Marine Institute
PLYMOUTH UNIVERSITY

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see things differently

Marine Renewables, Biodiversity and Fisheries

Contents

Foreword

The scientific literature is awash with research that demonstrates that climate change will have a very significant net negative effect on biodiversity. Biodiversity isn't a luxury to be set aside when times are hard; biodiversity is integral to the ecosystem services that our natural environment provides to humans and other species; services that are essential to human wellbeing.

It is necessary to rapidly and significantly reduce greenhouse gas emissions in order to prevent levels of climate change that would decimate biodiversity, and for marine biodiversity also to prevent severe acidification of the oceans. This in turn will require countries to, inter alia, develop renewable energy to reduce the quantity of fossil fuel energy used. In the UK this will require the development of marine renewable energy.

The quantity of marine renewable energy needed in the future in the UK is debated but all main political parties, as well as the Committee on Climate Change, believe it must be a significant part of the energy mix. Friends of the Earth suggests that 5-10,000 offshore wind turbines may be necessary, alongside hundreds of kilometres of wave power and thousands of tidal stream turbines. Others, such as National Grid or Atkins, suggest less marine renewable energy than this is necessary, either by recommending large-scale nuclear power deployment and/or by advocating energy pathways with much greater greenhouse gas emissions. But all agree marine renewable energy is necessary.

Within this context Friends of the Earth and the Plymouth University Marine Institute – who are leading researchers in marine renewable energy – agreed that it would be beneficial to inform debates on the issue of marine renewable energy deployment with evidence and expert opinion with regards impacts on biodiversity and fisheries. This publication is the result. It is the work of expert academics at Plymouth University and elsewhere who, in the finest tradition of research, maintained their academic independence throughout.

We hope that you find this research of interest and use.

Mike Childs
Head of Science, Policy and Research, Friends of the Earth

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About the authors

Professor Martin Attrill – Director of Plymouth University Marine Institute

Martin is a marine ecologist whose research has focused on patterns of biodiversity in time and space and how human activity can impact those patterns. He has published over 100 peer-reviewed papers, had two chapters in a recent summary textbook on climate change and is joint author of the UK's leading Marine Ecology textbook. He has been Director of Plymouth University's Marine Institute since 2009 and biodiversity coordinator for their work on marine renewable energy. In May 2012, Prof Attrill was invited to New York to advise the United Nations on the environmental impact of marine renewable energy.

Professor Brendan J. Godley – Professor of Conservation Science

Brendan is a conservation biologist with wide ranging interests in biodiversity conservation. His research has largely focused on the study of marine vertebrates, but more recently has involved invasive species and the impacts of renewable energy facilities.

Professor Richard Thompson – Professor of Marine Biology

Richard's research focuses on the ecology and conservation of shallow water habitats and habitat modification to enhance biodiversity of marine engineering such as coastal defences and off-shore renewable energy devices. Richard has examined ways to make space for nature by incorporating habitat modifications within marine engineering structures and for example to enhance stocks of commercially important species of shellfish. He has over 100 scientific papers and book chapters including work for the International Union for the Conservation of Nature on the ecological effects of renewable energy installations. He also has a very active research programme on marine debris and in particular microplastics. He acts as an advisor on marine debris for the European Commission Marine Strategy Framework Directive and is working with the United Nations Environment Programme to identify solutions to prevent the accumulation of marine debris.

Dr Manuela Truebano – Lecturer in Marine Biology

Manuela is a marine biologist interested in the multidisciplinary study of evolutionary adaptations to the marine environment and how individuals cope with changes in the environment. She is ultimately working towards increasing our understanding of individual responses to global change, and their relevance at the population and species level.

Dr Anthony Bicknell – Postdoctoral Research Associate

Tony is interested in the ecological processes that effect foraging behaviour, dispersal and population/meta-population dynamics of species and how ever increasing environmental change may alter them. Ultimately it is working towards understanding the direct and indirect effects humans have on animal populations and how best to reduce potential negative impacts and conserve species and biodiversity.

Dr Stephen Votier – Associate Professor

Steve is a marine ecologist interested in understanding how marine top predators (mostly seabirds) respond to global change. His research focuses on understanding individual-, population- and community-level responses.

Dr Richard Inger – Postdoctoral Research Fellow

Richard's research aims to understand the interaction between animals and their habitat. Specifically how resource availability and individual foraging decisions influence the current and future condition of both individuals and populations. To achieve this he uses a range of field, modelling and lab techniques, particularly the use of stable isotopes, which allows him to address a number of fundamental questions, and applied conservation and management problems.

Dr Clare Embling – Associate Research Fellow

Clare's research focuses on understanding the links between marine vertebrates and the marine environment, so as to inform conservation management and investigating the impacts of human activities on marine vertebrates. She is studying the behaviour of cetaceans prior and post installation of wave energy devices using the WaveHub, the wave energy test site off North Cornwall. This contributes to the SOWFIA project which aims to streamline the Impact Assessment process for installation of wave energy devices.

Dr Matthew J. Witt – Lecturer in Natural Environment

Matthew's work integrates spatial ecology and conservation biology. He is particularly interested in assessing the effects of human activities on marine species and habitats e.g. fisheries and marine renewable energies, and developing approaches that integrate large datasets to achieve a greater understanding of human influence on ecosystems.

Dr Emma Sheehan – Marine Institute Research Fellow

Emma is a marine ecologist with a wide range of interests in marine conservation. Her research focuses on environmental impacts, both positive and negative, of offshore marine renewables. Emma has been developing new techniques for measuring animal communities on the sea bed, which are non-destructive and suitable to use in the vicinity of renewable energy devices. These are being used to assess the impacts of the WaveHub facility on marine organisms on the seabed. In addition Emma is monitoring the recovery of Lyme bay reefs from the cessation of bottom towed fishing.

Mr Matthew Ashley – PhD student "The effects of implementing no take marine protected areas around offshore wind farms"

Matthew's research background is in behavioural ecology of mobile marine species as well as people's social and economic use of the sea. Matthew's research focuses on assessing the feasibility of utilising offshore windfarms as marine protected areas. He is interested in the economic and social issues associated with windfarms alongside the environmental issues, leading to a balanced evaluation of the true impacts and opportunities, both short and long-term, of marine renewables development.

Summary overview: Marine renewable energy: necessary for safeguarding the marine environment?

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Introduction and context

It is necessary to rapidly deploy large quantities of marine renewable energy to reduce the carbon emissions from fossil fuel burning which are leading to ocean acidification, global warming and climatic changes. Done well and sensitively its deployment could be beneficial to marine wildlife compared to the alternative scenario of greater levels of climate change. This overview outlines current evidence and the following papers in this report go into greater detail.

According to the Met Office in the UK[1], global emissions of greenhouse gases (GHGs) need to peak in 2016, with annual declines of 3.5% every year afterwards, in order to provide even a 50:50 chance of avoiding a 2 degree rise in global average temperatures.

Yet despite major international meetings and agreements focused on reducing the output of GHGs, global emissions have continued to rise, indeed accelerate, over the last 10 years. Consequently, recent predictions of future global warming are now at the top end of models produced a decade ago or so and suggest that, without rapid action, temperatures may increase by 4 degrees or more above pre-industrial temperatures.

Climate change is now a visible reality. Each year of the 21st century has ranked amongst the 14 hottest since record keeping began in 1880. Notable warming of the seas around NW Europe has been recorded over the last 30 years, with extensive spatial changes to plankton and fish assemblages[2,3] that have subsequently impacted top predators such as cod and seabirds[4,5]. 2012 also saw the lowest ever cover of summer Arctic Sea ice.

Sea level rise is now measurable, due to both thermal expansion and ice melt, with a global average rise of 3.3 mm/year between 1993-2009[6]. This rate is accelerating: a 1m sea level rise by the end of the century in some areas is an increasing possibility, with major consequences for the integrity of low-lying coastal and wetland ecosystems.

Finally, ocean acidification is becoming measurable[7], heading us on the predicted locked-in path to lower pH seas with severe consequences for organisms using $CaCO_3$ (calcium carbonate) in their biology, such as reefs, molluscs and some key planktonic producers. It is thought that the current rate of acidification is 10-100 times faster than any time in the past 50 million years. Today's change may be unlike any previous ocean pH change in Earth's history[8].

It is therefore clear that the marine environment is already being damaged by the increasingly apparent impacts of climate change; however it is not too late to make a difference to avoid more extreme impacts.

To do so requires a major decarbonisation in the UK and other countries. The Committee on Climate Change has recommended that the UK decarbonise electricity to 50g/KWhr of CO_2 by 2030. This will require at least a ten-fold expansion of Marine Renewable Energy (MRE) even if carbon capture and storage technology or nuclear power is deployed (both of which seem unlikely at significant scale by 2030).

It is a truth that to prevent extremely negative impacts on marine biodiversity – and society – it will be necessary to intrude into the marine environment by building large amounts of MRE. Done well – in consultation with marine ecologists and conservation groups, within the spirit and letter of the Habitats Directive – MRE could hold overall benefits for the marine environment.

This paper will summarise the key main issues in terms of environmental impact of MRE devices and farms and the likely concerns. It assesses the biological impacts of offshore wind, tidal turbines and wave energy converters[1]; it will not cover barrages as such constructions have a very different range, and scale, of issues. Four main categories of potential impact are considered: collision and displacement; noise; electro-magnetic fields; introducing physical structure to the environment. The paper builds on four key reviews[9,10,11,12],plus further evidence. As a summary document can only relay broad conclusions, detail is provided in the following more detailed papers.

