THE UNIVERSITY OF HULL

Offshore wind farms: their impacts, and potential habitat gains as artificial reefs, in particular for fish

being a dissertation submitted in partial fulfilment
of the requirements for the Degree of MSc

In

Estuarine and Coastal Science and Management

By

Jennifer Claire Wilson

BSc (Hons) Marine and Freshwater Biology, University of Hull

September 2007

Abstract

Due to both increased environmental concern and an increased reliance on energy imports, there has been a significant increase in investment in, and the use of, wind energy, including offshore wind farms, with twenty-nine developments built or proposed developments off the United Kingdom's coastline alone. Despite the benefits of cleaner energy generation, since the earliest planning stages there have been concerns about the environmental impacts of wind farms, including fears for bird mortalities and noise affecting marine mammals. Many of these impacts have now been shown to have fewer detrimental effects that originally expected, and therefore the aim of this report is to try and determine whether another environmental concern – that of a loss of seabed due to turbine installation – is as significant as originally predicted.

Using details of the most commonly used turbine foundation, the monopile, and the methods of scour protection used around their bases – gravel, boulders and synthetic fronds – calculations for net changes in the areas and types of habitat were produced.

It was found that gravel and boulder protection provide the maximum increase in habitat surface area (650m^2 and 577m^2 respectively), and although the use of synthetic fronds results in a loss of surface area of 12.5m^2, it would be expected that the ecological usefulness and carrying capacity of the area would increase, therefore it would still be environmentally beneficial. Each of these methods would generate specific communities, and by increasing habitat heterogeneity within the area of the wind farm, could potentially improve biodiversity and abundances.

The study has shown that through careful planning and design at the earliest stages of development, it would be possible to further increase the role of offshore wind farm foundations as artificial reefs, with factors to consider, drawn from this report, including:

- Using all three main scour protection methods within a single development, to increase habitat diversity, including a range of hydrodynamic niches.
- Maximising surface area to allow greater levels of colonisation by benthic organisms, vital to begin the development of a food web.
- Incorporating specifically designed materials, such as reef balls, which have already been proven to aid colonisation, biodiversity and abundance.
- Matching dominant scour protection methods to existing local ecosystems and communities to provide support.

Acknowledgements

For their help and advice:

- Professor Mike Elliott, Nick Cutts and Sue Travers of the Institute of Estuarine and Coastal Studies.
- Dr. Thomas Wilding of the Scottish Association for Marine Science.
- Peter Madigan of the British Wind Energy Association.
- Ronnie Bonnar of Talisman Energy UK.
- Adrian Pattison of Npower Renewables.
- Kathy Wood and Glen Evertsen of AMEC Wind Energy.
- Paul Hatchett, Repower.
- Dawson Smith, Corus Bi-Steel.
- Chris Williams, Andrew Wilson, Katie Hunt and Edward Button for their help with the calculations and for reading through the final draft.
- My parents and grandparents for their support and help in completing the degree.

Table of contents

1. Aims and objectives

The wind power industry has grown rapidly over the last few decades, and over the last twenty years especially there has been growing interest in the offshore sector, for a combination of environmental and political reasons. Much research has been carried out into the potentially damaging aspects of offshore wind farm installation, however the focus of this report is to determine whether such developments can have a beneficial, rather than detrimental, effect on their receiving area.

The questions it aims to answer are:

1. What are the potential impacts of an offshore wind farm, in terms of seabed surface area, water column and air space?
2. How much of these habitats are lost through the development of a single turbine?
3. How much of these habitats is created through the development of a single turbine?
4. Is this created habitat likely to be beneficial to the surrounding environment?
5. What is the overall change in terms of habitat loss or gain?
6. Can careful design of the turbine foundations and scour protection methods aid habitat creation, thereby benefiting the area?

To do this, the currently documented impacts of wind farms will be studied, as well as the various designs of the foundations and scour prevention methods employed around their bases. The role of oil rigs and similar structures as artificial reefs and fish aggregating devices will also be focused on, as well as an attempt to quantify the volume of habitat which is lost, gained or altered as a result of the installation of an offshore wind farm.

