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The Potential for Habitat Creation around Offshore Wind Farms

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1. Introduction

The growth of offshore renewable energy generation is the biggest expansion of development in the marine environment in recent years, with offshore wind farms at the forefront of this. Due to its favourable wind resource, Europe in particular is rapidly expanding its portfolio of offshore wind energy generation; however, the rest of the world is also beginning to take advantage of this natural resource. This is due, in part, to the fact that Europe, especially the north-west region, has ideal conditions for development, due to the high offshore wind levels, and the fact that its coasts slope gently away from the land. This means that water depths increase relatively slowly in most areas, making conditions highly suitable for offshore construction (Ackermann and Soder, 2002).

In addition to this, the offshore wind environment is much more reliable than onshore wind, as it is less turbulent, and has a higher energy density. This is due to the convection caused by the differential heating and cooling of the land and sea over the daily cycle, making the offshore zone generally windier. Further offshore, the lack of surface roughness adds to average wind speeds, further increasing energy efficiency. It is estimated that an offshore wind farm can generate around 50% more electricity than can be generated from an equivalent sized land-based development (Linley *et al.*, 2007).

In the UK, the development of offshore wind energy generation has been undertaken in a series of Rounds. In April 2001, following a detailed consultation and application process, eighteen 'Round 1' sites were announced, with a maximum of 30 turbines (BWEA, 2005). Whilst these projects were in the planning stages, further consultation was undertaken, discussing topics which would be critical to future development, such as the consents process, legal frameworks and the electrical infrastructure required for future projects. Three Strategic Areas in UK waters were identified, with fifteen projects being granted permission to submit formal applications under 'Round 2'. In January 2010, a further nine zones were allocated to developers through a competitive application process, under 'Round 3'. On top of these, there have also been Round 2 extensions granted for certain projects, and a number of sites granted exclusivity agreements to apply for development in Scottish Territorial Waters.

In 2008, the UK overtook Denmark to become the world-leader in generating energy from offshore wind (Jha, 2008). With current UK emphasis on the construction of Round 2 projects, and the early development phases of Round 2 extensions, Round 3 and Scottish Territorial Waters projects, there is the potential for thousands more turbines to be installed

in the waters around the UK, with expansion also predicted for many other countries worldwide, as technology develops.

As with the expansion of any relatively 'young' industry, there are concerns over the potential for environmental impacts resulting from offshore wind farms, including damage to the seabed from the installation of the turbines, and from the temporary placement of jack-up vessels, generally used in the construction of offshore wind farms.

Of the four phases of an offshore wind farm (exploration, construction, operation and decommissioning), it is generally considered that for marine life, the construction period has the greatest potential for causing impacts. It is inevitable that the installation of a foundation and tower (currently up to around 6m in diameter) will cause the removal of an area of the receiving seabed as available habitat for infaunal and epifaunal species (animals living in and on the seabed). For immobile species, this can also result in mortality, either through the impact itself, or the noise from the piling hammer, if the foundations are to be driven into the seabed.

The potential impacts arising from the various phases of the project are illustrated in Figure 1, taken from Elliott (2002). These diagrams are not exhaustive, but give a good indication of the intricacies of the impacts which may be caused by the installation of an offshore wind farm.

It should be noted that the impacts demonstrated in Figure 1 are heavily weighted towards marine life, i.e. benthic fauna, fish and marine mammals. Other impacts include potential impacts on bird populations (more complex than demonstrated here), as well as socio-economic issues, such as changes in levels of tourism in an area, and possibilities for job opportunities.

As with any developing industry, focus has been on the potentially negative impacts on the environment, so that these can be reduced, and where possible, eliminated. In this light, one element of offshore wind farms which has yet to be fully investigated and acknowledged at a wider level, is the potential for the submerged towers and foundations of the turbines to act as artificial reefs, with the capacity to increase the abundance and diversity of species and habitats within the receiving environment.

This chapter aims to review the current body of work in this area, looking at the following areas:

- *Artificial reefs in the marine environment:* Almost any structure in the marine environment has the potential to be colonised by marine life, thereby acting as an artificial reef, whether intended for the purpose or not. As the issue of marine conservation grows in importance, the installation of structures specifically for the purpose of enhancing abundance and diversity has increased, along with the body of work into rates of colonisation and suitability of various materials for the purpose.
- *Current evidence for offshore wind farms acting as artificial reefs:* Although there is still a relatively low number of fully-constructed and operational offshore wind farms around the world, there are a number of studies which have looked at the way in which marine life interacts with the turbines and their associated scour protection, where deployed. This includes post-construction surveys, as required in the conditions of consent, as well as scientific studies, looking to further knowledge on potential impacts and benefits.
- *Potential habitat enhancement by offshore wind farms:* Once more is understood about the interactions between offshore wind turbines, any associated scour protection, and the marine environment into which they are installed, it may be feasible to adapt design or deployment methods in order to maximise the benefit to the environment.

