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The potential for cooperative management of elasmobranchs and offshore renewable energy development in UK waters

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The UK government's strategy for reducing greenhouse gas emissions to meet carbon mitigation obligations and the wider aims on sustainable development has provided the impetus for a rapid growth in activity associated with offshore renewable energy, particularly offshore wind farms. Recently, consents for offshore renewable energy development (ORED) were approved in three strategic areas—the Outer Thames estuary, the Greater Wash and the eastern Irish Sea. The scale of the planned developments means that each will have a large environmental footprint and multiple ORED will have a cumulative effect on the environment. Here we discuss current understanding of ORED construction, operation and decommissioning with regard to the potential interaction with elasmobranchs because of the worrying status of elasmobranch populations within the UK coastal zone. Based on the likely interactions between elasmobranchs and ORED a framework is proposed which aims to promote cooperative initiatives between elasmobranch conservation management and the offshore renewables industry.

INTRODUCTION

During 2004 the UK government set out its strategy for generating 15% of electricity from renewable sources of energy by 2015. The aim of the strategy is to reduce greenhouse gas emissions and thereby meet carbon mitigation obligations under European Union directives and the Kyoto protocol. Achieving this and the wider government aims on sustainable development has provided the impetus for a rapid growth in activity associated with offshore renewable energy, particularly offshore wind farms.

To support the developing offshore renewable energy industry a major plan was announced during 2003 to consent to development of multiple, large scale wind farms in three coastal areas of the UK, namely the Outer Thames estuary, the Greater Wash and the eastern Irish Sea. The UK is well placed for this development as 40% of the wind resource of Europe is found off the UK coast. In addition, there are initiatives to harness the substantial potential for other UK offshore energy sources such as tidal, current and wave (Morgan et al., 2003). An important implication of this increase in offshore renewable energy activity is a huge shift in the use of localized areas of the coastal environment (Gill, 2005), and these are areas which support many of the UK's elasmobranch species (Rogers et al., 1998; Rogers & Ellis, 2000). This raises the question of whether there will be any interaction between offshore renewable energy developments (ORED) and elasmobranchs.

Over a number of decades coastal waters globally have been subject to large scale human impact (e.g. fishing, pollution, coastal development and operations; see Gill, 2005). During this time, coastal elasmobranchs worldwide have suffered dramatic reductions in their numbers, which has been attributed to unregulated fishing leading to over-exploitation of the larger elasmobranch species and degradation of functional habitat (Walker & Hislop, 1998; Rogers & Ellis, 2000; Myers & Worm, 2003). Of particular concern is the destruction and degradation of feeding and spawning grounds and nursery areas of the many species of elasmobranch that require such areas for completing their life cycle (ICES, 1996). When this is added to the small number of recruits and long maturation periods typical of the elasmobranchs then populations cannot recruit individuals fast enough to replace those lost to overexploitation, pollution and habitat degradation (Camhi et al., 1998).

Nationally there have been relatively sharp declines in the numbers of many of the larger elasmobranch species (Rogers et al., 1998; Walker & Hislop, 1998; Rogers & Ellis, 2000). Some formerly important fisheries species, such as *Dipturus batis* Linnaeus, 1758 (common skate) and *Squatina squatina* Linnaeus, 1758 (angelshark), are now extirpated from or only occur rarely in localized areas of the UK. The status of other commercially important species of the north-east Atlantic and North Sea, for example *Raja clavata* Linnaeus, 1758 (thornback ray), other large rajiids, and *Squalus acanthias* Linnaeus, 1758 (spurdog), has been of increasing concern for both fisheries and wildlife managers (Walker & Hislop, 1998; Fordham, 2004).