Ultimately, the aim of this report is to produce a set of guidelines, which will increase the environmental benefits of an offshore wind farm development, improving the surrounding area, and strengthening the argument for their further development. This work will focus on the monopile design of wind farm foundation, due to its position as the most commonly used foundation design. Therefore in addition, points will be included as to the continuation of this work, potentially bringing in other elements, such as different foundation designs scour protection methods.

2. Offshore wind power

The power of the wind has been harnessed for pumping water or grinding grain for at least 3,000 years. Wind power was first used for generating electricity in 1891 in Denmark, where the first onshore ‘wind farms’ were developed (Ackermann and Soder, 2002). In recent years, interest in the development of renewable energies has increased, due to two major political factors. The problem of global climate change is making the need for cleaner energy generation a pressing matter, but the European Union’s increasing dependence on external suppliers to meet its energy needs has also increased interest in developing renewable sources.

2.1 European Union offshore wind power and commitment to renewable energy

Currently, the EU imports around 49% of its energy, expected to rise to over 80% in 2020 if no action is taken to counter this (Jager-Waldow, 2007). One possible action is to increase the amount of energy generated within the EU, and as part of this to increase the role of renewable energy. In 1996, renewable energy in the EU made up 6% of total internal energy consumption, with the target being to double this by 2010, supported by a commitment to the Kyoto Protocol to reduce greenhouse gas emissions by 8%, compared to 1990 levels (Jager-Waldow, 2007). The United Kingdom’s own Kyoto commitment is an even stricter target of a 20% reduction by 2010 (Linley *et al*, 2007), and 60% by 2050 (Dolmon *et al*, 2003).

Within the UK specifically, the aim is to generate 10% of energy by renewable means by 2010, increasing to 20% by 2020 (The Energy Review, 2002). Despite the UK’s wind resources being amongst the strongest in Europe, due to its geographical position, wind generated power (both on and offshore) in 2007 contributes only 0.49% of the UK’s power, but by the time the second target is due to be met, it is expected to be the dominant renewable energy generation method (Sinden, 2007). Economics is key in this, with the installation costs for a large scale wind farm now being one sixth of those in the late 1980s (Ackermann and Soder, 2002), which has led to the global capacity doubling every three years of the last decade. The capital cost of developing an offshore wind farm can be around 30-50% higher than its equivalent onshore. This additional cost can often be justified however, by the increased revenue of between 20 and 40%, again in comparison with an equivalent site (Villalobos *et al*, 2004).

In terms of offshore wind power, Europe is particularly well situated, due to its high offshore wind levels, and the fact that its waters slope gently away from land, meaning depth increases very slowly, ideal for the construction of offshore wind turbines (Ackermann and Soder, 2002), with north-west Europe, including the UK, having some of the best locations around its coasts (The Energy Review, 2002). The offshore wind environment is also much more reliable than onshore wind, as it is less turbulent and has a higher energy density, meaning 50% more electricity can be generated than an equivalent land-based wind farm (Linley *et al*, 2007). This increase in efficiency is due to the convection caused by the differential heating and cooling of the land and sea over the daily cycle, making the offshore area, especially near shore sites, generally windier. In more open water, the lack of surface roughness also increases average wind speeds, furthering increasing efficiency of energy generation.

2.2 Political arguments for offshore wind power generation

The initial argument for the development of renewable energy after the Oil Crisis of 1973 was that concepts such as wind power and hydro-electric plants were seen as the solution to the finite resource of fossil fuels (Voogt and Uyterlinde, 2006). Although in more recent times the environmental argument has taken over as the predominant reason for developing the renewable energy sector, other political reasons have also held strong down the years. As described above, reducing Europe's dependency on externally supplied energy was a strong motive, and the 2006 diplomatic tensions between the Ukraine and Russia over gas supplies illustrates how contentious the issue of external energy supplies can be. Offshore wind power, although it has its limits in terms of suitable locations and current technology limits how far offshore it can go, is basically immune from external political pressure.

