Grey seal distribution and abundance for North Wales, 2002-2003. . Countryside Council for Wales, Bangor.

Westgate, A. J., A. J. Read, P. Berggren, H. N. Koopman and D. E. Gaskin (1995) Diving behaviour of harbour porpoises, *Phocoena phocoena*. Canadian Journal of Fisheries and Aquatic Sciences, 52, 1064.

Whitfield, D. P. and M. Madders, (2006) A review of the impacts of wind farms on hen harriers *Circus cyaneus* and an estimation of collision avoidance rates. Natural research information note 1 (revised). . Natural Research Ltd., Banchory, UK.

Wilson, B. P. S. Hammond and P. M. Thompson (1999) Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecological Applications, 9, 288.

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.

Zamon, J. E. (2001) Seal predation on salmon and forage fish schools as a function of tidal currents in the San Juan Islands, Washington, USA. Fisheries Oceanography, 10, 353.

Zollett E.A. and Rosenberg A.A., (2005) A Review of Cetacean By-catch in Trawl Fisheries. 35. University of New Hampshire.