To address the worrying status of elasmobranch populations a number of initiatives have been put in place at national level, such as a UK Biodiversity Action Plan for *D. batis* and strict protection for *Cetorhinus maximus* Gunnerus, 1765 (basking shark). Other Rajiid species are currently being considered for protection under the UK government Wildlife and Countryside Act (1981). Internationally, the United Nations Food and Agriculture Organization (UN FAO) plan of action for the conservation and management of sharks (which covers all chondrichthyan fish) identifies the need to: assess threats to

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Table 1. *The potential implications of ORED for elasmobranchs based on distinct ORED related features and their interaction over different time scales.*

Timescale	ORED features	Potential implications for elasmobranchs
Short term	Construction – Installation of foundations and devices – Cable laying – Noise (surveying and installation)	Habitat disturbance Increased prey availability for opportunistic species Short term displacement
	Decommissioning – Installation of foundations and devices – Noise	Habitat disturbance Increased prey availability for opportunistic species Short term displacement
Long term	Energy generation – Noise – Electromagnetic fields (EMFs) – Moving devices	Low frequency noise Electric fields Magnetic fields Barrier to transit routes Collision Long term displacement
	Electricity transmission – Connection to shore – Device interconnections	High voltage electric fields High voltage magnetic fields
	Areal extent – Multiple devices – Cable array – Scour protection	Large scale increase in habitat heterogeneity – Benthic – Water column Ecological enhancement
	Decommissioning – Removal of devices – Removal of cables	Habitat removal Large scale decrease in habitat heterogeneity Long term displacement No EMF No noise

elasmobranch populations; determine and protect critical habitats; identify and provide special attention to vulnerable or threatened elasmobranch stocks; contribute to the protection of biodiversity and ecosystem structure and function (FAO Marine Resources Service, 2000).

To assist such conservation management initiatives elasmobranch research needs to identify specific impacts and potential threats to elasmobranchs and the habitats that they rely upon to complete their life history and also promote opportunities for sustainable management. In this context the industrial scale expansion of ORED will have implications for elasmobranchs (see Table 1) and the wider coastal environment, however, it is uncertain if the impacts will be positive or negative (Gill, 2005). What is certain is that an opportunity exists to put in place cooperative initiatives that will enable the planned ORED to contribute to sustainable management of UK elasmobranchs, based on an understanding of the potential interactions between them.

ENVIRONMENTAL INTERACTIONS BETWEEN ORED AND ELASMOBRANCHS

Direct interactions between elasmobranchs and ORED will occur during three distinct phases: construction (including pre-construction surveying); routine operation; and decommissioning of ORED, and these interactions need to be considered over both short and long time scales (Table 1). Whether the interactions have any ecological relevance can be considered at three different levels: individual, population and community.

Short term

The construction and decommissioning phases of an ORED are relatively short lived (several months), however, physical removal and burial of local sedentary infauna and reef builders would be expected during the installation of devices and cable laying (Table 1; Gill, 2005). During construction the eggs and juveniles of elasmobranchs may be vulnerable to burial or direct removal or they may suffer from abiotic changes (e.g. oxygen depletion) and large variations in available resources (e.g. food).

The high level of activity associated with construction and decommissioning will create subsea noise within the range 170–260 dB re 1 μPa @ 1 m (Nedwell et al., 2003). This level of acoustic emission could potentially mask biologically relevant sounds, cause sensory impairment or injure individuals. The ORED already reduce the potential for affecting coastal biota by using a soft-start-up procedure during construction, which gradually builds the noise towards a maximum over a period of minutes to hours. The aim of this procedure is to encourage mobile species to move away. However, species with life history stages that last a number of months and are restricted in movement (e.g. juvenile benthic sharks) or cannot move (e.g. rajiid eggs) from the location where an ORED is being developed are likely to be particularly susceptible to the noise emitted. Relatively mobile adult elasmobranchs would be expected to detect the noise but the levels are greater than those that will attract them (Myrberg, 2001), hence the net result is likely to be displacement to another location (Table 1). The extent of displacement will be related to the length of the construction period and the

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number and timing of other developments in adjacent waters. As the UK government has defined the three strategic development areas additive and cumulative implications are particularly relevant here.