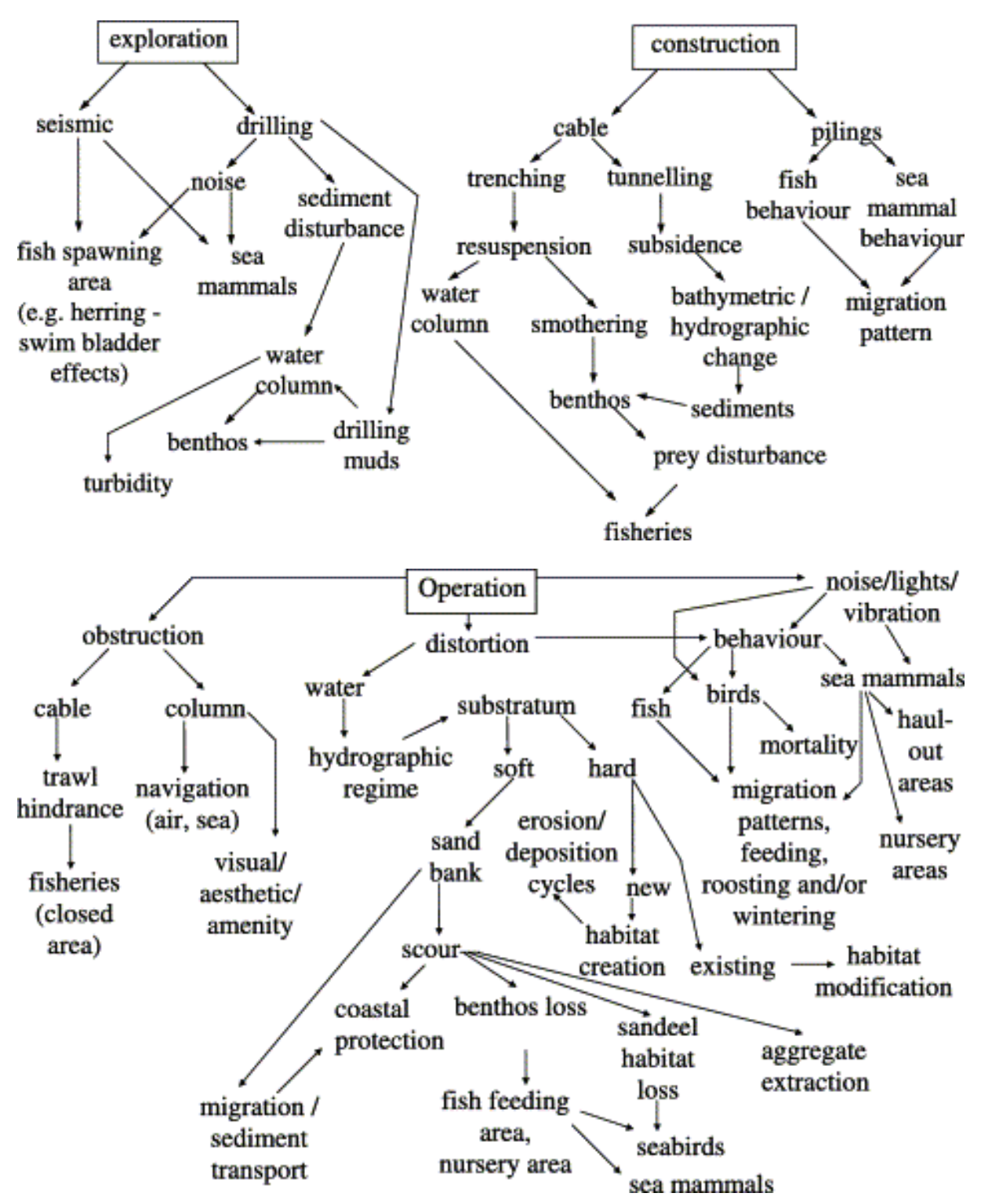


Fig. 1. Environmental impacts of offshore wind farms during pre-installation exploration, construction (similar effects are likely to occur during decommissioning) and operation (adapted from Elliott, 2002).

Finally, areas of future study requirements will also be addressed. As with almost all areas of study, the potential for habitat creation around offshore wind farms will benefit greatly from additional work in the field. With more developments planned, more surveys around operational wind farms will determine the significance of habitats created around the turbines, as well as assisting in possible modifications to future designs, construction plans or survey methodologies. Further work on artificial reef deployment in general will also add to understanding.

2. Artificial reefs in the marine environment

Already, there exists a large body of both anecdotal and scientific data on the benefits of artificial reefs – both intentionally created and otherwise – to marine life. Anyone who has seen a pier support or harbour wall will know how rapidly colonisation of any introduced surface into the environment can occur, with the initial populations soon attracting more individuals and species to the newly-developed community. A number of studies have focused on the sequence of colonisation, how rapidly it occurs, and what benefits it can have to the surrounding environment.

For many years, there has been anecdotal evidence of oil rig workers fishing from platforms, reporting high numbers of large fish, suggesting that the fish were using the reefs as shelter in an otherwise featureless ocean environment. Lokkeborg *et al.* (2002) conducted a study around two North Sea platforms, one partly decommissioned and one still operational, using gill nets. It was found that catch rates increased rapidly close to the platforms, indicating a distinct increase in fish abundance (a linear relationship between catch rate and fish abundance was assumed in the study). Similar results have also been found around oil rigs in the Gulf of Mexico. It is thought that shelter from prevailing currents, lower risk of predation and higher prey densities all contribute to the tendency for fish to aggregate around oil rigs (Lokkeborg *et al.*, 2002).

Several projects around the world have taken advantage of this function of oil rigs, including the Louisiana Artificial Reef Programme, established in 1986 to take advantage of the obsolete oil and gas platforms which had been shown to be important habitats for the region's fish populations. It was recognised that to remove the platforms once decommissioned would be to remove potentially valuable habitat from the environment, despite regulations that platforms be removed a year after the end of production (Louisiana Department of Wildlife and Fisheries, 2005). Since the installation of the first platform in the region in 1947, it was noted that fishermen of Louisiana and neighbouring states had recognised the value of the surrounding waters as fishing grounds, with the structures being the destination of over 75% of recreational fishing trips departing from Louisiana (Wilson *et al.*, 1987). When it became apparent that the majority of the rigs would be removed on decommissioning, the project was launched in order to save the habitat and resulting fish populations. The programme followed similar ventures in South Carolina, Alabama and Florida (with one of the first documented artificial reefs being initiated by a private individual in the 1800s in South Carolina), as well as in other countries. Following a large-scale consultation with key user groups, including local fishermen, who were hoping to benefit most from the programme, several sites were selected for the structures to be located. It has been estimated that a single 4-pile platform jacket (standard construction for underwater support for a platform) can provide between 2 and 3 acres of habitat (Bureau of Ocean Energy Management, Regulation and Enforcement, 2010), a valuable addition to a

flat, plain environment, dominated by mud, clay and sand, with very little natural rock bottom or reef habitat.