It is important at the outset to differentiate between *response* and *impact* on marine organisms from the construction and deployment of MRE. Organisms may respond to MRE – e.g. relocate for a period during construction, avoid tidal turbines. This may, or may not, have any negative impact on the species population. The *impact* of displacement on population size is poorly understood and is likely to be species and location specific. For example, do the responses result in energetic loss that affects survival and reproduction? Does the whole population move elsewhere, and is there anywhere for it to move to (and what of the species already in that habitat)? Is any mortality significant relevant to other factors and thus reduces overall population numbers? It is the *impact on species populations* that is of primary concern for future maintenance of biodiversity.

Collision and displacement

The potential of organisms to collide with MRE devices, in particular wind turbines, probably has the highest profile with the public and media of all the environmental issues associated with MRE, beyond aesthetics. Certainly birds and bats are killed by onshore turbines where evidence is most detailed, and can include important conservation species such as raptors. The American Bird Conservatory estimates up to 40,000 birds are killed each year in the US by wind turbines, although it is important to put this mortality in context. Erickson et al[13] analysed unnatural bird mortality in the US, reporting that 4.5 million birds are killed by flying into communication towers, 100 million by domestic cats and approximately 500 million from flying into buildings. Nevertheless, poor location of a wind turbine can have an impact on the population of *certain species,* particularly large birds of prey of conservation value such as eagles and vultures, which is why choosing the correct locations is important.

Offshore there is less evidence of significant levels of bird collisions, although collecting data is more difficult. Many species fly low over the water and so would not encounter blades of large turbines; whilst certain species such as large gulls may be more vulnerable, but data are lacking. There is some evidence that some species avoid wind turbines, or even whole wind farms, but also that some species may be attracted.

Overall, in general the main issue associated with birds and offshore wind farms appears to be one of displacement rather than collision impacts at a scale that significantly affects populations, although evidence for this is sparse and a poorly-located wind farm near colonies of species with low populations and slow breeding rates could potentially have negative impacts at a population scale. The consequences of displacement is as yet poorly understood and needs further research, although over 10 years of monitoring from some European wind farms has not evidenced any major impact.

In addition, whilst wind farms remain comparatively small, they do not seem to act as a barrier causing major energetic cost to migrating species, but extensive farms in sensitive areas may well cause major impacts. Location, spacing and the provision of corridors in large developments may mitigate this and should be considered as ways of preventing detrimental displacement.

Wave energy converters, as currently designed, present a minimal collision risk to birds unless designs develop that significantly rise above the water surface[14]. However, underwater tidal current turbines pose a similar potential collision risk as wind turbines, particularly for marine mammals, fish and some diving species of bird depending on location, design and depth of the device[15]. Clearly locating devices next to diving bird colonies or key foraging areas should be avoided.

There is much more concern about collision between marine mammals and turbines, but currently there is little evidence this occurs as to date. Cetaceans may be able to avoid the devices but only if they are able to detect the objects, realise they are a threat and be able to take appropriate action i.e. swim around, evade, swerve etc. This can be aided by the sensitive design of turbines; large, slower moving turbines should also cause less of a problem. Turbines may, if poorly sited, impact on migrating fish populations.

As for the expansion of offshore wind, however, potential problems may arise from large increases in the scale of tidal turbine deployment, with possible displacement effects at a scale that could have negative population impacts. For certain species of cetacean with a large foraging range this may not be a problem, but design and deployment needs to prevent forming long barriers to movement. Large-scale tidal turbine developments underway in other parts of the world, such as South Korea, may provide useful data.

Noise

The effect that noise has on an organism is dependent not just on the noise level, but on frequency as animals have a wide range of levels of frequency detection, often much different from humans. There is little doubt that pile driving during the construction of a wind farm produces a level and frequency of noise that organisms, particularly marine mammals, notice, as potentially can extensive use of sonar mapping methods from survey ships. Hearing loss may occur within 1.8 km for porpoise and 400 m in seals[16]. Such organisms therefore have been shown to leave an area when constructing a wind farm. Mueller-Blenkle et al[17] also found responses to distant pile driving noise in cod and sole. Construction of the Scroby Sands wind farm caused marked reductions in clupeid fish, the prime food item for a local tern colony resulting in egg abandonment and lack of chick hatching[18]. Pile driving (for not just wind farms of course) can therefore cause displacement of local populations.

The operational noise created by MRE devices appears to have a much lower impact on marine organisms than construction, primarily because the highest levels of noise are produced at low frequencies at the edge of hearing for many species[19,20].

New technologies for offshore wind may significantly mitigate the levels of noise from construction and operation. The development and use of suction pile foundations may significantly mitigate construction noise impacts, as could a move towards floating wind turbine technology, which would remove the need for major pile driving (although moorings need fixing) and there are designs for offshore, vertical axis wind turbines much more suitable for marine conditions and floating platforms. These newer technologies should be encouraged as they are likely to be a better ecological option, reducing the unequivocally most damaging aspect of MRE developments, which is pile-driving during construction.

Electromagnetic Fields (EMFs)

EMFs are produced by sub-surface cables transferring electricity to (and from) the shore, as well as, potentially, by wave generating devices that utilise magnets in their design. A range of marine organisms can detect EMFs, such as some bony fish and marine mammals, but in particular species of elasmobranch (rays and sharks) are sensitive to EMFs and can use them, for example, to detect prey or navigate during migration. The strength of EMFs from offshore cables depends on design, magnitude of current and how deep the cable is buried[21]. Potentially, sensitive species may have their behaviour changed by the presence of these fields, or their feeding disrupted, for example. Although studies have shown magnetic fields could affect fish, as yet there is little evidence that underwater cables are having any major effect[22] beyond an inconsistent range of small-scale behavioural response such as a change in swimming direction[23]; it is unsure whether this would represent a biological effect.

Whilst some have raised concerns about the potential for impacts when MRE has a greater network of cables, there is limited evidence of any wider impact of the current offshore power cables that have been in the sea for a considerable time[24]. The greater potential for cables to have an impact is not the EMF but the routing of the cables from sea to shore. The routing should be carried out sensitively and avoid biologically diverse rich areas.

Addition of Physical Structure

The majority of wind farms are situated in areas of soft substratum, primarily due to the need to fix monopiles into the seabed; however, this would not necessarily be the case for wave, tidal stream and floating wind devices as often optimum high-energy conditions may be on rocky or mixed ground. Whilst the latter three structures will have moorings and some below-water structure, the current design of offshore wind turbines result in the greatest change of habitat, replacing soft sediment with a hard substratum. Wilson[25] estimated that each turbine results in approximately 452 m^2 of sedimentary seabed habitat (including scour protection) and 102 m^3 of water column habitat lost. For the Thanet wind farm, for example, this would give a total loss of 45,000 m^2; however, this only represents 0.13% of the total wind farm area across the same habitat. Wilson & Elliott[26] state, however, that the amount of area created by wind turbine monopole is 2.5 times the area lost through the placement.

Such constructions therefore result in loss of organisms within the existing habitat – as does infrastructure development on land – but what also needs to be considered is that much of the subtidal soft sediment habitat around the UK, particularly in the south and east, is already significantly damaged. Olsen[27] published a piscatorial atlas of the North Sea in 1883 that included a map of the distribution of seabed types. This included a huge 20,000 km^2 area across the southern North Sea that was a vast oyster bed, plus a range of rocky/stony reefs along the south UK coast and up the east coast. Much of this habitat has been lost due to over 100 years of intensive trawling and dredging (the oyster bed was last harvested in 1936 and had completely gone by 1970[28]), together with an important ecological filtration function that the huge areas of bivalve molluscs and other filter feeders provided. Therefore, a large part of the current soft sediment within UK waters is not the original habitat. We have lost vast areas of biogenic and stony reef, but this shouldn't be taken to imply that all soft sediment areas are fair game; soft sediment areas of conservation importance should be avoided.

Also it has to be recognised that benefits may accrue from adding physical structure to the environment in some locations, as it provides a new, albeit artificial, reef habitat for organisms to settle on (such as filter feeders). Such structure tends to attract and concentrate fish[29,30,31]. Provision of physical structure results in increased benthic and fish biomass, though whether this is a concentration effect of fish or is a true boost to local populations is as yet unsure, in parallel with other artificial reef structures.

Another impact of introducing extensive new hard structures across parts of the seabed is to reduce the level of current destructive fishing activity within the area[32], particularly restricting the use of towed fishing gear. Although this may have socio-economic impacts, particularly if coupled with displacement of fishermen from Marine Protected Areas, this may be offset through the use of static gear and increases in populations of commercial fish and shellfish. In addition, there is also much scope for looking at co-locating aquaculture, algal biomass production etc. within a wind farm to maximise use of the marine space.

MRE areas could function as *de facto* Marine Protected Areas, as long as they were additional to, not instead of, MPAs designated specifically to preserve biodiversity. As Wilson and Elliott[33] state, such potential to protect or enhance biodiversity raises important issues for marine nature conservation managers and, if marine spatial planning is done carefully, the environment can benefit from offshore renewable energy developments[34].

Summary and conclusions

Due to the great threats climate change poses to marine biodiversity it is, paradoxically, critical that MRE is rapidly deployed at scale around the UK. This overview and the following papers suggest that it may be possible to do so in a way that does not have a significant negative overall impact on marine biodiversity; however monitoring is needed during and after deployment, particularly regarding the species that may be at greater risk than others. It is likely that the deployment of MRE could be beneficial to some species, especially in association with Marine Protected Areas, and could be beneficial for commercial fisheries.