If a number of individuals are affected or are displaced then it is probable that the local elasmobranch population will also be affected if ORED noise occurs at times of the year where they congregate naturally (Table 1; e.g. Walker et al., 1997). Information on the spatial and temporal distribution and occurrence and life stage vulnerability is important to reduce the potential for impact on the elasmobranchs.

Displacement or changes to the number of individuals in a population will also have consequences for the community in two main ways. Firstly, if the elasmobranchs are displaced then their predatory influence will reduce locally but increase elsewhere. Secondly if population recruitment processes are affected then the resultant changes will alter the community dynamics and possibly the metapopulation in the longer term (Gill, 2005).

In contrast, the physical disturbance and removal of habitat and the subsequent benthic community response to ORED construction and decommissioning may provide significant benefits to species that are opportunistic and more general in their diet (Table 1; e.g. scavenger species, *Scyliorhinus canicula* Linnaeus, 1758; Lyle, 1983).

Long term

Whilst the construction and decommissioning of ORED will cause significant, short term physical and acoustic disturbance, there are a number of longer term (years to decades) and operation related effects that should also be considered (see Table 1).

Energy generation

During operation an offshore wind farm has been shown to emit low frequency noise of up to 153 dB re 1 μPa @ 1 m (Nedwell & Howell, 2004). However, the level of acoustic disturbance associated with an ORED will be a function of the number of devices, their power output and operating procedure (Nedwell & Howell, 2004). Further acoustic disturbance is likely with multiple ORED being located within the three strategic areas defined along the UK coast. Elasmobranchs respond to low frequency sound (40–800 Hz; Myrberg, 2001) and sound at this level can play a role in the location of food, conspecifics and possibly predators (Popper & Fay, 1993). Piscivorous elasmobranchs could also be indirectly affected by the sound from an operating ORED impacting other fish species. The situation regarding other energy generation devices is unknown at present but there is likely to be some amount of noise associated with moving parts during operation.

It is important to understand whether the type, frequency and intensity of sounds associated with ORED will have any implications (such as reaction or habituation) for the elasmobranchs that inhabit or migrate through the affected coastal waters. Although there is currently no direct evidence of noise related disturbance of elasmobranchs it should be possible to predict effects based on research of individuals response to different noise levels and biological thresholds. It is likely that determining the predictability and suddenness of change in sound intensity will be key to mitigating any noise effects on elasmobranchs (Myrberg, 2001).

Energy transmission

With present technology the electricity generated by an ORED is transmitted between devices and to the onshore network via 50 Hz high voltage alternating current (AC) or direct current (DC) cables. The electricity transmitted through the cables will emit electromagnetic fields (EMFs). Elasmobranchs respond to magnetic fields (25–100 μTesla; Meyer et al., 2004) and are thought to use the Earth's magnetic field (approximately 50 μTesla) for migration, whilst they respond behaviourally to electric fields emitted by prey species and conspecifics. Although the cables that are presently manufactured have a high shielding against both electric (E) and magnetic (B) field emissions, industry standard AC cables leak B fields of approximately 1.6 μTesla (CMACS, 2003).

Elasmobranchs may be able to detect the magnetic fields associated with an ORED. Any effect (such as a confusion effect as seen in some migrating eels; Westerberg, 2000) however, is likely to be temporary whilst moving through the area following geomagnetic cues. Resident species could also possibly react but they may be able to habituate to the magnetic fields emitted. Current expectation is that as the leaked B field is much lower than the background geomagnetic field then no significant response will occur, this however, is likely to depend on the predictability and variability of the emission.

The leaked B field also induces E fields in the water adjacent to the cable which come within the range of electrical emissions detectable by elasmobranchs (CMACS, 2003). Generally, elasmobranchs respond to an E field at a distance of up to 30 cm from the source and are attracted to DC fields in the range 0.005 to 1 μV/cm (Kalmijn, 1982), whereas they avoid DC fields of approximately 10 μV/cm (Kalmijn, 1982). There is little research to date on the effects of AC E fields (Kalmijn, 1988) and only neurophysiological studies of the frequencies detectable by electrosensitive fish (Bodznick & Boord, 1986; Sisneros & Tricas, 2002). It has been suggested, however, that low frequency emissions are more likely to be detected in the environment (Kalmijn, 1988). If the induced E fields emanating from the cable can be detected by elasmobranchs, then at the emission levels that approximate the bioelectric fields of prey there is the potential for species to be attracted. Stronger fields close to the cable may result in repulsion. The potential for damage to the electrosensory system is considered low as E fields are only detected over short distances and will be encountered as a voltage gradient in the seawater to which the elasmobranch can respond accordingly.