Further reasons for the desire to develop renewable energy, and especially wind power, once Europe's good geographical positioning for it had been recognised, are put forward by Voogt and Uyterlinde (2006). These include increasing high skilled work opportunities in lower economically growing zones, and allowing Europe to increase its competitive strength and strategically position itself in the new, liberalised electricity market.

2.3 Offshore wind power development in the UK

It has been estimated that an area of sea the size of London could be capable of meeting 10% of the UK's energy needs (Flin, 2005). There are currently three major offshore wind farms around the UK – North Hoyle (Liverpool Bay), Kentish Flats (off Whitstable) and Scroby Sands (off Great Yarmouth), which, when combined with other minor installations such as Blyth (Northumberland), made a total of 90 turbines in 2006, estimated to rise to 400 by 2015 (Boyle, 2006). The first coastal wind farm in the UK was located at Blyth, Northumberland, with nine turbines erected along the harbour's old pier, with generation beginning in 1993 (Still, 2001). Blyth was also the location of the first truly offshore wind farm, with two turbines located 1km out to sea (Still, 2001). A study at the time estimated that in the UK alone there was 21,750km^2 of potential sites for similar installations, focusing on 5km offshore, and waters 50m deep or less. Although current technology limits installations to water generally 30m or less (Fayram and de Risi, in press), in the future this may not be so limiting, allowing wind farms to be in much deeper waters, further offshore. Water depth is not the only current limiting factor in terms of offshore wind farm placement. The issue of transmission loss would also need tackling before they could move further out to sea than the current limit of 20km offshore. Today's wind farms have a relatively small rated capacity, a maximum of 160 MW, compared with Heysham One nuclear power station, with 1150 MW (Negra *et al*, 2006). Transmission loss occurs due to Joule Heating, or the production of heat as electricity passes through a conductor, and the only way to significantly reduce losses is to increase the voltage, which reduces the current, and therefore the amount of power lost. For an offshore wind farm, the only way to achieve this is to have an offshore substation, which only three of the currently installed offshore wind farms have employed (Negra *et al*, 2006), which would increase the overall costs of the developments.

2.4 Rounds One and Two of UK offshore wind power

Offshore wind farm development in UK waters has been in two stages. In December 2000, after consultations between the Crown Estate, the British Wind Energy Association (BWEA) and other interested parties, information was released by the Crown Estate regarding site allocation and the leasing process (Flin, 2005). The number of applications received was much higher than anticipated, and those which qualified were announced in April 2001, under Round One (Figure 1). Eighteen sites were given consent, with a maximum of thirty turbines each (BWEA, 2005). While the Round One projects were in their planning stages, the Department of Trade and Industry (DTI) held a consultation from November 2002 to February 2003, called Future Offshore, with the aim of developing a strategic framework for offshore wind and marine renewable energy generation methods (Flin, 2005). At this consultation, upwards of 20 issues were discussed, including the consents process, legal frameworks and the electrical infrastructure which would be required to continue offshore development (BWEA, 2005). A further result was the production of Strategic Environment Assessments

(SEAs) – documents combining a wide range of information, allowing the selection of the most environmentally responsible sites and practises for the second Round of offshore wind farm developments. Three SEAs were produced, for what were considered the top three potential sites around the UK – the Thames Estuary, the Greater Wash and the North West coast (BWEA, 2005).