A number of research programmes have followed the development of the rig structures as artificial reefs, including those undertaken by the Minerals Management Service's own divers, who recorded plant and invertebrate colonisation within only a couple of weeks of installation. Within a year of first installation (as an operational rig), the rig can be completely covered, and already forming the base of a highly complex food chain. Researchers found that fish densities could be up to 50 times greater around the sunken platforms, with each former rig serving as habitat for between 10 and 20 thousand individual fish, many of commercial or recreational importance for the region (Bureau of Ocean Energy Management, Regulation and Enforcement, 2010). Although not all rigs are utilised by the rigs-to-reef programme, every one which is has the potential to bring about large benefits for the surrounding marine environment. They have also been found to be of benefit economically, with recreational charter boats, fishermen, and diving operators all listing the rigs as amongst their most popular destination for recreational fishermen and divers, both keen to take advantage of the rich biodiversity the rigs create. The programme is so successful that in 2002 it was recognised as such, with the main leaders of the project receiving special citation at the Offshore Technology Conference, Houston.

Other structures have been introduced to the marine environment with the direct aim of enhancing the populations in the surrounding area, as well as bringing possible economic benefits through the attraction of human visitors. Large-scale examples of this are ships such as HMS Scylla, off the south coast of England in 2004, and more recently, in 2009, HMAS Canberra off Australia. These ships are often scuttled with the deliberate aim of creating habitat for both marine and human life, namely in the shape of SCUBA divers. For the Scylla, the main purpose for the sinking was the creation of a purpose-built, safe dive site, bringing in high-spending divers to the area. However, it has also presented local scientists with an opportunity to study colonisation of an underwater structure from just days after entering the water. Surveys showed that after only 10 days, fish had started to use the area, followed by tube worms, barnacles, hydroids etc, and wandering species such as crabs. After ten weeks, there was significant variety of life on the wreck (Hiscock, 2009). By the end of the first year of survey work, 53 species had been recorded on or in the Scylla, with the sequence of colonisation and loss of species being traceable through regular study. In March 2009, it was reported that 258 species had been recorded on the Scylla (Hiscock, 2009), and although a number of 'expected' species were yet to be noted on the wreck, and some species were not found in the abundances expected after five years, it is still a significant increase in abundance and diversity for the immediate area. It has also become a major diving attraction for the area.

One of the key issues with artificial reefs is whether the installation is actually producing its own life, and thereby contributing to the surrounding community, or simply attracting life away from nearby habitats, and therefore perhaps actually having a negative effect, by 'thinning out' local populations. A number of studies have investigated this in relation to fish or motile invertebrate communities, but there is little work done on benthic communities (Perkol-Finkel and Benayahu, 2007). Part of the difficulty in determining whether artificial reefs simply divert propagules from their natural destinations, or attract those which would otherwise be lost, is due to the difficulty of following larval movements in the ocean, despite many advances in this field. In their 2007 study, Perkol-Finkel and Benayahu undertook experiments in the Red Sea, using settlement plates to determine any

differences between artificial and natural reefs. It was found that recruitment of fouling invertebrates and corals clearly differed between the artificial and natural reef areas, both in species composition and abundance. It was suggested therefore, that the majority of the organisms which colonised the artificial reef area were not derived from adjacent natural reefs, and so in all likelihood, would not have been recruited to the area were it not for the artificial reef being present (Perkol-Finkel and Benayahu, 2007). It is therefore noted that artificial reefs are able to increase the species diversity of an area, perhaps through the introduction of different conditions, habitat types and available niches, to those already available naturally.

3. Current evidence for offshore wind farms as artificial reefs

Due in part to the youthful nature of the offshore wind industry, there are still relatively few fully comprehensive studies into the influence of turbine arrays on fish and benthic populations, other than the monitoring requirements set out in the consent conditions. However, where datasets do exist, it is suggested that offshore wind farms are demonstrating benefits for such populations.

The effect on commercial stocks, such as lobster and crab, are an obvious concern to those directly and indirectly involved in the exploitation of such stocks; therefore any impacts are key to the Environmental Impact Assessment (EIA) process. Observations made onboard a commercial potting vessel deploying gear within the operational Barrow Offshore Wind Farm, off the north west coast of England, eighteen months after construction was completed, found that catch rates for lobster were similar inside and outside of the wind farm boundary (Centrica, 2009). In addition to this, the number of undersized crabs taken within the wind farm was greater than the number found outside the boundary, suggesting that the wind farm site is acting as a haven for juvenile crabs. Initial thoughts that this may be due to lack of fishing effort, with the wind farm acting as an unofficial nature reserve, were discounted in the case of Barrow due to anecdotal evidence, which stated that potting had recommenced within the wind farm boundary a matter of weeks after construction was completed (Centrica, 2009).

A recent study by Langhamer and Wilhelmsson (2009) looked into the colonisation of wave power devices off the Swedish coast, with some of the foundations being perforated with holes at different heights and positions around the block foundations, to determine whether this would have a positive influence on colonisation. Surveys on the blocks were carried out by divers. Although fish populations in the area were generally relatively low, it was found that numbers were significantly higher around the foundations than in the control sites (sites of the same area, generally of sandy seabed, near to the foundations). Although the number of lobsters found was low, with individuals inhabiting crevices around the base of the foundation rather than the drilled holes, the foundations were found to have a positive effect on the number of edible crab, which increased around foundations with or without holes (Langhamer and Wilhelmsson, 2009).