Subsea cables are typically laid on or in a soft sediment substratum therefore benthic elasmobranchs are most likely to encounter any EMF emission, particularly if the ORED is constructed in an important local feeding or breeding ground or nursery area.

There are no data on interactions between the few existing ORED cables and elasmobranchs and there is only one published article of a direct response by elasmobranchs to an undersea cable. Marra (1989) reported that

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a major optical communication cable was damaged by biting elasmobranchs (Carcharhinid species and *Pseudocarcharias kamoharai*). The cable emitted two forms of electric fields. The first was an induced 50 Hz E field (6.3 μV/m @ 1 m) caused by an induced alternating current through the power feed to the cable. The second E field (1 μV/m @ 0.1 m) was induced by the sharks crossing the magnetic field emitted by the cable. The damage caused by the shark bites required sections of the cable to be reinforced at depths where the species that bit them were most likely to occur. Subsequent behavioural tests in the laboratory and at sea were inconclusive; however the cable reinforcing reduced the incidence of shark bites damaging the cable.

Collision with ORED

The potential exists for elasmobranchs to collide with the energy generating devices. However, there is currently no information concerning aquatic fauna colliding with offshore energy generation devices. The biggest concern appears to be mortality of migrating species caused by collision with underwater turbines located in enclosed waters (Dadswell & Rulifson, 1994). The probability of subsea collision will depend on the size of each device and in particular any of its moving parts, the number of devices, their spacing and whether the whole ORED is located along a transit or migration route of elasmobranchs. The potential for collision also will depend on the number of elasmobranchs migrating and the use of the water column by them. For example, when feeding in the surface waters for continuous periods lasting many hours (Sims & Quayle, 1998), *Cetorhinus maximus* would be expected to be susceptible if its feeding areas coincided with ORED. Other species may need to be considered if their behaviour increases the likelihood of encountering an ORED. If migrating elasmobranchs respond to the B field emitted, there may also be an increased risk of collision.

Data on migratory routes, habitat and water column use can be provided by elasmobranch researchers and fed into the ORED planning process to ensure that elasmobranch collisions are appropriately considered in addition to other aspects.

Areal extent

An ORED will alter a large area of sea bed as multiple energy generation devices will be interconnected with cables and each device foundation will be protected from the erosive action of the sea using anti-scour material (e.g. concrete blocks). If more than one ORED is constructed in the area then the cumulative extent of ORED may have further implications for a number of components of the coastal ecosystem and the elasmobranchs that depend on them.

Ecological implications

In ecological terms ORED may have implications for the amount of habitat available to elasmobranch species, with consequences for their distribution and community dynamics. In addition, they may be limiting for critical stages in the life cycle of a species (e.g. juvenile nursery habitat). This is particularly important for those species that migrate between habitats or use them as core breeding, nursery or seasonal feeding areas (e.g. *Galeorhinus galeus*, tope and *Lamna Nasus*, porbeagle). If a species is severely compromised at one stage of its life history because of habitat changes associated with an ORED then population regulation and recruitment may be affected.

The physical structure of an ORED will increase the heterogeneity of the benthic habitat and structure in the water column. Such changes represent a greater colonization opportunity for the benthos, more recycling of local energy, and may enhance survival, growth and refuge for the early life stages of many elasmobranchs. Increased food availability and greater opportunity for refuge may also promote individual growth and survival until such time as they are able to recruit to the adult population, as has been seen in other fish species (Blaber et al., 2000). Local changes in prey type, size and abundance which are likely to arise as a result of ORED are also expected to affect elasmobranch populations and communities through density dependent processes (Pimm, 1991) and trophic cascade effects (Pauly et al., 1998).