However, although rapid deployment of MRE at scale is necessary, this is not a reason to avoid deploying MRE sensitively and with care. Developers and regulators should work closely with marine ecologists and conservation groups at an early stage to identify suitable locations for the MRE and associated cabling. The Habitats Directive should be clearly complied with, in both spirit and letter. Developers should strive to enhance marine biodiversity and productivity.

The Government should also fund further research at a strategic-scale as well as site-specific, where environmental impact assessments are not always designed for wider interpretation or are deemed commercially sensitive. It is important to monitor the cumulative impact of MRE on the marine environment over time. Lessons learnt from this monitoring could not only help mitigate any negative impacts from MRE, it could help ensure lessons on enhancing benefits are learnt and spread.

The UK is current the world leader in deployment of offshore wind. It could, and should, be a leader in other MRE technologies. This brings significant employment and economic opportunities within an industry worth £billions. But with this leadership comes a responsibility to demonstrate how deployment can be carried out whilst protecting our precious biodiversity.

1: The potential impacts of marine renewable energy on fish and benthos

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Introduction

A decade after the Kyoto protocol, CO_2 emissions continue to increase[1], as atmospheric levels cross the symbolic mark of 400 ppm[2]. This is leading to increased temperature and CO_2 levels (and consequently acidity of the oceans) with effects on ocean productivity, food web dynamics, abundance of habitat-forming species and species distributions[3,4,5,6]. Globally, Marine Renewable Energy (MRE) will assist in the effort to reduce carbon emissions worldwide, thus mitigating climate change and minimising its effects on fish and benthic communities. However, the construction and operation of MRE devices, like any large-scale development, will inevitably result in changes to the marine environment on a local scale, which may induce responses in fish and benthos. These responses are likely to have both positive and negative effects on individuals and communities on a local scale, but it is not clear that the documented responses lead to negative, long-term impacts at the population level.

Potential effects include those associated with the physical presence of the devices themselves, as well as with activities associated with their installation and operation, namely noise and the creation of electromagnetic fields. While the construction period is recognised to result in negative effects (largely short-term), the presence of the physical structures will also alter the environment, both in terms of habitat loss and provision, potentially leading to both negative and positive effects.

This document presents an overview of the potential ways in which MRE devices could affect fish and benthos, with reference to offshore wind, wave energy converters and tidal turbines. Tidal barrages are not considered. A review of current thinking is provided, supported by scientific peer-review literature, and followed by best scientific judgement in the form of the views of further experts in the field of marine ecology. Potential effects are discussed below in separate sections, in no particular order of importance. Within each section, most examples are from offshore wind farms, which have been the most widely studied, probably because this technology is less novel. Nonetheless, different MRE devices will be considered where evidence is available.

Collision and displacement

Both floating and submerged structures have the potential to attract fish, which could lead to collisions between fish and MRE devices[7,8]. While fixed, submerged structures, such a wind turbine foundations, will pose limited risks; wave and tidal devices, particularly those with rotating turbines, have the potential to cause injury or death[7]. To date, documented fish collisions with MRE devices are lacking, but it is worth noting that data are difficult to obtain.

While behavioural responses to minimise collision with MRE devices could lead to population displacement, studies to date suggest little to no effects on fish densities and temporal or geographical patterns[9,10]. If poorly sited (e.g. narrow passages within migration routes), avoidance of MRE devices and associated displacement could be of some concern, highlighting the importance of appropriate site selection. Providing such areas are avoided, large scale displacement caused by the presence of physical structures seems unlikely.

Noise

Fish utilise biological noise to obtain information about the environment in terms of presence of prey and/or predators, communication and orientation[11] using a number of morphological structures to detect sound (noise and vibrations). These hearing structures are extremely diverse among fishes, resulting in different auditory capacity and sensitivity and, consequently, different responses to noise between fish species[12]. Different aspects of the construction and operation of MRE devices result in noise levels that could have a negative effect in some fish. During the construction phase, wind turbine foundation installation can generate acute noise (peak levels around 206 dB re 1 μPa)[13], potentially leading to mortality, physical injury, hearing loss and avoidance responses. During wind farm operation, more subtle effects could be expected, including physiological and behavioural changes, such as impairment of aggressive and reproductive strategies through masking of communicative signals[14].

Construction noise

While no evidence of fish mortality associated to the construction of MRE devices is yet available, noise levels during the construction of a major road crossing, comparable to those expected during the installation of large wind farms (approximately 250 dB re 1 µPa at the source) resulted in significant mortality during the programme (reviewed by Nedwel et al[15]). The potential for sub-lethal injury during pile driving has also been discussed, and Thomsen et al[14] estimated a detection distance of up to 80 km from the source for a number of commercial species, with potential for physical injury only in the close vicinity (peak sound pressure 189 dB re 1µPa). Other sub-lethal effects are poorly understood and while pile driving has been shown to induce changes in swimming speed and direction in some fish[16], the transcendence of these responses is unclear. Risk of significant harm to fish populations exists if the installation overlaps with important recruitment areas for threatened or weak populations. Avoidance of such areas, with particular consideration for important growth and spawning areas for fish or environments with high nature values[17] is recommended. The application of mitigation measures such as the use of ramp-up procedures and acoustic deterrent devices, restrictions to the number of pile driving operations to be carried out simultaneously, and limiting these activities, when possible, to periods when fish are likely to be less vulnerable, will minimise any potential effects on fish[18]. The development of floating wind turbines may mitigate many of these construction problems as, like wave energy devices, they will utilise moorings rather than the need to pile drive.

Operational noise

Operational noise is expected to be below the level required to cause physical injury even at a distance of a few metres during operation[12]. The detection distance for some of the major commercial species (e.g. salmon, cod and herring) could range from 0.5 to 7km and will likely depend on the species and life cycle stage, background noise, scale of the installation, and environmental conditions[12,14]. It is unclear whether detection will lead to a response, but there is some evidence that fish do not avoid wind farms in operation[9,18]. The lack of avoidance could be due to fish not experiencing a significant nuisance from the sound produced by the devices, or a result of habituation through prolonged exposure to low noise levels[12]. Alternatively, the attraction to physical structure may simply be outweighing any impact of noise (see below).

Masking of fish communicative signals during operation is a possibility for some species which use low-frequency sounds, comparable to the low-frequency part (95 Hz) of the pile-driving pulse[12]. However, given the level of marine anthropogenic noise in general[9], it would be difficult to disentangle those effects associated with MRE devices, if any. Studies on the potential long term effects of stress due to an increased noise level and effects of noise disturbance on fish spawning are lacking. For benthic communities, the colonisation of wind turbines is taken as an indication that noise and vibration have no detrimental effects on the attached fauna[18].

Based on the studies presented, there is evidence that noise during the construction of wind farms can cause physical damage to individuals in close proximity to the source, trigger changes in behaviour at greater distances, and lead to temporary displacement. Mitigation measures are available to minimise the effects of pile driving. For wind farms, the initial construction noise may induce avoidance reactions, with later return of the fish to the habitat, provided the sound levels are low and allow habituation to take place. Other MRE devices are less understood. Neither wave nor tide use pile driving to locate devices and so concerns during construction may be minimised. Operational noise for most such devices, however, is yet to be measured.

Electromagnetic fields

MRE installations require underwater electric cables to transmit electricity between devices, as well as from the devices to land and *vice versa*. These produce electromagnetic fields (EMF), which could affect fish and some crustaceans, and create boundaries to movement and migration. Some bony fish, such as eels and salmonids, and all elasmobranches (sharks and rays) are considered to be particularly sensitive. These utilise magnetic fields for orientation and prey location[19,20,21]. Several laboratory studies have shown effects of magnetic fields on the reproduction and development, swimming behaviour and physiology of some fish and shellfish[22,23,24,25], while others have suggested no effects on physiological or behavioural responses, locomotion, survival or general condition[26,27]. The relevance of the observed responses at the population level is unknown.

The potential interference with magnetic fields could affect some migratory fish, which use the Earth's magnetic field to navigate during migration[24,28]. Our understanding of how their migratory behaviour may be affected is limited as it is difficult to measure in the field and, while laboratory studies significantly contribute to our background knowledge, the applicability in the natural environment, where other factors are likely to act in a cumulative fashion, is limited. While laboratory studies have provided some evidence of minor directional responses to changes in magnetic fields[29], field studies have reported minor to no detectable responses to EMF[20,30,31]. It must also be noted that magnetic field detection is not the only means of orientation for most fish, which also rely on senses such as vision and olfaction; or environmental cues such as temperature[32].

Although studies have shown that fish could be affected by magnetism, as yet there is little evidence that underwater cables associated with MRE devices are having any effects. Nonetheless, mitigation measures, other than cable burial, are becoming available, as cable designs and the use of shielding materials can reduce the emitted magnetic flux[20,21].

Addition of physical structure

The deployment of MRE devices and addition of physical structures into the marine environment will lead to habitat loss, as well as provision and in combination habitat change. Habitat loss may occur during construction, i.e. by disturbance of the seabed, as well as permanent site occupation by the devices, particularly monopiles and foundations for wind turbines. Habitat provision is expected from structures, acting as Fish Aggregation Devices (FAD), as well as from foundations and towers, acting as artificial reefs[8].