At the Horns Rev Offshore Wind Farm, off the Danish coast, Forward (2005), found that in terms of benthic community structure, there was no significant difference between the wind farm site and a reference area. However, there was a substantial increase in the density of sand eels, rising by 300% within the operational wind farm in 2004, compared to a rise of only 20% at the reference site. This increase within the wind farm was mainly due to an increase in the number of juvenile sand eels, with the main reasons behind the increase

thought to be reduced mortality through predation, and a reduction in mean particle size as a result of construction. In addition to this, eight new species were recorded within the wind farm site, compared to pre-construction surveys (Forward, 2005).

A number of studies have investigated the potential for offshore wind turbines to act as fish aggregating devices (FADs). FADs are not a modern phenomenon, and have been employed for centuries to concentrate marine fish and ease their capture, proving highly successful (Fayram and de Risi, 2007). In open-water areas, the catch-rates of some tuna species have been found to be 10-100 times greater near FADs, based on mark and recapture studies. This would clearly benefit local fish communities, of both commercial and non-commercial species, and where commercial stocks exist, would have the potential of enhancing such stocks for the local fishing industry. However, there is need for caution to be exercised here. It has been noted that in some situations, juveniles of some species are more associated with FADs than adult fish, thereby potentially resulting in the increased catch-rates of juveniles over adults, should these areas be fished (Fayram and de Risi, 2007).

This element would need further survey work before the true benefits for the fishing industry, if any, could be estimated.

Wilhelmsson *et al.* (2006) undertook research into the effects on fish populations at five wind farm sites in Sweden, and found that large communities of both demersal and pelagic fish populations developed around the turbines. It was noted that the presence of such populations may in fact lead to further enhancement of benthic communities around the base of the turbines, as a result of the deposition of organic material such as faecal matter, organic litter and dead organisms, all of which provide material for benthic organisms to feed on. In addition, it was reported that mussel beds were starting to develop in the areas adjacent to the wind turbines, possibly as a result of mussels being dislodged from their original attachment locations on the towers. A cyclical effect could develop here, as more benthic organisms means more food for fish, which increases the level of organic waste, thereby allowing further growth of benthic organisms, and so on.

The development of mussel populations on turbines could itself be of interest to the fishing community, as it was noted that previous studies have identified a link between mussel beds and increased fish numbers (Wilhelmsson *et al.*, 2006). Given that mussel growth is present on almost all turbine structures in the correct environmental conditions, this could be of particular interest.

The potential for the advantages of offshore wind farms acting as artificial reefs, and the ever-growing interest in the industry, means that there are frequently new research projects being designed to look into their capacity for colonisation and production.

The development of life around turbines is of key interest to the owners of the wind farms, as excessive build up of life can be damaging for the turbine. Surveying around the towers can also be specified as a condition of consent. For the operational Barrow Offshore Wind Farm, in the East Irish Sea, near Barrow-in-Furness, the surveying of colonisation of the monopile foundations and scour protection was required as part of the Food and Environment Protection Act (FEPA) licence granted for the project. The turbines had been installed in 2005, with the surveys being undertaken in 2008 (EMU, 2008a), consisting of video footage, still photography and sample collection by divers.

It was noted that on the four turbines surveyed, colonisation had taken place in a generally similar pattern, with a gradual change in community observed as depth increased. At the intertidal level on the turbines, there was found to be green algae, with barnacles slightly lower, giving way to increasingly dense populations of mussels moving down the tower. As

depth increased, anemones increased in number, with mussels decreasing, with crabs and barnacles also being found. Around the base of the monopile was an area of coarse sediment, including shell fragments, pebbles and gravel (EMU, 2008a).

In general, the communities observed were typical of hard-surface communities, and commonly found in waters around the UK and Ireland. It was noted that no species of particular conservation interest or invasive / alien species had been found during the surveys. The results of the 2008 surveys were compared to initial survey work undertaken on six turbines, in 2006, around eight months after construction was completed. It was found that in general, the species found were similar between the two surveys, with abundances and densities increasing in the two years between surveys, as would be expected. Further comparison was also made with surveys undertaken on the North Hoyle Offshore Wind Farm, in Liverpool Bay, completed one year after construction. Again, broadly similar communities were found to be developing on the turbine towers (EMU, 2008a). There was found to be minor variations in community structure; however, this is to be expected given the different locations, and therefore differing environmental influences.

Similar survey work has been undertaken on the Kentish Flats Offshore Wind Farm (EMU, 2008b), in the outer Thames Estuary, approximately three years after the installation of the turbines. In this survey, two turbines were assessed, and again, similar patterns of colonisation were found on each tower. Again, a change in community with depth was noted, with barnacles and mussels dominating the intertidal and infralittoral zones of the tower. As depth increased, mussels became scarcer, being replaced by anemones, with hydroids also becoming more prevalent. As with the other developments, at the base of the towers, shell fragments, pebbles and gravel dominated the seabed, with a number of crab species being found, as well as high numbers of starfish, unsurprising given the high densities of mussels, their key prey species (EMU, 2008b).

These studies show the capacity for colonisation within just a few months of the turbines being installed. Although in these cases, there has not been significant variation between turbines, or even wind farms, it is still a useful contribution to the productivity and ecological carrying capacity of the surrounding marine environment, with the potential to attract other species into the area looking for food sources, as the community continues to develop.

4. Potential habitat enhancement by offshore wind farms

As stated previously, the introduction of turbines and their associated scour protection has the capacity to increase the abundance and diversity of both species and habitats. The level of increase depends on the type of scour protection deployed, with the three main materials – boulders, gravel and synthetic sea-fronds – being included in a study which aimed to quantify the amount of habitat area created.

The need to deploy scour protection around the base of turbines depends on a number of factors, including seabed type, potential for seabed movement, and the design of the turbines themselves. Where used, as stated above, there are three main types of protection deployed, as illustrated in Figure 2.