Patchily distributed food resources are indicative of shallow coastal waters (Hall et al., 1994) and the predicted changes to the benthos associated with ORED will add to the existing spatial network of food patches (Gill, 2005). The importance of the patchy resources will be determined by the extent and distribution of other viable patches and their connectedness over different spatial and time scales (Doody, 2001; Dulvy et al., 2003). Changes in patch dynamics as a result of one or more ORED may indirectly affect the temporal or spatial distribution of elasmobranchs or their population abundance through changes in local food web dynamics, species competition, predator–prey relationships and reproduction (Gill, 2005). If any effects result in species of elasmobranchs not being able to replenish numbers quickly enough then the resources that they exploited will be open to others through the process of competitive release. It is often smaller species with faster rates of reproduction and quicker growth that replace existing species. The subsequent increased competition for resources will further reduce the chances of species recovering to their original population level. Such processes are implicated, in addition to the major effects of over-exploitation, in the significant alteration of the absolute and relative abundance of ray species in the North Sea (Walker & Hislop, 1998; Dulvy et al., 2003).

The ORED may also provide refuge from fishing for elasmobranchs and/or their prey. Current regulations exclude commercial fisheries activity within and around a wind farm. Hence direct mortality from fishing would be reduced and adjacent fisheries areas may indirectly benefit from stock replenishment linked to recovery of ORED associated species populations.

Following decommissioning, the removal of habitat and species is also likely to significantly alter the local food-web dynamics. Decommissioning will affect the whole extent of the ORED as the devices, foundations, scour protection and interconnecting cables will be removed. As a consequence the local habitat heterogeneity and the abundance of species present will be reduced. Habitat loss may slow or even prevent the recovery of a breeding

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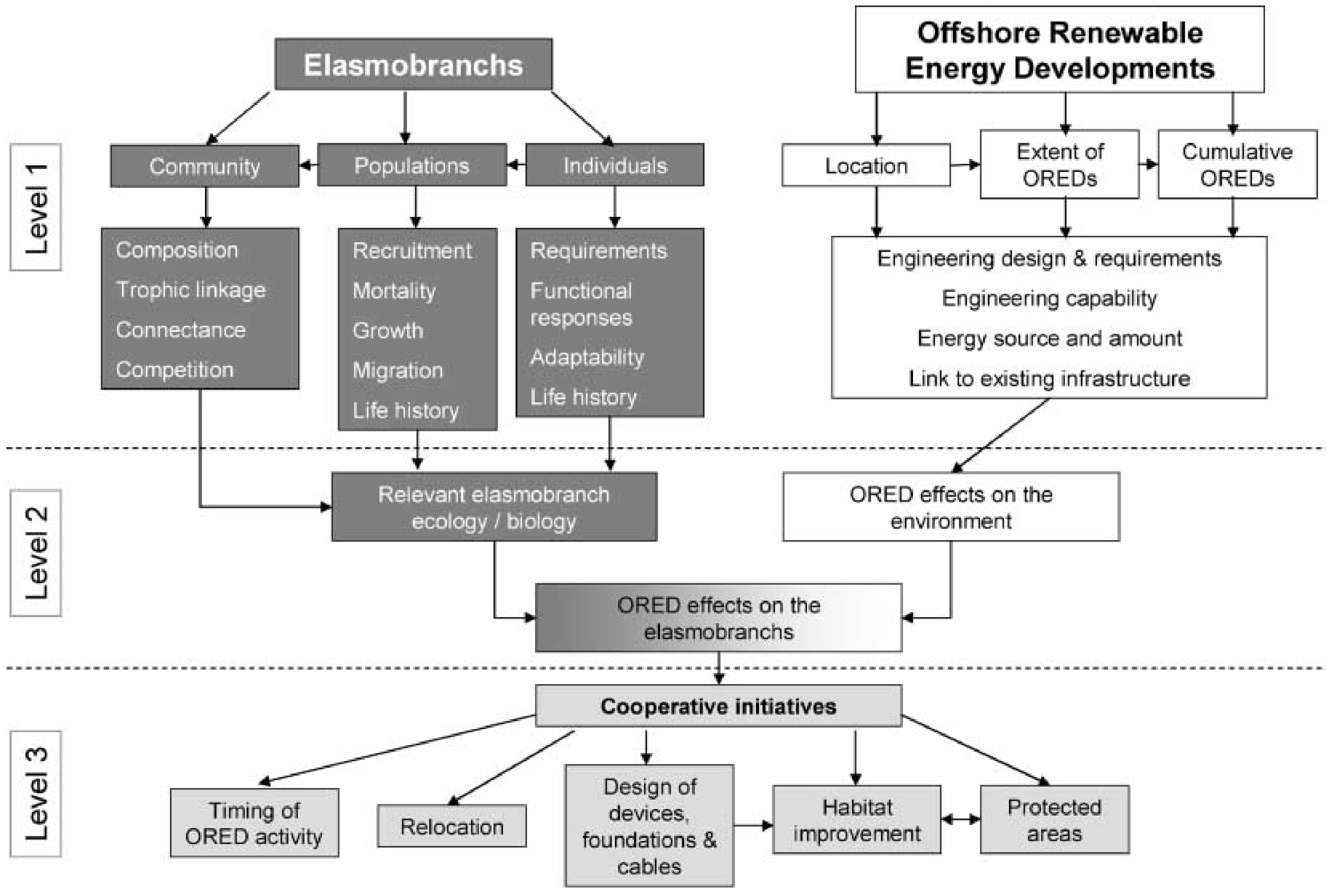