Habitat loss

Habitat loss during installation could arise from the unavoidable disturbance of the substratum sediment, increasing turbidity and potentially leading to a reduction of light in the water column, and the consequent decrease in algal growth[33]. Such changes could have consequences further up the food chain[8]. Such disturbance, however, would be expected to be short term, and thus unlikely to result in long term changes in communities. Direct habitat loss as a result of the space taken up by the devices during the operation period has also been discussed, particularly in relation to wind farms. While the lost area is small compared to the total habitat generated by the monopiles and associated hard and floating structures (i.e. a monopile creates 2.5 times the amount of area lost through the placement[34]) it is important to note that the habitat lost is often very different to the habitat gained; a loss of soft sediment but a gain of hard substratum. In addition the scale of some proposed MRE farms is considerable such that substantial areas of surrounding sedimentary habitat may be altered as a consequence of changes in the hydrodynamic regime and associated depositional regime leading to localised changes in deposition and erosion[35].

Habitat provision

While habitat loss cannot be mitigated, it can be compensated for by creating new, suitable habitats, through the appropriate design of hard underwater structures, which have the potential to attract key species and enhance biodiversity[34].

Floating devices have the capacity to act as FADs. The phenomenon of fish aggregating around floating objects has been exploited by fishermen for centuries[36.] For recently deployed MRE devices, aggregation can occur over a short period of time[37,38], likely as a result of the benefits associated directly with the devices including food availability, shelter or the presence of a suitable spawning area; and indirectly such as the presence of mates[36]. Given such rapid aggregation, devices could be concentrating fish from the vicinity, rather than increasing recruitment. While this is possible, there is a clear benefit in aggregating fish stocks if the area provides protection and food, and is free from fisheries pressure, as envisaged in the case of floating devices associated with or forming part of MRE developments. Species richness and assemblage size are known to correlate with the size of the FAD and thus larger installations, such as wave energy devices, have the potential to attract more species[33].

In addition to floating devices, the deployment of different materials, whether especially designed concrete or steel units, or scrap materials such as car tires and shipwrecks, has been extensively used to enhance fisheries, protect or rehabilitate certain habitats, or to increase the recreational value of an area[39]. Likewise, the monopiles and associated hard structures, used for support and scour protection, increase the amount of artificial hard substrate[39], thus increasing the area available for organisms to colonize[34]. As in the case of FADs, there is some concern that MRE devices may be merely attracting organisms from the vicinity. However, there is evidence to suggest that such hard structures act as artificial reefs, providing a combination of refuge and food availability, and enhancing recruitment thus increasing productivity[38,40,41].

While the provision of habitat from MRE devices is undeniable, the consequences to the local environment are less clear and some concern arises regarding the associated shift in community composition. There is some evidence that initial fouling assemblages in and around the MRE devices may differ from that on nearby natural substrata[42,43]. In other cases, changes in species abundance and biomass are observed without shifts in species composition (e.g. Andersson et al[44]). The provision of hard substrate in an otherwise soft seabed may thus lead to changes in the composition and/or abundance of species and assemblages, potentially affecting species dominance and competition, accessibility to resources, predation pressure, and facilitating the settlement of invasive species[8]. The consequences of such changes are unclear, but it is important to consider that much existing soft-sedimentary subtidal habitat is "unnatural" due to extensive modifications by generations of industrial bottom fishing[45]. MRE devices are, by definition, installed in high energy mobile sites, which are intrinsically highly variable. Studies on macrobenthic fauna changes comparing before, with during and after the construction of offshore wind farms, suggest species richness and abundance, as well as diversity, are within a highly variable natural situation[8]. Nonetheless, current local species abundance and diversity must be taken into consideration before the installation of MRE devices, particularly in sites where changes in assemblages might be undesirable[7.]

There is considerable potential for variations in the design of the components of the installation to influence the type of species they attract[39,46]. Designs could potentially be adapted to maximise the presence of certain species, as well as to increase the distribution of mobile species within the local area[14]. For example, the use of large boulders around the base of wind turbines creates a rocky environment suitable for lobsters, crabs and reef fish[8]. Wilhelmsson et al[40] recorded different fish species confined to certain structural fisheries of wind farm monopiles (e.g. small fish only found in pockets of steel mouldings, eelpouts observed in the corner where the wall met the seabed, turbot on the seabed near the turbine etc.) The low level of structural complexity provided by holes on wave power foundations was sufficient to provide some level of protection for edible crabs, which were largely found associated with the holes, but not for fish, which did not utilise them to any significant degree[38.] Andersson et al[44] found that, during the first few months after submersion, different materials were colonised by specific assemblages of epibenthic organisms. These studies highlight the importance of a careful design and choice of materials.

Effects on fisheries

The exclusion of fishing vessels and gear to avoid interference with the devices will result in the creation of *de facto* fisheries exclusion zones, effectively acting as marine protected areas (MPA) to most fisheries[7]. With fishing prohibited in and around the immediate vicinity of the devices (e.g. up to 500 m for wind farms), these arrays have the potential to serve as refuges for fish. For example, Wilhelmsson et al[40] found higher density of fish in the immediate vicinity of an offshore wind farm. There was no difference in species diversity. An examination of the effects of the Danish Horns Rev wind farm on the lesser sandeel showed that the density of individuals increased within the wind farm during operation (approximately 300%), suggesting a positive effect[18]. This species is of particular importance as it is present in high densities in some areas, and constitutes an important food source for larger fish, marine mammals and birds. While activities associated with the construction period are expected to be disruptive to the local environment, these are temporary and minimal when compared with the damage incurred by fishing activities such as trawling or dredging. The restriction of these extremely damaging methods within the array will undoubtedly enrich the benthic communities (based on assessments of the ecological impacts of towed fishing gears[47]).

Offshore wind farms, especially at the scale of planned developments of many hundreds of turbines, will therefore limit fishing activity. Therefore changes in hydrodynamic and sedimentation regime which could be considered detrimental will be accompanied by a reduction in fisheries in fisheries impacts. The additional availability of hard surfaces and especially complex stone or boulder habitat though scour protection has also been shown to aid specific commercial crustaceans and smaller non-commercial reef associated fish[38,40,44]. Recently available environmental monitoring reports from Horns Rev wind farm in Denmark, Egmond an Zee wind farm in the Netherlands and Lillgrund windfarm in Sweden provide evidence of benefits extending to larger commercial fish species associating with turbines and scour protection[17,48].

These emerging patterns are encouraging as they begin to show benefits to fish stocks similar to those in MPAs[49,50]. A review by Halpern[51] that incorporated all before and after studies or inside outside comparisons for full no take zones concluded that evidence was considerable: regardless of their size, marine reserves led to increases in density, biomass, individual size and diversity in all functional groups. The major difference is that these examples are of existing reserves that have been specifically designed for conservation of habitat, species or fisheries augmentation. Even when assessing specifically designed marine reserves there is debate over their effectiveness, especially as fisheries management tools; there is a limited evidence base due to low numbers of effectively managed reserves globally and the lack of rigorously designed before and after studies[52,53,54]. The emerging benefits to abundance of species utilising habitat within wind farms therefore require specific attention to fully understand how geographic location, existing habitats and different environmental conditions influence species responses.

Increase in abundance of commercial species in marine protected areas with fishing restrictions or full no take zones has been shown to benefit catches of fishermen in the region[49,55]. Studies of fisheries-related effects exist for the largest and smallest of these reserves, the 340km^2 Start Point ‘Inshore potting agreement’ and the 17000km^2 Georges bank area closure. Beneficial results were identifiable at both sites with either identifiable larger size of individual fish from within the reserve compared to outside[56], large scale increased abundance within populations or increased catches of commercial fish in adjacent areas[57]. Further examples exist for beneficial lobster catches adjacent to reserves in New Zealand and Florida, USA[58,59,60], seabream catches in South Africa61, scallop and yellow tail flounder in the north west Atlantic[57,62,63] as well as a variety of Caribbean reef fish in St Lucia[49,64]. There is significant potential for offshore wind farms to therefore provide economic benefits in addition to conservation benefits if commercial species association with wind farm habitat continues. It is important, however, that increases in species occurrence within windfarms provide a spillover effect, as in the regional stock is enhanced and not merely aggregate fish that are later caught in the surrounding area[65].

Offshore wind farm development is currently centred in Europe where a number and variety of fishing fleets exist. While wind farms presence as de facto marine protected areas may enhance local fish stocks, the loss of available ground has been identified as a significant impact on inshore and offshore fishing fleets[66]. Loss of fishing ground will unavoidably lead some redistribution of fishing effort. Consideration of effort displacement, and the knock on effects on area closures, is increasingly being called for when considering the overall ecological impacts of area closures on a wider region[67,68,69].

Prior to area closures fishers will have made decisions on spatial locations of operation on the basis of past catch rates[67]. Therefore it can be assumed that in the case of a wind farm development, boats successfully utilising that ground at particular seasons will be forced to search for new less familiar grounds, potentially incorporating greater fuel costs and less predictable catches during that period if MRE farms are located within prime fishing areas. Hiddink et al[68] modelled the effect of redistribution of beam trawl effort on benthic communities following assumed area closures in the North Sea using this assumption that fishers select grounds based on their knowledge of past catches.