Figure 2a illustrates the general scale of boulder or gravel protection around the base of a wind farm, for relative scales compared to average turbine dimensions. Although actual dimensions vary with specific turbine makes and models, and deeper water will bring about new designs and technologies, in general, projects currently under construction, or well-advanced in the planning process are in waters up to around 30m. Projects entering the

planning process now, such as some in Scottish Territorial Waters, or as part of the large Round 3 zones, are in waters of 50m or more. The majority of turbines installed globally to date follow the same design as illustrated in Figure 2, the monopile design, with a single pile driven or drilled into the seabed, with the tower, nacelle and blades fitted on top. This is the foundation design which was used in the calculations by Wilson and Elliott (2009), the results of which are discussed below.

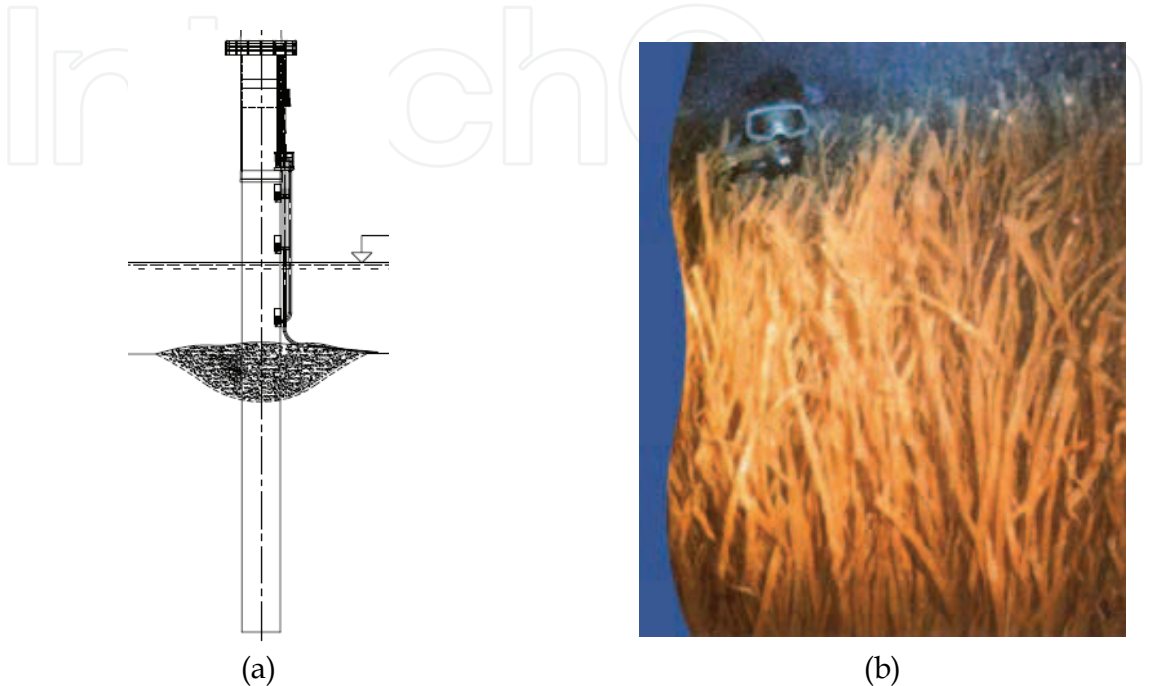


Fig. 2. a) Approximate extent of rock / gravel protection around the base of a monopile wind turbine foundation; and b) Polypropylene frond mats around a foundation. Both taken from Linley *et al.* (2007).

From Figure 2b, it can also be seen that the synthetic frond mattresses can be relatively large in height, allowing plenty of shelter and protection for a wide variety of fish species. Wilson and Elliott (2009) assessed the level of habitat lost and gained through the installation of a 4m diameter turbine, with an area of scour protection extending 10m from the base of the turbine. The results of the calculations from this study are shown in Table 1.

	Area (m²)		
	Gravel Protection	Boulder Protection	Synthetic Sea-fronds
Seabed lost through turbine installation	452	452	452
Habitat created by scour protection	1102	1029	439.5
Net habitat loss / gain	650 (gain)	577 (gain)	-12.5 (loss)

Table 1. Habitat loss / gain due to the installation of an offshore wind turbine and associated scour protection. For these calculations, a turbine foundation diameter of 4m was assumed, with 10m of scour protection extending from the edge of the foundation. For gravel, a mean diameter of 5cm was assumed, with a 2m diameter for boulders.

From Table 1, it can be seen that for each turbine, there will be a gain in the surface area available for colonisation through the use of gravel or boulders as scour protection. For synthetic sea-fronds, although the values indicate a reduction in surface area, the change in habitats available should be noted. As offshore wind farms are generally located in relatively flat, biologically-sparse areas of seabed in order to reduce impacts on the seabed and associated organisms, the introduction of a sea grass type habitat will increase habitat diversity, thereby potentially still having ecological benefits for the area.

Each of the main scour protection materials has the potential to attract a distinct biological community, based on the type of habitats it can create, e.g. the level of shelter provided, or the lower organisms which are initially attracted to the structure.

Where gravel protection is deployed, the area will generally be inhabited by low numbers of robust polychaetes or bivalves, with occasional epibiota including echinoderms and crustaceans. According to the JNCC 2004/5 Comparative Tables, available through the JNCC website, other dominant species can include the parchment worm, which create extensive 'beds', within which can be found large populations of shrimps and small crab species, in turn providing food for species such as pipefish and seahorses, which are able to anchor themselves to the tubes by their tails (Anthoni, 2006).

Pipefish and seahorses are also amongst the species most likely to be found where synthetic sea-fronds have been used as scour protection, which, from anecdotal and photographic evidence, most closely mimics a sea grass bed once semi-buried by accumulating sediment. Sea grass beds are important habitats for fish, providing shelter from predation, nursery areas and refuges from larvae, as well as feeding grounds (Kopp *et al.*, 2007). Gobies also make up a large component of the sea grass community, with densities within sea grass beds reaching up to four times those in surrounding non-grassed areas (Pihl *et al.*, 2006).