Figure 1. A conceptual framework for cooperative initiatives between elasmobranch research and ORED related activity. Level 1 highlights specific components for which data are either available or can be specifically collected. Level 2 brings together the data from level 1 to be analysed in a wider context linking both disciplines. Level 3 suggests integrated initiatives that use information from levels 1 and 2 to ensure mutual benefit and/or minimization of any detrimental effect on elasmobranchs.

elasmobranch population (Dulvy et al., 2003). In addition, the length of time the structure has been in place, the level of species colonization and ecological connectivity and the conservation importance of species present will be important aspects to determine for an appropriate assessment of the effects of decommissioning on elasmobranchs.

It is evident that it is ecologically important to understand the susceptibility of elasmobranchs, the species and habitats that they rely upon, and their response and resilience to the effects of ORED construction, operation and decommissioning (Gill, 2005). Understanding such factors will provide a strong foundation on which to base advice on measures to assist elasmobranch conservation management objectives.

Linking elasmobranch conservation with ORED

Currently issues relating to ORED focus on aesthetics, effects on the value of water front properties and beachside tourism, and specific effects on seabirds and marine mammals. Issues concerning the wider coastal environment, including elasmobranchs, have not been sufficiently addressed (Gill, 2005). There may be detrimental effects to the local environment (e.g. shifts in benthic community composition), which may have consequences for elasmobranchs. However, it is entirely possible that there may be benefits (e.g. new habitat for fish populations), which could significantly improve the environment for elasmobranchs. Proper identification of the positive and negative issues could provide the appropriate drivers necessary to ensure the offshore renewable energy developers and the elasmobranch conservation interests can converge on combined benefit or mitigation.

A framework that may allow these two disparate disciplines to integrate and provide a considered approach via cooperative initiatives is illustrated in Figure 1. The figure shows elasmobranch research in an ecosystem context by linking components at different scales (e.g. individual, population and community) and their associated attributes. Each attribute provides specific information that is important for moving between ecosystem components and levels 1 and 2 of the framework. Level 2 uses evidence provided from level 1 to address wider ecological questions relevant to ORED. Figure 1 also suggests that for ORED specific information can be obtained on a particular site and the analysis can use information at different scales (e.g. areal extent, cumulative ORED) to address the wider question of ORED effects on the environment. At level 2 the information from both disciplines is set within a similar context which facilitates discussions on the overall effect of ORED on elasmobranchs. The next stage is to integrate the findings from the discussions and move to level 3 to formulate cooperative initiatives with the aim

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of benefiting both or minimizing any effects for either discipline.