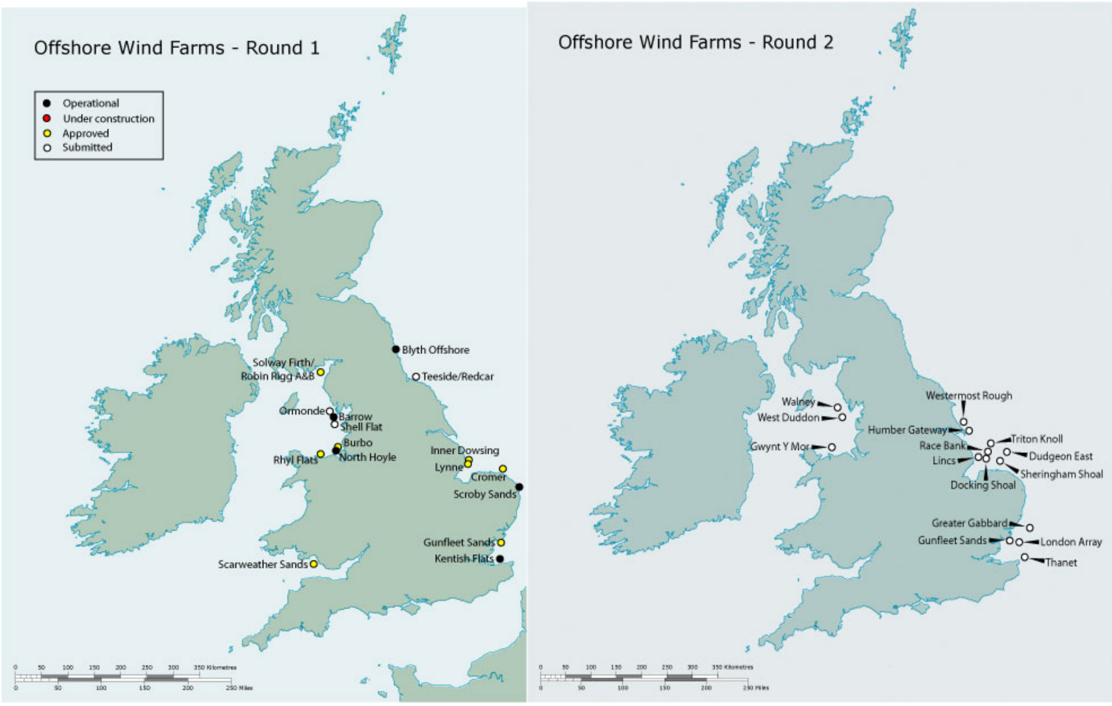

Figure 1 - Round 1 and 2 offshore wind farms around the UK coastline, from the British Wind Energy Association

Following Future Offshore, the call for Round Two projects came in March 2003 (Figure 1), producing registered interest from twenty-nine companies and consortiums for over 70 sites, some of which would generate power equivalent to a nuclear power station (BWEA, 2005). Once criteria had been applied, fifteen projects were allowed to submit a formal application, and the successful projects are due to be constructed between 2008 and 2010 (Flin, 2005), contributing to a DTI estimate that one in six homes will be powered by offshore wind farms by 2010 (BWEA, 2005).

2.5 Anatomy of an offshore wind turbine

All commercially-produced wind turbines are what are described as “horizontal axis wind turbines”, with the shaft mounted horizontally, parallel to the ground, on a vertical tower (Figure 2).

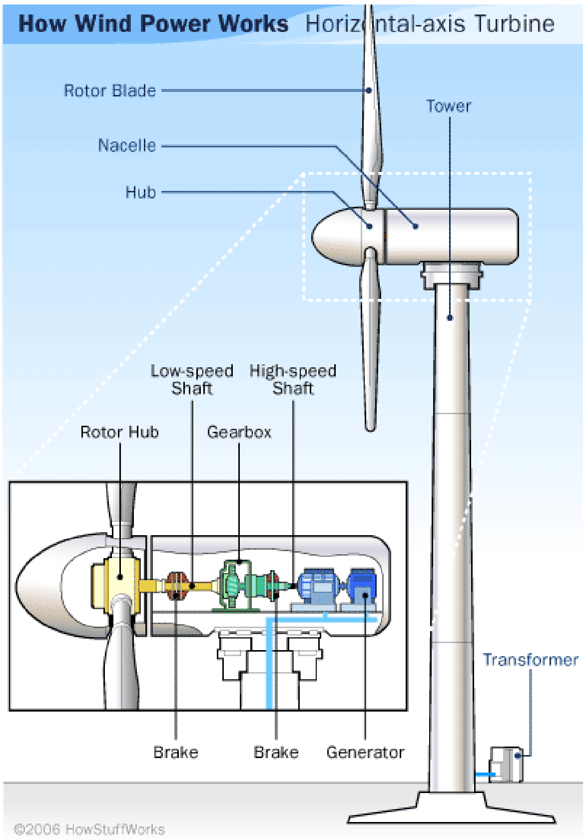

Figure 2 - Anatomy of a horizontal axis wind turbine, taken from Website 13

The main components of the horizontal axis wind turbine are as follows (Website 13):