The random utility model used predicted redistribution to impact biomass, production and species richness of benthic communities with a trade-off between the negative impact on open areas and the recovery of closed areas. The findings of this study suggested that closure of lightly fished areas had the strongest positive effect: closing large areas, especially those receiving high fishing effort, concentrated that effort within smaller spatial scales increasing the regional impact on benthic communities. Without reducing allowed fishing effort concurrently with area closures, positive effects of the area closure may be outweighed by negative impact of the redistributed effort[68]. This effect is not confined to offshore MRE, but is also particularly relevant to the designation of large Marine Protected Areas. Potentially, offshore windfarms, for example, may provide new socio-economic opportunities within local areas allowing some change of use to compensate for lost fishing. Total area closures within offshore wind farms, particularly the larger sites currently being planned may not be necessary. While mobile trawls and dredges risk entanglement with wind farm infrastructure such as cables, static gears such as pots and nets may be possible to utilise within wind farms. A ban on towed gears (mobile gears) within a designated area within Lyme Bay, UK is displaying recovery of biodiversity within the closed area[70]. In addition the designated area is providing satisfactory fishing catches for static gears (nets and pots) with decreased risk of conflict with mobile fishing gears[71]. The displacement scallop fishery however has led to increased conflict in remaining grounds, particularly on the west coast of Wales and social and economic impacts for the fishermen[71]. The experiences from Lyme Bay however provide useful indications of potential benefits and disadvantages to species abundance and fishery effects within wind farm development regions.

Summary of expert panel horizon scanning for the effects of MRE developments that will have population-level impacts on fish and benthos

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- Impacts to benthic habitats from anthropogenic structures and activities are often considered important, e.g. abrasion, collision and disturbance from mobile fishing gear, smothering and loss of habitat by drill-cuttings and contamination by hydrocarbons from the oil and gas industry, eutrophication, deoxygenation, smothering and contamination below sea cages from the aquaculture industry. In contrast, impacts from these activities via the mooring of floating structures e.g. impacts from anchors and mooring chains often scarcely merit a mention in EIAs. Most types of wave-energy converter (WEC) are floating structures that need to be moored, either by embedment or deadweight anchors. It is unlikely that loss of habitat or disturbance to the seabed arising through these moorings will prove to be a major problem, provided that areas for development are not co-located with species or habitats that are particularly rare, vulnerable or protected. Perhaps removal of disturbance (through exclusion of mobile gear) will have greater ecological effects than introduction of new disturbance to the seabed.

- More likely to be of ecological importance are potential artificial reef effects provided by moorings and structures on the seabed. There has been a large amount of work on the artificial reef effect caused by structures in the offshore oil and gas industry, particularly off the Californian and Louisianan coasts of the US. There is also a growing body of literature about such effects from wind-turbine pilings and deadweight anchors (as reviewed in this report). Directly linked to this is the spread of invasive species. Many developments in the UK are happening in areas where new non-native species are being recorded. At least two academic institutions in Scotland are studying the distribution of these species, how they are changing and how this may be influenced by marine renewables, using empirical fieldwork and numerical modelling.

- An important topic may be aggregation of fish under floating structures or around structures on the seabed. This could be tied to the artificial reef effect as there may be trophic linkages (i.e. fish feeding on benthic growth, and tertiary consumers).

- Consequences for migratory fish ought to be considered. Marine Scotland Science (MSS) has highlighted that development may affect migratory Atlantic salmon, a species with a value to the Scottish economy estimated at over £100 million and supporting many jobs and wages. Potential impacts will depend on where developments occur, the technologies used and the as yet unknown, migratory routes. To understand the potential impacts on these economically valuable fish, it is crucial to know the routes taken by salmon leaving or returning to their rivers and whether these coincide with regions of development for marine renewable energy. For fish that do enter areas of development, what are the biological consequences of direct (e.g. collision) or indirect (e.g. barrier, confusion) interactions.

- In terms of other fish (excluding basking shark), a review of potential impacts of wave and tidal energy developments on marine species and habitats in Scotland did not consider that developments at the scale of 10 MW arrays would result in a change in the stability of Scottish populations of fish, bearing in mind that some species may already be under pressure due to other factors (e.g. climatic change, fisheries pressures).

- Effects (and by extension potential impacts) currently considered tend to be looking at the short term response, particularly relating to the construction phase. The operational phase of 25-30 years is likely to be significant ecologically. We need to keep an ecological focus over the long term. This is not just because it is fundamental for understanding how the environment will respond to MRE devices but recent legislation is requiring us to e.g. the Marine Strategy Framework Directive. The current focus on species and habitats will continue but the ecological status will increase in importance, so we don't want to be behind the curve on this as the ecological approach covers these species and habitats and essentially reduces the likelihood of having issues with specific species and habitats in the future. We are still only at the stage of looking and recording responses or effects. Whether this is demonstrable in terms of ecological impact (e.g. reduce population level) needs to be addressed.

- We know very little about how different life stages of organisms may/may not be affected. The majority of studies focus on the adult forms (e.g. mollusc abundance, crustacean use of scour, migratory route of fish). We do know that many juvenile forms settle out around the MRE structures. This has potential implication for the source-sink scenario. Are these settled organisms relocated from another area or do they represent an overall increase in biological productivity and biodiversity (potentially). This is a crucial aspect to understand as it has important implications for food web interactions and community dynamics.

When measuring effects at an MRE device we are recording the combined effects of multiple stressors/effectors. Some of these may be additive, other may counteract. A good example is that we assume the artificial reef effect or the FAD effect will bring fish in and protect them from fishing, which is good. However this MPA or No Fishing Zone effect may not occur if for example the operational EMF or noise causes some counteracting effect. The change in effects over greater spatial and/or temporal scale should be highlighted too. So whilst a small development may not be regarded as causing any significant change (particularly in light of other influential factors) many of them or larger sized developments may cause significant change. There is also the aspect of cumulative effect not just of other MRE devices but other activities that need to be considered. This consideration should be objective as there may be trade-offs whereby the MRE device reduces other pressures on species or where a combination of different activities causes a differential outcome (there is a lot to develop within this topic area but it all comes under cumulative aspects).

- The ambient conditions at a site need to be factored into any consideration of environmental effects and impacts. For example, in an area of shifting sandbanks, the effects of ploughing in a cable are likely to be less than if the habitat is a more sheltered site. The benthic community and the dynamics associated with it will go a long way to determine the scale of effect – i.e. impact level.

Conclusion – fish and benthos

During the construction of MRE devices, negative effects are expected as a result of sediment disturbance, temporary displacement from the area and noise. However, these are expected to be temporary. In the longer term, large arrays of turbines in wind farms have the potential to modify sediment transport over substantial areas of seabed and associated effects on benthos would be permanent. During the operation period, MRE devices have the potential to create additional habitats, acting as artificial reefs and modifying the local benthic communities with consequences for higher trophic levels. Floating devices also have the potential to act as FAD and attract fish to a suitable habitat with enhanced food availability, spawning substrate and free from fisheries pressures. At the same time, the devices will provide new habitats for epibiota and could alter community composition from that present in the natural environment. The associated consequences for the local environment are unknown. Benthic assemblages are not well known in terms of spatial and temporal natural variation, and finer scale descriptions are needed if we are to understand the effects of MRE devices at the population level. Nonetheless, we must remember that human activities have significantly impacted the marine environment and the communities inhabiting it, which now have little resemblance with those existing pre-human activities. Evidence suggests that, if mitigation measures are used during construction, and hard structures are carefully designed in order to favour the settlement of key species, MRE has potentially positive effects on marine assemblages in an otherwise degraded environment while, at the same time, contributing to the reduction of carbon emissions. Restrictions on fishing activity within new MRE farms can potentially lead to displacement and concentration of such impacts elsewhere, giving a balance of positive release from fishing pressure within farms to increased impact outside. Such impacts can be mitigated to some extent through careful planning and socioeconomic incentives.

2: The potential impacts of marine renewable energy on marine mammals

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Introduction

Global climate change can affect marine mammals in a number of ways[1]. Marine renewable energy (MRE) has the potential to produce large amounts of low carbon energy, thus contributing to the reduction of CO_2 emissions, and mitigating the impacts of climate change[2]. The expansion of the MRE sector, however, requires the installation of offshore MRE devices, which have the potential to impact marine ecosystems and both positive and negative effects of MRE devices on different taxa must be adequately evaluated. This document presents an overview of the ways in which marine mammals may be affected by MRE devices, with reference to offshore wind farms, wave energy converters and tidal turbines. A distinction is made between impacts at the population level and individual responses, as described in the overview section of this report. This report presents a review of current thinking presented in a wide range of sources, some of which is supported by scientific peer-review literature.

Marine mammals present in British waters include two species of seals and 28 species of cetaceans[3]. Such species can be negatively impacted by human activities in a range of ways, from fisheries bycatch[4], noise[5] or chemical pollution (e.g. Jepson et al[6]) through to more indirect effects of climate change on marine ecosystems[7]. While offshore renewables have the potential to mitigate the impacts of climate change, and consequently minimise its effect on marine mammal distribution, abundance and behaviour[8], if poorly planned, the rapid development of MRE could also pose threats to these animals at local and regional scales.

These concerns have resulted in a number of studies examining the potential impacts of MRE on marine mammals and a number of useful reviews[9,10,11,12,13]. Nonetheless, studies are still scarce and potential impacts have been largely hypothesised. There is also a high level of uncertainty regarding whether the documented responses may lead to impacts at the population level. Potential effects are discussed below in separate sections, in no particular order of importance. Within each section, different MRE devices are considered where evidence is available.

Collision/entanglement

There is a concern that marine mammals may collide with MRE devices. Risk of collision is likely to be a function of species, body size and swimming behaviour, but also device type. While fixed, submerged structures, such a wind turbine foundations, might pose limited risks; wave and tidal devices, particularly those with rotating turbines, have the potential to cause injury or death[13]. Some marine mammals, such as harbour porpoises, have been shown to concentrate their movements in small focal regions close to islands or restricted channels, which are often optimal sites for tidal energy extraction[14]. Associated infrastructure, including cables, power lines and free moving components, could also present an entanglement risk[15,16].