Of the three scour protection materials, boulder protection has perhaps the greatest potential to enhance populations of commercially-fished species. If well designed, then lobster, edible crab and velvet swimming crab may be attracted, as well as reef fish such as wrasse and conger eels (Hiscock *et al.*, 2002), as the boulder protection will mimic rocky outcrops, which generally have higher levels of biodiversity and abundance than surrounding sandy seabed areas.

Due to the commercial status of lobster, a number of studies have been undertaken into how populations may be impacted / influenced. For example, one study looking into the settlement patterns of juvenile lobsters found that no lobsters were recorded settling onto sandy areas of seabed, compared to 19 lobsters/m² on large cobble and boulder covered areas (Linnane *et al.*, 2000). Work focusing on the colonisation of wave power foundations (Jensen *et al.*, 1994), suggested that the deployment of such structures into areas where lobster populations were habitat-limited could have the potential to enhance biomass production. It has been noted that shelter from predation may be a serious bottleneck for many species, lobster and crab included, therefore the deployment of wind and wave energy structures and associated boulder protection may increase production at a local scale (Langhamer and Wilhelmsson, 2009).

A major argument for the capacity for habitat creation around offshore turbines is the increased level of habitat diversity which is brought about through the introduction of a new habitat, whether it be rocky outcrop, gravel bed or sea grass patch. Diversity of available habitats is important in bringing about diversity in the number of species able to colonise and thrive in an area, and by mixing the various types of scour protection material within the same wind farm, it may be possible to bring about all three new habitat types, and the animals and plants which they attract.

There is also the potential for fin-fish species to benefit from the installation of turbine structures, with any of the associated scour protection materials deployed. As discussed above, the newly-created habitat will either attract in, or increase the productivity of, a wide range of species, including prey species for fin-fish. Increased productivity in the benthic community will, over time, enhance productivity all the way up the food chain, to the larger fish species, and potentially even marine mammals.

A further aspect of the habitat-creation benefits of offshore wind farms which must be considered is the deliberate targeting of scour protection and the materials deployed to directly benefit specific populations. On a simple level, this may involve using boulder protection in an area where there is an established lobster or crab fishery, in order to provide additional habitat, and improve productivity, as demonstrated by Linanane *et al.* (2000). By making deliberate attempts to increase the number of juveniles settling in an area, and ensuring the correct habitat type is available for adult lobsters, this has the relatively rare effect of encouraging both ecological and commercial benefits, in addition to the environmental gains of the renewable energy generated from the wind farm itself.

Taking this further, there are a number of specially-designed materials which could be easily adapted to be suitable for scour protection. One such example is the reef ball, designed and marketed by the Reef Ball Foundation, a non-profit environmental Non-Governmental Organisation (NGO), based in America. These structures come in a range of styles and sizes, designed to suit varying types of environment and seabed community. In general though, they are concrete domes, with a number of holes drilled into them at various levels and of various sizes, to provide a range of habitats for different species groups to utilise. Figure 3 shows the standard reef ball design. More complex designs, such as the 'layer cake' and 'stalactite' designs, are each designed with specific purposes in mind, from attempts to rehabilitate dead areas of coral reef to creating a surface on which to grow shellfish commercially.

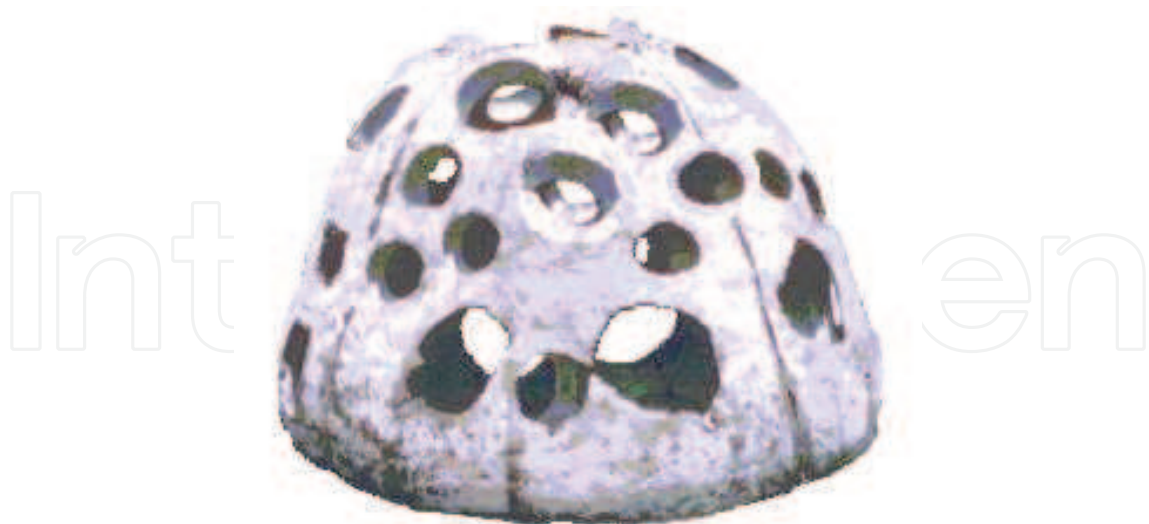


Fig. 3. The standard reef ball design (from the Reef Ball Foundation, www.reefball.org).

Through a combination of specifically-designed materials, and the placing of such materials in environments in which commercial populations of certain species such as lobster exist, a situation beneficial to both the local environment and local fishing communities may be reached. As the reef balls come in a range of sizes, including that similar to the boulders

installed where required around offshore wind turbines, they should be relatively easy to adapt to ensure they also fit the purpose of reducing scour around the base of the turbines, thereby also satisfying the key engineering purpose for which scour protection is deployed. However, as with any development, economics is a major factor in the design, planning and construction of offshore wind farms. With projects already costing millions of pounds to get into the water, additional costs for items such as the Reef Balls, when standard gravel or boulders are equally effective for the primary need, may not be easily approved by developers.