An example of the usefulness of this approach relates to the EMF emitted by the subsea cables. An engineering analysis provided evidence for the level of emission of both B field and E fields from industry standard cables (CMACS, 2003). The cable manufacturers use appropriate specifications to omit direct E field emission, however, the B fields that are emitted induce E fields. The biological analysis centred on the range of detection of EMF by elasmobranch individuals. Knowing that all individuals possess electroreceptors and presuming that each individual within a population may be able to detect the emissions, many individuals of different species could be affected thereby creating consequences for the community. As yet no effect has been determined but the potential result may be avoidance or attraction to the E field. Engineering modelling showed that the induced E field will be present in the water adjacent to where a cable is buried, suggesting that cable burial in a non-magnetic substratum to the normal depth of one to three metres will not mitigate EMF emissions. Hence bringing together understanding of the cable emissions and the detection abilities of the fish shows that there is no rationale based on EMF for burial of the cable (CMACS, 2003). Moving to level 3 in Figure 1 leads to the recommendation of cooperative efforts to consider other potential effects such as the timing of EMF emissions during ORED operation, which is important to consider in relation to habituation of the elasmobranchs. Alternatively, the cooperation could concentrate on other management such as improving habitat for elasmobranchs or their prey through ORED structural design or assigning some legal status to restrict the effects of other human activity in the area such as currently exists for fishing.

By understanding how an ORED may affect elasmobranch individuals, populations and communities there is an opportunity for cooperative initiatives to build conservation management into the plans for ORED and help in the sustainable management of vulnerable UK elasmobranchs.

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REFERENCES

Blaber, S.J.M. et al., 2000. Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. *ICES Journal of Marine Science*, **57**, 590–602.

Bodznick, D. & Boord, R.L., 1986. Electroreception in Chondrichthyes: central anatomy and physiology. In *Electroreception* (ed. T.H. Bullock and W. Heiligenberg), pp. 225–256. New York: John Wiley & Sons.

Camhi, M., Fowler, S.L., Musick, J.A., Brautigam, A. & Fordham, S.V., 1998. Sharks and their relatives—ecology and conservation. *Occasional Paper of the IUCN Species Survival Commission*, no. 20, 39 pp.

CMACS (Centre for Marine and Coastal Studies), 2003. A baseline assessment of electromagnetic fields generated by offshore windfarm cables. COWRIE-EMF-01-2002, 71 pp.

Dadswell, M.J. & Rulifson, R.A., 1994. Macrotidal estuaries—a region of collision between migratory marine animals and tidal power development. *Biological Journal of the Linnean Society*, **51**, 93–113.

Doody, J.P., 2001. *Coastal conservation and management: an ecological perspective*. Dordrecht, Netherlands: Kluwer Academic Publishers.

Dulvy, N.K., Sadovy, Y. & Reynolds, J.D., 2003. Extinction vulnerability in marine populations. *Fish and Fisheries*, **4**, 25–64.

FAO Marine Resources Service, 2000. Fisheries Management. 1. Conservation and management of sharks. *FAO Technical Guidelines for Responsible Fisheries*, no. 4, Supplement 1, 37 pp.

Fordham, S., 2004. Conservation and management status of spiny dogfish sharks (*Squalus acanthias*). *CITES Animals Commitee*, AC20 Inf. 22, 7 pp.

Gill, A.B., 2005. Offshore renewable energy—ecological implications of generating electricity in the coastal zone. *Journal of Applied Ecology*, **42**, 605–615.

Hall, S.J., Raffaelli, D. & Thrush, S.F., 1994. Patchiness and disturbance in shallow water benthic assemblages. In *Aquatic ecology: scale, pattern and process* (ed. P.S. Giller et al.), pp. 333–376. Cambridge, UK: Blackwell Science Publishing.