- **rotor blades** - capture wind's energy and convert it to rotational energy of shaft
- **shaft** - transfers rotational energy into generator
- **nacelle** - casing that holds the gearbox, generator, electrical control unit, yaw controller and brakes.
- **gearbox** - increases speed of shaft between rotor hub and generator
- **generator** - uses rotational energy of shaft to generate electricity using electromagnetism
- **electronic control unit** (not shown) - monitors system, shuts down turbine in case of malfunction and controls yaw mechanism
- **yaw controller** (not shown) - moves rotor to align with direction of wind
- **brakes** - stop rotation of shaft in case of power overload or system failure
- **tower** - supports rotor and nacelle and lifts entire setup to higher elevation where blades can safely clear the ground
- **electrical equipment** - carries electricity from generator down through tower and controls many safety elements of turbine

3. Wind farm foundations

In terms of both potential marine habitat creation and stability of the structure, the most important section of the wind turbine is the sub-tidal section – the foundations – the properties of which will determine whether organisms are able to colonise and inhabit them, creating the base of a food web. There is a wide range of factors which influence benthic invertebrate settlement, and therefore general success as an artificial habitat. These include spatial orientation, structural complexity, composition and texture (Perkol-Finkel *et al*, 2006), and it is important that these are met by the construction methods used if the wind turbines are going to be successful as habitat.
The three main foundation types for turbines are illustrated in Figure 3.

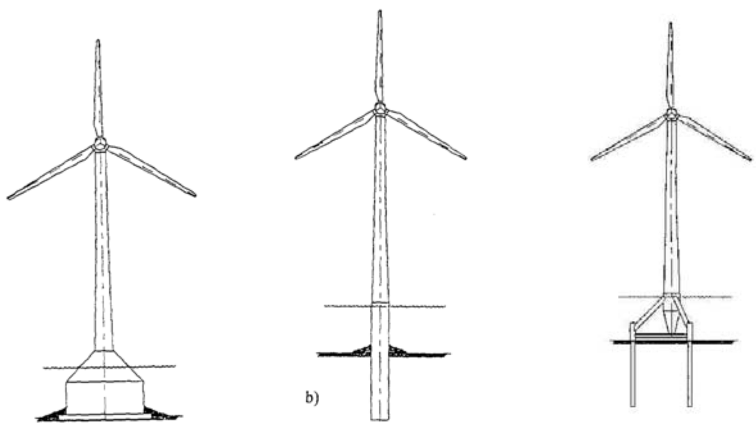

Figure 3 - Different types of wind turbine foundation. From left to right: gravity based support structure; monopile; tripod; taken from Teske, 2000

3.1 Gravity-based support structure foundations

In this situation, the weight of a concrete caisson is used to keep the structure upright against the forces of wind and waves, with no penetration of the seabed by the structure (Figure 4). They have historically been restricted to waters less than 20m deep due to the physical constraint. Although there is no connection to the seabed, the area needs extensive preparation, in terms of levelling and covering it with a layer of crushed stones (Teske, 2000). Because of this reliance on gravity to hold them in place, these are the heaviest foundations, generally weighing around 1050 tonnes (Parkinson, 1999).

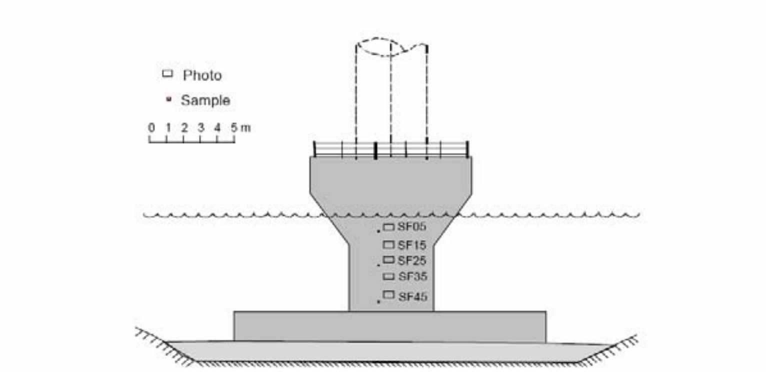

Figure 4 - A more detailed diagram of a concrete turbine foundation, taken from Linley et al, 2007

Large boulders may be placed around the edge as further erosion protection, and, if seen from above, the base has several sections within the base, which can be filled with gravel etc. for further stability. This may also enhance potential for habitat creation, by providing a rocky environment with many crevices available for colonisation (Linley *et al*, 2007).