Studies documenting collisions between marine mammals and MRE devices are scarce. Based on model predictions, between 3.6 and 10.7% of the harbour porpoise population in an area surrounding a commercial underwater turbine development on the west coast of Scotland (estimated around 1300 individuals) would be expected to encounter a rotating blade within a year (assuming the presence of 100 turbines)[15]. Thus the risk of interaction with tidal turbines is quite high. However, encounter rate is not synonymous with collision, as it does not account for the ability of mammals to avoid the devices or the effectiveness of any mitigation measures put in place. To our knowledge, the only study on the interactions between marine mammals and turbines to date was carried out as part of the Environmental Monitoring Program (EMP) at the SeaGen turbine in Strangford Lough, where marine mammals were monitored for a three year period immediately after the construction of the device[17]. This program showed no evidence of lethal marine mammal collisions with the turbine, but rather an avoidance response, with evidence of small scale (a few hundred meters) redistribution of harbour seals in the survey area during operation. This suggests that seals have the capacity to change their behaviour to avoid physical injury. Potential occurrences of lethal collisions were monitored by conducting shoreline surveillance of strandings hotspots, followed by post mortem evaluations of carcasses. While these showed no evidence of blade strikes, this method does not allow for the evaluation of sub-lethal injuries. Moreover, the detectability of stranded individuals is influenced by currents and potentially other factors, of which we have little understanding. There are therefore potential limitations in using strandings as a proxy for lethal collisions. It should also be noted that this study used active sonar to detect marine mammals approaching the turbine which resulted in a series of precautionary shutdowns of the turbine over the three years. This may have been a key factor in avoiding fatal encounters, highlighting the importance of mitigation methods, where warranted[15].

Further concerns are associated with the use of ships with ducted propellers during the installation of MRE devices. Injuries consistent with seals being drawn through a ducted propeller have been reported in several sites in the UK (e.g. St Andrews Bay, Blakeney Point nature reserve and Strangford Lough)[18]. Since tidal turbines are not present on all of these sites, they are unlikely to be responsible for any of the seal mortalities. However, ducted propellers are common to a wide range of ships, some of which may be used during the construction and maintenance of MRE devices. While relatively small numbers of injured seals is unlikely to have a significant impact on large seal populations[18], an increase in traffic during the construction period could be of concern.

Displacement

Avoidance of MRE installations can lead to displacement of marine mammals from an area into another which could be less suitable (e.g. feeding and breeding grounds, or key migratory routes). Displacement is difficult to measure since for most marine mammals it is not possible to determine whether the same or different individuals return to a prior disturbed area, making it difficult to determine the number of animals being affected. Studies tagging and tracking individuals are required to further understand the implications of displacement at an individual level. Population level effects are more difficult to assess, depending on a range of factors including location, installation size, the species affected, inter-connectivity between population groups, and indirect effects such as displacement into areas more or less at risk of human interaction (e.g. fisheries bycatch). However, there are modelling approaches currently being developed to attempt to assess population level effects on marine mammals from MRE[19].

MRE Noise

Anthropogenic noise in the marine environment has increased dramatically over several decades as a result of, for example, increased shipping, oil and gas developments, defence-related activities and research[20]. Marine mammals detect and emit sound for purposes of communication, orientation, predator avoidance, prey seeking and mating. Notably, many cetacean species use echolocation to navigate and find food, by emitting sounds and listening to the echoes as they reflect from nearby objects. Marine mammals can hear frequencies from less than 100 Hz up to 180 kHz, and emit sounds up to 200 kHz with amplitudes reaching 235 dB re 1 µPa rms[21]. The wide range of frequencies and amplitudes used and detected by different mammal groups make predictions of the potential effects of particular sounds a less than trivial task. Given their reliance on sound and sensitive auditory systems, underwater noise and vibrations could have diverse effects on marine mammals by causing injury, behavioural responses, or masking of communication and echolocation systems. Different aspects of the construction and operation of offshore installations, including MRE devices, result in noise levels that could incur physical damage or cause behavioural responses in marine mammals. In this respect, offshore wind farms have been the most widely studied, probably because this technology is less novel. The studies discussed below are therefore mainly on wind farm areas. Where examples from tidal devices are available, this is specified. While underwater noise levels are low during operation, noise is known to be more severe during construction and decommissioning[10].

Construction noise, physical injury and behavioural responses

The construction phase of MRE installations has been highlighted as the most likely to have an impact on marine mammal populations, mostly as a result of noise associated with anchoring activities, particularly the use of pile driving[10]. However, increased boat activities associated with the construction phase can also increase background noise considerably (e.g. up to approximately 20 dB re 1 µPa within 1 km of the wind turbine site Bailey et al[22]).

The potential effects of pile driving have received some focused attention. For wind turbines, monopile foundation installation can generate acute noise (peak levels around 206 dB re 1 µPa)[23], which could lead to injury to acoustic organs in some species and/or behavioural responses, including avoidance. For example, the distance from pile driving activities at which injury and hearing loss was considered a concern was calculated to be 1.8 km in porpoises and 400 m in seals (at peak sound pressure level of 189 dB re 1µPa)[24]. Impulsive noise can not only result in hearing impairment (Permanent or Temporary Threshold Shifts PTS/TTS) but in potentially fatal tissue damage (e.g. Jepson et al[25]), although such affects have not yet been associated with pile driving noise. Moreover, the potential stress experienced by mammals could have long lasting effects at the population level, by impacting their health and reducing reproductive success. While studies on physiological stress in response to noise associated with MRE devices are lacking, other sources of anthropogenic noise have been suggested to cause chronic stress in some marine mammals. In right whales, a reduction in baseline levels of stress hormones was observed following a five year period of decreased underwater noise (6 dB)[26]. As a mitigation measure, hazing devices are often a requirement during installation of wind farms in the UK, particularly when it includes pile-driving activities. These include a range of acoustic deterrents devices (ADDs) and/or gradual starts (e.g. increasing energy and/or frequency of during pile driving operations) to alert the animals and scare them away from the construction site before noise levels reach PTS/TTS levels. Other methods, such as the use of air bubble curtains, have been successfully applied to attenuate sound, and prevent avoidance reactions of harbour porpoises to pile driving activities, but their use is restricted to certain conditions[27]. There is also considerable potential in alternative installation systems, such as the recently developed suction bucket foundation, eliminating the need for pile driving[28].

Avoidance responses to pile driving and/or the use of acoustic deterrents have been documented in a number of studies, mostly on harbour porpoises and, to a lesser extent, seals. Studies on other marine mammals are lacking. Studies have reported harbour porpoise behavioural response to pile driving by monitoring echolocation clicks over long construction periods (3 to 18 months)[29,30,31,32,33]. These suggest that behavioural responses can extend beyond the wind farm construction area, as far as 20 km away. In all cases, there was a pronounced negative effect of construction, reflected in a decrease in porpoise echolocation activity, which may indicate physical avoidance or a reduction in echolocation use. While some studies on seals around wind farms do not suggest large scale displacement during construction[34], others have shown a significant decrease in the use of haul-out areas[35]. However, acoustic deterrents were used to deter animals from the pile-driving area making it difficult to separate behavioural changes associated with the pile driving from those of the acoustic deterrents.

Of greatest concern is whether populations return to MRE development areas soon after the construction period, or whether there is a long-lasting effect with permanent displacement. In this respect, the scale of the installation will be important as large commercial scale projects will require extended construction periods, potentially resulting in long term exclusion of animals from the area. A recent study on porpoise populations at the Nysted Offshore Wind Farm, in the Danish western Baltic[36] showed that echolocation activity inside the wind farm gradually increased (from 11% to 29% of the baseline level) following a decline during the construction of the wind farm. This slow recovery may reflect the habituation of porpoises to the wind farm or enrichment of the environment due to reduced fishing and artificial reef effects. While it is still unclear whether population numbers at this site will return to baseline levels, it is not possible to determine whether changes in population numbers years after the installation are a response to the wind farm, or a result of natural variability in distribution patterns[37]. Monitoring changes in the abundance and distribution of seals and porpoises using a wide range of methods during and after the construction of the SeaGen tidal turbine revealed no major turbine related changes[17]. Harbour porpoises appeared to be displaced from some areas during construction, but abundance returned to pre-construction levels once this was complete[17].
A similar response was observed for grey seals at the Nysted offshore wind farm[35].

Operational noise

During wind turbine operation, underwater noise is generated by vibrations in the tower of the turbine. Evidence from a number of studies, some of which are presented below, suggests that operational noise from wind farms is likely to have much less of an effect on animals compared to construction noise. Estimates for the distance at which marine mammals can detect the sound vary between species and with the scale of the farm. For example, at Horn Rev estimates for harbour seals audibility vary from less than 100 m to several km whereas the detection range for porpoises is estimated to be lower (20-70 m)[38.] These levels are not expected to cause physical injury, nor interfere with the animals' acoustic communication at any distance from the turbines[38]. Behavioural reactions, including avoidance, are possible; and their effects at the population level are unknown. At Horns Rev, behavioural reactions to operational noise (maximum 127 dB re 1 µatm) were considered unlikely for porpoises, but possible in seals within a few hundred meters from the turbines[38]. At the Egmond aan Zee offshore wind farm in the Dutch North Sea acoustic monitoring of porpoise populations showed increased acoustic activity in the wind farm[39]. While the authors attributed this to an increase in porpoise abundance as a result of increased food availability inside the wind farm, and the absence of vessels in this heavily trafficked area; the possibility that changes in acoustic activity reflect a modification of behaviour (i.e. increased echolocation activity in response to higher prey densities or devices in the water) should not be excluded. Evidence to date suggests that marine mammals do not avoid the wind farm area during operation. It must be noted, that these studies focus on wind farms. While some mammals, such as harbour porpoises and seals, are able to detect the low frequency sounds generated by offshore wind turbines[40], these devices are likely to result in less underwater noise emissions than wave or tidal devices. Studies at the SeaGen tidal turbine showed that harbour seals and porpoises were not excluded from the area when the turbine was in operation, nor were significant changes in the use of haul out sites observed[41].