ICES, 1996. Report of the Working Group on ecosystem effects of fishing activities. *ICES C.M.* 1996/Assess/Env., 1.

Kalmijn, A.J., 1982. Electric and magnetic field detection in elasmobranch fishes. *Science, New York*, **218**, 916–918.

Kalmijn, A.J., 1988. Detection of weak electric fields. In *Social communication in aquatic environments* (ed. J. Atema et al.), pp. 151–186. New York: Springer-Verlag.

Lyle, J.M., 1983. Food and feeding habits of the lesser spotted dogfish, *Scyliorhinus canicula* (L.), in Isle of Man waters. *Journal of Fish Biology*, **23**, 725–737.

Marra, L.J., 1989. Sharkbite on the SL submarine lightwave cable system: history, causes and resolution. *IEEE Journal of Oceanic Engineering*, **14**, 230–237.

Meyer, C.G., Holland, K.N. & Papastamatiou, Y.P., 2004. Sharks can detect changes in the geomagnetic field. *Journal of the Royal Society Interface*, DOI: 10.1098/rsif.2004.0021, FirstCite, 2 pp.

Morgan, C.A., Snodin, H.M. & Scott, N.C., 2003. Offshore wind: economies of scale, engineering resource and load factors. A report for the Renewables Innovation Review. *Final Report. Garrad Hassan*, 3914/BR/01, issue C, 39 pp.

Myers, R.A. & Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. *Nature, London*, **423**, 280–283.

Myrberg, A.A. Jr, 2001. The acoustical biology of elasmobranches. *Environmental Biology of Fishes*, **60**, 31–45.

Nedwell, J. & Howell, D., 2004. A review of offshore windfarm related underwater noise sources. *Subacoustech*, Report no. 544 R 0308, 63 pp.

Nedwell, J., Langworthy, J. & Howell, D., 2003. Initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise, Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife. *Scubacoustech*, Report no. 544 R 0424, 72 pp.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres, F., 1998. Fishing down marine food webs. *Science, New York*, **279**, 860–863.

Pimm, S.L., 1991. *The balance of nature? Ecological issues in the conservation of species and communities*. Chicago: University of Chicago Press.

Popper, A.N. & Fay, P.R., 1993. Sound detection and processing by fish—critical review and major research questions. *Brain Behaviour Evolution*, **274**, 97–103.

https://doi.org/10.1017/S0025315405012117 Published online by Cambridge University Press

Rogers, S.I. & Ellis, J.R., 2000. Changes in the demersal fish assemblages of British coastal waters during the 20th century. *ICES Journal of Marine Science*, **57**, 866–881.

Rogers, S.I., Rijnsdorp, A.D., Damm, U. & Vanhee, W., 1998. Demersal fish populations in the coastal waters of the UK and continental NW Europe from beam trawl survey data collected from 1990 to 1995. *Journal of Sea Research*, **39**, 79–102.

Sims, D.W. & Quayle, V.A., 1998. Selective foraging behaviour of basking sharks on zooplankton in a small-scale front. *Nature, London*, **393**, 460–464.

Sisneros, J.A. & Tricas, T.C., 2002. Neuroethology and life history adaptations of the elasmobranch electric sense. *Journal of Physiology-Paris*, **96**, 379–389.

Walker, P., Howlett, G. & Millner, R., 1997. Distribution, movement and stock structure of three ray species in the North Sea and eastern English Channel. *ICES Journal of Marine Science*, **54**, 797–808.

Walker, P.A. & Hislop, J.R.G., 1998. Sensitive skates or resilient rays? Spatial and temporal shifts in ray species composition in the central and north-western North Sea between 1930 and the present day. *ICES Journal of Marine Science*, **55**, 392–402.

Westerberg, H., 2000. Effect of HVDC cables on eel orientation. In *Technische Eingriffe in Marine Lebensraume* (ed. T. Merck and H. von Nordheim), pp. 70–76. Bundesamt fur Naturschultz.

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