However, there may be a mid-point to the discussions, if a material was identified which was relatively cheap to purchase and install (compared to the specially-designed Reef Balls), as well as being able to function equally well as scour protection and increased habitat around the base of the turbine towers.

Materials commonly used in sea-wall construction, such as dolos blocks, tetrapods or concrete jacks, are built for strength, able to withstand large amounts of pressure, and also have unique shapes which lock in to each other, gradually shifting in the weeks after installation to form tight bonds with adjacent blocks. Using these materials would allow the creation of a wide number of niches, and increased surface area compared to boulders of a comparable size, thereby allowing greater potential for colonisation.

Another key element in the potential habitat creation by offshore wind farms and their associated infrastructure / scour protection is the argument that these areas may become unofficial marine protected areas (MPAs). Although fishing activity is not directly banned within the boundaries of many offshore wind farms, and in many is taking place successfully, some fishing gear is not conducive to the environment within the site boundary, such as dredging, which could lead to entanglement in the inter-array cables associated with the turbines. It is therefore possible that some offshore wind farm sites may have low levels of fishing taking place within them. Fayram and de Risi (2007) suggest that by creating an MPA in the area surrounding offshore wind farms, with limited entry to fishing activity (both commercial and recreational), it may be possible to provide circumstances which would be beneficial to a number of parties. It is noted that in some cases, oil platforms have acted as *de facto* MPAs due to prevailing currents and the platform themselves preventing the use of several types of fishing gear. If the same is true for offshore wind farms, then the wind farm owners would benefit due to reduced risk of damage from passing vessels, fishing groups could benefit from locally enhanced stocks, and the benthic and fish communities could benefit from reduced disturbance from fishing activity. Therefore, although the main aims of offshore wind power generation and MPA designation vary considerably, in some situations they may be complimentary (Fayram and de Risi, 2007).

Through the installation of offshore wind turbines, one of the key changes for the surrounding marine environment is the introduction of a new dimension in habitat terms. Many of the areas into which offshore energy generation is expanding is, for ease of construction, relatively flat seabed, with very few vertical elements such as reefs or cliffs. Therefore, the addition of the turbines and their foundations can add vertical habitat where before there only existed horizontal habitat for species to colonise.

Although it is impossible to physically increase the volume of water column already existing as habitat, and it could be argued that the installation of turbine towers actually removes a negligible amount of water in the area, the installation alters the form of the water column habitat available.

Despite turbines being up to almost 1km apart in some larger developments, the addition of the vertical habitat can act as shelter for some fish species, creating structure in an otherwise featureless open ocean. Therefore, an increase in the ecological 'usefulness' of the area is brought about, and as a result, its carrying capacity.

This distance between individual turbines will also determine whether, from a community perspective, the turbines are independent of each other, or are able to act as one large area of introduced habitat. This varies between species, with 1km being well within the range of larger, motile species such as cod, lobster and some crab species (Linley *et al.*, 2007), but for smaller fish species, or benthic organisms, which develop where they settle, there is less likely to be mixing between turbines. Although the design of the turbine layout is heavily based on economics, to ensure maximum wind, and therefore energy yield, consideration of the biological perspective in the array design at an early stage, could increase the potential for habitat creation to be as effective as possible.

5. Future study requirements

The status of offshore wind energy generation as a relatively young industry has both positive and negative aspects for developing its potential in habitat creation.

With few long-term studies of the changes in abundance and diversity of species within wind farms available, due to the relatively low number of developments currently operational, there are few datasets to fully analyse for the potential habitat gain which have been discussed in this chapter.

This problem of lack of long-term data also exists within the field of 'standard' artificial reefs, with few study programmes running longer than a couple of years in order to establish the initial stages of colonisation and succession (Perkol-Finkel and Benayahu, 2005).

In their research, Perkol-Finkel and Benayahu (2005) returned to previously-studied artificial reefs in the Red Sea, to determine what further developments occur ten years after deployment. It was noted that despite their close proximity, and equivalent depths, the community structure and species diversity differed between the artificial reefs and neighbouring natural reefs, which had acted as control sites for the early stages of the comparative study. Similar results are reported where shipwrecks and adjacent reef areas have been studied, with higher species diversity on the natural reefs. Naturally, the age of an artificial reef, whether intentional or not, will greatly affect its community structure, as certain species can only recruit after initial settling species have increased the complexity of the surface, making it suitable for secondary species. In one long-term study, it was estimated that the development of benthic communities in Pacific temperate waters might take up to fifteen years (Aseltine-Neilson *et al.*, 1999).

These findings highlight the need to ensure surveys of already operational offshore wind turbines, and their associated scour protection and infrastructure, continue throughout the lifetime of the project, which can be up to fifty years (Centrica, 2009). The Perkol-Finkel and Benayahu (2005) study also highlights the fact that surveying the development of life on turbines alongside neighbouring natural communities will allow evaluation of the biological and environmental benefit of the turbines as artificial reef structures.

Despite the issue of the lack of long-term datasets, the 'youth' of the industry could also mean that any methods identified for increasing the benefits of offshore turbines in terms of habitat creation may still be incorporated into the design of future projects as they come into

the detailed design phases, prior to construction, where appropriate. It is therefore even more important for the results of survey work which has been undertaken to be widely distributed and discussed, allowing any possible design adjustments to be made before the major Round 3 developments reach the turbine-selection stage.