Electromagnetic fields

MRE devices require the use of cables to allow the transmission of power between devices and the mainland. These produce at least some electromagnetic fields (EMF) even when insulated[42]. The emitted electric and magnetic fields have an interrelationship, which is currently not well understood. There is evidence, however, that marine mammals use magnetic fields for orientation and migration[43]. Marine mammals might therefore be able to detect the EMF generated by the devices have the potential to affect marine mammals. Evidence for any effect or electromagnetic fields on marine mammals remains poor. Comparisons with magneto-sensitive teleost fish could be of relevance and, while studies have shown temporary changes in swimming direction, it is not clear whether this represents a biologically significant effect[44].

Indirect and cumulative effects

The disturbance of the substratum sediment during installation, and potential modification of water circulation and currents associated with some devices could change the amount of sedimentation and organic material within the water column. For example, increasing turbidity could lead to a reduction of light in the water column, and the consequent decrease in algal growth[12], with potential knock on effects on higher trophic levels some levels up the food chain, altering the entire community[45]. Similarly, other effects on the environment such as oil spills and leaks, as well as release of chemicals such as antifouling paints, have the potential to impact marine mammals both directly, and indirectly through alterations of lower trophic levels.

Many of the MRE developments discussed throughout the present document represent small construction projects, and the cumulative impact of multiple large-scale developments in coastal waters poses considerable uncertainty. Given the scales of the planned developments and the potential spatial extent of some impacts, an interaction between adjacent developments could be expected[46]. Cumulative impacts may also occur because of other anthropogenic stresses (e.g. shipping and fishing), or through the accumulation of small responses to a series of factors discussed in this report. Such interactions could result in impacts not predicted when looking at each potential effect in isolation. Mitigation of negative cumulative impacts can be done at the planning stage, and requires an understanding of marine mammal distributions, breeding grounds and migratory routes.

Possible benefits

Indirect positive effects of MRE installations on marine mammals have also been suggested. The potential for MRE devices to act as new habitats has been advocated[12,45]. These may act as artificial reefs[47], increasing the available habitat for sessile marine species and consequently, attracting marine life in search of food, hence providing prey for marine mammals. The floating nature of wave energy converters may lend them to become fish aggregating devices, thereby attracting potential prey. This could draw predatory species into the area increasing the risk of collision and/or entanglement, as well as prolonged exposure to noise[41]. Risks ought to be taken into consideration when designing the devices and implementing mitigation measures. Commercial fishing may be reduced in the vicinity of the devices to minimise the potential collision between fishing gear and MRE devices, which may lead to the establishment of de facto marine protected areas[12] albeit that there is still significant anthropogenic influence within them. This could further enhance fish stocks and increase prey availability. Data to examine whether these potential effects are manifested are only likely to be available after several years of monitoring and only once devices are in operation. If there is evidence for creation of beneficial habitats, these need to be maintained beyond the life span of the device, to ensure that the loss of habitat during decommissioning is not more dramatic than during construction.

Conclusion – mammals

MRE projects can undoubtedly deliver environmental benefits, by making a major contribution to the mitigation of climate change. While there are clear risks associated with the construction and operation of the devices, there is currently insufficient scientific evidence to determine the long-term, wide scale impacts of MRE devices on marine mammal populations. Differences between the devices need to be taken into consideration. For example, while installation is of concern for wind farms as a result of pile driving, the operational phase seems to present less potential risks. However, in the case of tidal and wave developments, our understanding is more limited and while no evidence is yet available, some risks (e.g. injury through strike or collision, barriers to movement) could apply to the operational phase. In order to understand the consequences of MRE developments, there is a need for continuous monitoring of marine mammals populations, particularly in the areas where installations are planned, and more strategically at a much larger scale[45]. Increasing our understanding of marine mammal distributions, ecology, behaviour and life histories is necessary to ensure adequate protections of areas constituting feeding, breeding and nursery grounds, or those located within migratory routes. The acquisition of baseline (pre-construction) data is required to evaluate the effect of construction on populations, and assess their capacity to recover, if they are displaced from the area. Mitigation measures, such as restricting construction activities to certain times of the year (e.g. locally avoiding breeding seasons) or employing acoustic deterrents as a means of preventing physical injury to marine mammals from pile-driving noise have been recommended[47]. Knowledge of local and regional populations, together with careful planning of activities and appropriate mitigation measures can prevent impacts from the construction and operation of MRE. If impacts are minimised so that major damage to marine mammal populations does not occur, the potential positive effects may outweigh long term detrimental effects.

3: The impact of marine renewable energy on birds

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Introduction

Marine Renewable Energy (MRE) has the potential to provide a significant amount of clean, low carbon energy and reduce our current dependence on fossil fuels[1, 2]. The rapid change in global climate is having significant impacts upon many aspects of animal and plant ecology[3]. Birds have been particularly badly impacted with changes in phenology, distribution and ultimately population size all attributable to the impacts of climate variability[4,5]. Whilst the expansion of the MRE sector is important to help combat climate change, via a reduction in carbon emissions, the environmental impact of wind, tidal and wave installations remain poorly understood. Our increasing need for clean energy should be delivered without major harm to wildlife or ecosystems and, conversely, construction should not be prevented due to unfounded concerns. Moreover, MRE installations may have positive impacts in some instances. Assessing and monitoring the impact of MRE installations is vital if we want to achieve ecologically sustainable development of this renewable energy resource.

Many taxa may be impacted by MRE installations but birds, especially marine species (seabirds, sea ducks, divers and grebes) and migrating passerines, are thought to be particularly vulnerable through direct (e.g. collision and displacement) and indirect (e.g. prey abundance) effects. Their reliance and use of the marine environment means many species come into direct contact with MRE installations during breeding and migration with potential detrimental effects. The recent expansion of coastal and offshore developments in breeding and foraging areas, and migratory corridors has raised important questions regarding potential population-level impacts and stimulated research on the effects of various MRE technologies[6,7].

This report presents the expected key issues for birds in terms of the effects of offshore wind turbines, tidal turbines and wave energy convertors, and discusses which are most likely to have impacts at the population-level. Moreover, areas where the applied research community collectively lacks evidence to make informed inference are highlighted. We use impact as described in the summary report and illustrated by Fox et al. 2006[8] as a population-level impact, not an effect or response to the presence of MRE installations.

Potential effects (responses) of MRE devices have been categorised into three types: direct, indirect and cumulative effects. To horizon scan for potentially important issues relevant to bird conservation in terms of population-level impacts, we have summarised the opinions of a panel of experts that have recently published, and are working on, the impacts of MRE devices.

Direct effects

Collision risk (mortality)

Mortality of birds through collision with MRE devices may have direct population-level impacts. However, quantifying collision rates (inferred mortality) for different species at offshore installations is a major constraint to assessing its impact[9]. Novel survey methods, such as radar and infrared detection systems, are now being applied and developed for offshore wind-farms[10,11,12], but there are still limited data on collision rates. Research indicates the risk of collisions is likely to be species and site specific[13], and affected by many factors: flight behaviour (e.g. altitude and manoeuvrability), avoidance ability, proximity of migratory corridors and/or feeding areas, weather conditions[14, 15] and structure lighting[16]. In addition, age and reproductive stage may affect collision risk, and different mortality between age classes may lead to quite different population-level impacts[17]. Overall, for offshore wind-farms the evidence suggests that avoidance (see Displacement and barriers to movement) is the most likely cause of negative impact on local bird abundance (with much site and species variation) rather than a direct effect of collision[13,18].

The collision risk of tidal or wave devices is largely unknown with no quantitative studies to date, but thought to be much less than wind turbines[6,19]. The low profile of current wave energy converters means they pose little collision risk to birds during flight; however the moving parts and infrastructure of tidal turbines (e.g. blades, cables etc.) present potential risk for diving marine birds, such as cormorants, gannets, auks, divers and sea ducks[6]. The risk will vary with species avoidance ability, and likely be influenced by visibility[20] and tide conditions[21]. Until direct evidence is gathered at installed (test) devices the potential collision risk is uncertain, but considered relatively low for most species based on ecology and behaviour assessment[6].

Further research is required on the collision risk with MRE installations, and a standardised framework for assessment would help enable meta-analyses of impacts over multiple sites. The current evidence suggests the impact is low and, in isolation, will be unlikely to have population-level impacts. It should not however be underestimated for vulnerable and/or migratory species[16, 22] and may contribute to potential cumulative effects (see Cumulative effects) which can be potentially mitigated by the thoughtful siting of wind-farms.

Displacement and barriers to movement

Avoidance of MRE installations by birds appears to be the main direct response of their presence and a principal factor in low collision risk. However, the behaviour can also result in displacement of birds from important foraging habitat[18] and extension of flights during feeding or migration, where wind farms act as barriers to movement[18,23].