Further study work should also be directed at the various types of material most commonly used for scour protection, where deployed. Calculations have already determined that the level of habitat created varies depending on the type of scour protection deployed around the base of offshore wind turbines (Wilson and Elliott, 2009), and this could be developed further to incorporate other variables. These calculations were based upon a single diameter for gravel and boulder scour protection; however with slight changes to the size of the material used, significant changes may be made to the area available for early colonizing species, which will in turn attract a wider range of species. Taking this further, combining the methods of scour protection used within a single development, could have an additional beneficial effect. By introducing gravelly substrate, rocky reef environment and sea grass environment into a predominantly sandy seabed area, habitat diversity will be significantly increased, with each habitat created bringing with it the various communities which inhabit them.

Detailed survey work of the colonisation and succession of species on a range of scour protection materials, in the field, will assist in demonstrating the potential that offshore wind farms have in creating viable habitat, as well as allowing countries to reach their renewable energy targets.

The usefulness of specially-designed reef materials, such as the Reef Ball, as scour protection, should be investigated. If these materials are able to perform the main role of scour protection, then their deployment around turbines may be particularly beneficial to the receiving marine environment.

Despite the many potential benefits which may occur as a result of habitat creation around offshore wind farms, there must also be some level of caution. The introduction of new habitats in environments where such habitats did not previously exist may also introduce new species into the area, outside of their usual ranges. In addition, there is the possibility for high concentrations of certain predatory species, such as starfish, to colonise the turbines in such high numbers that they may have a negative impact on existing communities. Therefore, future colonisation studies around offshore turbines and their associated infrastructure should take particular note of these new species, and any interactions which may be taking place with existing communities.

6. Summary

The expansion of offshore wind farm development has the potential to bring about great benefits. Not only will the increase in renewable energy generation help in the fight against climate change, but through the introduction of new habitats into the marine environment, turbines can also act as artificial reefs, potentially increasing both species and habitat diversity.

For true artificial reef design and installation, a number of key factors need to be considered, including geographical location, size, orientation, complexity, durability, type of material, surrounding substratum, proximity to natural habitats, depth and water conditions (Perkol-

Finkel and Benayahu, 2005). Only purposely-planned artificial reefs can satisfy the full range of requirements for a truly successful reef, encouraging full colonisation and succession sequences, and becoming a useful tool for conservation or restoration of existing habitats / stocks / communities; however, with a bit more planning at the early stages of development, it should be possible for the development of offshore wind energy to satisfy a number of these requirements, and thereby become at least partially successful at creating habitat around its tower and foundation.

To illustrate the importance of structures placed within the marine environment, when four small oil platforms were removed from Californian waters in 1996, over 2000 tons of marine life were removed from the platform legs, and disposed of in landfill sites onshore (California Artificial Reef Enhancement Programme's website). Therefore, it is important to consider the decommissioning of any offshore turbines even before they are installed. Although it may not be feasible from a navigational safety point of view to leave all foundation structures in place once the towers and nacelles have been removed, it may be possible to leave some foundations in place, for example as part of an MPA once the wind farm itself has been decommissioned and removed.

A key aspect of the habitat creation argument is to get the issue wider appreciation at a higher industry level. If the gains to both the ecology and economy of the surrounding marine environment are known and understood more widely by developers, regulators and other stakeholder groups, then they may be able to form part of early discussions and negotiations with regards to specific project design and construction methods. Survey and research results should be published with an eye as to how they can be further utilised and adapted, with greater emphasis on the broader range of conservation, commercial or recreational gains which could be achieved.

Economics is another major aspect in offshore wind farm generation, another reason why better understanding of all implications, positive and negative, is essential. As described previously, the potential additional cost required to take full advantage of the habitat-creation potential of offshore wind farms may prove too great to convince developers, mindful of costs and profits, to alter plans and designs for their projects, without absolute evidence as to the benefits. However, given the potential for enhancement of commercial stocks, or conservation of particular communities or species, perhaps there is the possibility for local councils, fisheries associations or nature conservation groups to become involved, 'sponsoring' the installation of targeted scour protection, given the benefits that could be expected.

In conclusion, there is a large body of evidence for the benefits of artificial reefs in the marine environment, both intentionally designed and placed, and otherwise. Studies have shown that the introduction of almost any structure into the oceans will result in the colonisation of that structure, and that in many cases, this brings about increased productivity, rather than simply aggregating life from adjacent areas.

This increased productivity has the potential to bring about further benefits from both conservation and commercial perspectives, depending on the area in which the turbines are being installed, and whether any commercial / sensitive species already exist locally. The use of targeted scour protection could increase the capacity to help particular species, for example, through the installation of boulder protection in an area with a strong local lobster fishery. Using specially-designed materials may increase this beneficial capacity even further.

However, as with all young industries, there is still a need for greater understanding of both the impacts and potential benefits of offshore wind farms, and how the habitat-creation potential around the turbines and other infrastructure can be fully taken advantage of. Therefore, the results of all post-construction surveys, such as those discussed briefly previously in this chapter, should be collated and reviewed in detail, to gain an understanding of how colonisation works on specific foundation types, in specific areas, taking into account the communities already in existence in the receiving environment. Incorporating further survey results as they become available will increase this understanding, and give a range of time-frames for the study. With careful consideration and planning then, the installation of wind turbines into the marine environment has the capacity to help combat climate change, and bring about benefits for not only the communities which already exist in the area, but potentially, introduce new such communities, with their subsequent commercial and conservational benefits.

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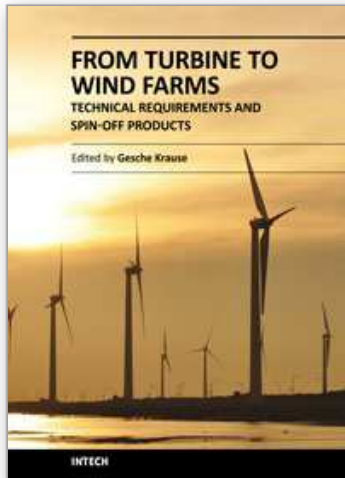
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