Displacement (effectively habitat loss) due to MRE installations will be detrimental to birds if they cannot compensate by feeding elsewhere. For species that are restricted to forage in specific habitats the ability to find alternatives could be limited and they may be disproportionately impacted[24]. For example, shallow coastal waters are important for wintering sea ducks (e.g. common eiders Somateria mollissima and scoters Melanitta spp.), which show strong avoidance responses to wind turbines[18], so large scale development of these habitats may affect their ability to exploit winter food resources and potentially have consequences for subsequent breeding performance[25]. However, there is further evidence indicating sea ducks and other species may become habituated to wind turbines so displacement may only be short term[26,27]. Species such as gulls, terns and cormorants show no avoidance response to MRE devices and may instead be attracted to installations through prey aggregation and their use as resting/foraging platforms, indicating effects would be species-specific and potentially positive[9,28,29]. The lack of well controlled and long term assessments of displacement have meant studies are largely inconclusive[30] and so research has yet to determine any effects on productivity or survival of bird populations. These data are central to whether or not displacement is likely to have population-level impacts so currently it would be unwise to assume that large arrays will not be having any detrimental impact.

An increase in flight distance while foraging or migrating to avoid a MRE installation will have a higher energetic cost to birds. In many species, reproductive success is related to body condition[31], so any reduction in mass resulting from increased flight requirements could be detrimental and directly impact breeding success and population size. A study of ~200,000 migrating common eiders at a Danish offshore wind-farm recorded flight trajectory changes that corresponded to an increase of 500m to a 1400km journey. The increase in energetic cost was found to be trivial and only an avoidance response equivalent to 100 similar size wind-farms would cause detectable change in bird body mass[23]. The intrinsic cost of flight, however, varies between species[32], as does the energetic requirements and constraints of foraging, so this needs to be considered when assessing possible impacts of MRE installations[32,33]. Moreover, cumulative effects of regular avoidance of MRE installations (e.g. during foraging or provisioning flights, multiple site on migration), may increase the energetic cost and significantly affect body condition, survival or reproduction in certain species[33,34].

The impact of these non-lethal effects will be highly dependent on the species and location, size, and number of MRE installations. Wind-farms are of most concern as they are highly visible to birds and known to invoke strong avoidance responses in some species, but tidal and wave may still cause displacement from feeding habitat if badly located, especially during construction[19]. A site- and species-specific approach needs to be taken to assess the effects, but sensible development planning to avoid sensitive foraging areas and improve wind-farm design (e.g. spacing of turbines and flight corridors) will help mitigate possible population impacts[35].

Indirect effects

The impact of indirect effects of MRE installations on bird populations has yet to be examined in detail so much of the evidence is circumstantial and requires further research. The potential effects and likely population impacts are however briefly discussed below.

Noise

Pile driving during construction of MRE devices produces a level and frequency of noise that can impact organisms. Estimates suggest fish can detect noise over large distances, and may cause injury or mortality at close range[9]. A reduction in fish abundance due to noise could be detrimental to birds that rely on this food resource. The marked decrease in clupeid fish abundance at the Scroby Sands wind-farm, Norfolk was attributed to noisy pile driving during construction and resulted in a reduction in foraging success of little terns Sternula albifrons. This then led to high abandonment of eggs and low hatching success at the local colony[36]. If noise during operation was to reduce fish abundance in a similar manner over the long-term it could impact local bird populations; however, operation noise does not appear to impact fish and the effect beyond a couple of years is unlikely.

Electromagnetic fields (EMFs)

EMFs are produced by sub-surface cables transferring electricity to (and from) MRE devices. Although there is evidence that EMFs may have small scale effects on fish behaviour[37], there is little evidence this has a major impact on fish abundance and limits prey availability for birds. The potential impact on bird populations is considered minimal but data is lacking[9].

Fisheries activity

The development of areas for MRE will result in a reduction or cessation (through closures) of fishing activity, especially towed gear, in and around installations. Comparable to the effect on birds, fishermen will be displaced from these areas and need to find other sites to compensate for this loss. The effect on fish abundance and, therefore, availability of food for piscivorous birds has the potential to be both positive and negative. MRE installations could become de facto Marine Protected Areas and fish abundance will likely increase through lack of exploitation, providing better feeding grounds for species such as gulls, terns and cormorants that are insensitive to devices. Fishing will however be displaced and concentrated in alternative areas outside installations, which may lead to overexploitation of fish stocks with effects on prey availability for species that avoid installations. The impacts of these reciprocal effects will be dependent on the present (and future) level of fishing activity and the composition of bird species breeding or visiting the area[38].

Habitat modification/enhancement

MRE devices have the potential to attract marine organisms by modifying the seabed and sea surface habitat, and acting as artificial reefs and/or fish aggregation devices (FADS). The likely increase in fish density and recruitment around wind turbines and wave-energy devices[19, 39] will provide increased foraging opportunities for piscivorous birds with possible consequences for breeding success and survival. The hard-structures will also provide habitat for sessile organism, such as mussels[39], an important food resource for wintering common eiders. The benefits of this increase in food will however only be appreciated by species that are insensitive to installations and an increase of collision risk is possible if large numbers of birds are attracted to MRE devices in search of food.

Cumulative Impact

With the increasing introduction of MRE installations it is important that their cumulative impact be considered rather than focusing on individual effects or sites. Direct and indirect effects have the potential to combine over multiple MRE sites to produce significant population impacts, whereas alone they may be minor[23, 40]. The interaction of positive (e.g. habitat enhancement, de facto MPA) and negative effects (e.g. collision risk, displacement) also needs to be considered and will certainly not be simple or predictable[9]. Mitigation of negative cumulative impacts can only be done at the planning stage so it is essential developers are aware of vulnerable species, important habitats, breeding areas and migratory corridors when making these decisions. Energetic and movement models would also help position and design installations to reduce cumulative impacts to bird populations[34,35].

Summary

The increasing development of coastal and offshore habitats for MRE will undoubtedly impact the marine environment and has potential consequences for bird populations. There is evidence for both direct and indirect effects on various species and at single MRE installations, but there are no data, as yet, on long-term negative effects on reproduction or survival that would cause population impacts. The difficulty in assessing some of these effects at offshore sites has hindered research, but the evidence available suggests that, in isolation, negative effects are unlikely to have an impact on most bird populations. However, cumulative impacts caused by an interaction of direct and indirect effects, and/or encounters with multiple MRE installations are possible. Future developments need to consider, and mitigate, for such impacts, particularly avoiding important foraging habitats and creating barriers to movement. Habitat enhancement and de facto MPA offer potential positive effects of MRE installations that have still to be quantified in terms of the impact on bird populations but could benefit local conservation and biodiversity.

Summary of expert panel horizon scanning for the effects of MRE developments that will have population-level impacts on birds

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It is uncertain which effect(s) associated with MRE will have future population-level impacts on birds, but predicting the most important issues, based on existing evidence and experience, is crucial to focus research and monitoring. The opinions of experts working and conducting research in the field can give insights into which known effects may be most important and the key emerging issues. The summarised points below are the current opinions from a panel of such experts:

- The cumulative effect of disturbance and displacement of individuals from key habitats such as foraging areas will have the greatest impact at a population level, both for breeding and migratory bird species. The topics of macro-avoidance and micro-avoidance of offshore wind farms/turbines should be a high priority for research as our current understanding of these is very poor and the very limited data available are contradictory and sometimes being misquoted.

- The increased noise from devices and boat traffic, for both construction phases and on-going servicing of MRE devices, will cause disturbances to prey species that may lead to changes in their availability and/or distribution, with consequential increased flight costs for feeding birds. This has the potential to reduce energy intake to levels that will affect individual condition and/or rate of chick provisioning, and ultimately population impacts.

- A reduction in water column mixing caused by the extraction of tidal and wave energy may alter the location of tidal heights and locations of frontal regions (e.g. moving closer to shore). Weakened mixing in areas can cause changes in local physical oceanographic characteristic (i.e. areas of shear, levels of turbulence), which seabirds utilise to locate and capture prey. A reduction in overall primary production due to reduced mixing could also be expected and thus change plankton species composition and food web linkages to higher trophic levels. These alterations could have population impacts for certain seabird species.

- The potential for population level impacts of MRE will depend on the location and size of arrays but also highly likely to be species specific.

- The evidence available to date suggests that impacts of fisheries and climate change are likely to be overwhelmingly important in determining marine bird population trends (for example a zero discard policy in the EU, and changes in the status of sandeel stocks). The closure of trawl fishing within MRE sites and alterations to benthic habitat (e.g. artificial reef effects) could potentially enhance food supplies for some marine birds.

- Our inability to predict the important effects of MRE on bird populations is primarily due to a lack of evidence and highlights the need for long-term studies collecting and analysing environmental and population data over large spatial scales, which is not an inconsiderable task.

Conclusion – birds

MRE will necessarily play an important role in providing the clean, low carbon energy needed to reduce global carbon emissions and combat climate change. However, the environmental benefits, where possible, should not come at detrimental impacts on marine ecosystems and species. The evidence suggests MRE developments will have both direct and indirect negative effects on certain breeding and migrating birds but whether these will cause population level impacts is still unclear, and any impacts need to be put into the context of potentially larger effects of climate change and variations in fishing activity. The potential for cumulative effects of multiple arrays is one of the major concerns associated with MRE and long-term, wide scale studies are required to elucidate any impacts on bird populations. Mitigating potential impacts can only be done at the planning stage of MRE developments and would require both local and international consultation. The impact on bird populations, however, does not seem to be entirely negative and potential positive effects may counter these detrimental effects and enhance local habitat and benefit populations.

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