3.2 Monopile foundations

These are the most commonly used method, and can cope with a maximum water depth of around 25m, but are generally found in water of around 20m, as illustrated in Figure 5, which shows more detail of the design. A simple steel tube of 3.5-4m diameter is driven approximately 25m into the ground with a piling hammer, and the turbine structure is then placed into this tube. It does not require seabed preparation, but is more vulnerable to scour. In terms of protection, artificial seaweed has been used, and no antifouling material is used. Boulders may also be placed around the base (Teske, 2000). All current offshore wind farms in the UK use this method of foundation for their turbines, and they are also one of the easier methods to remove, by lifting the turbine structure back out of the submerged foundation, or by cutting it off at the surface, leaving part of the structure behind. If the development is being built in rocky habitats, then a hole may be drilled into which the pile is lowered, and then the remainder of the structure is added as usual. If this method of installation used, then there is the risk of releasing chemical contaminants into the surrounding sediment, as well the issue of spoil disposal into the area, which may locally increase turbidity and smother benthos (Hiscock *et al*, 2002). Due to their dominance in offshore wind farm construction, all of the values generated within this study are based on the monopile design.

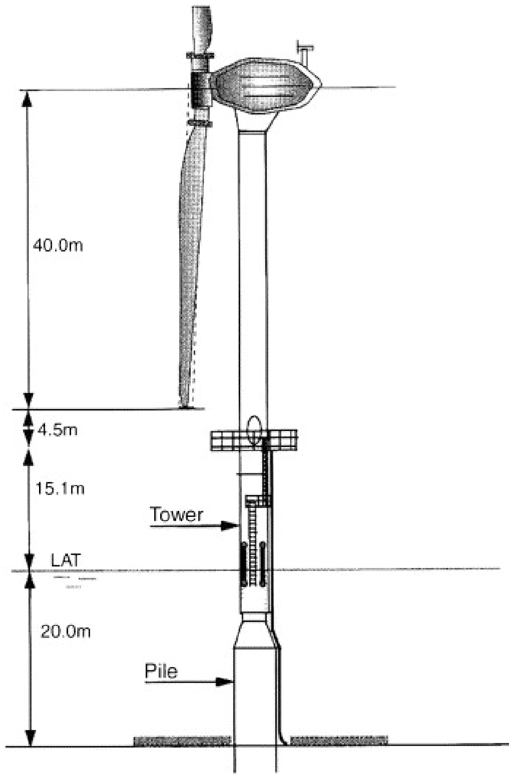

Figure 5 - Schematic of an monopile offshore wind turbine, taken from Manwell et al, 2007

3.3 Tripod foundations

This method began life in the offshore oil and gas industries, with a central column carrying the tower, as with the monopole, but with a space frame spreading the load and compression over the three piles driven into the seabed in the similar way to the monopile method. The piles are smaller, at 0.9m diameter, but driven in to the same depth, and the system is suited for deeper water. It is less suited for shallower waters, where there is the risk that boats could run into the frame's legs. Again, no seabed preparation is required, no antifouling paint is used, and boulders may be used for protection against erosion (Teske, 2000). At the current time, tripod foundation design is still in the early design and improvement stages, but studies suggest that it will become a dominant method as wind farms move further offshore into deeper water (Linley *et al*, 2007).

Table 1 - A comparison of foundation characteristics. References: Manwell *et al*, 2007; Houlsby *et al*, 2001; Teske, 2000

Comparison of foundation methods			
	Gravity caisson	**Monopile**	**Tripod**
Primary material	Concrete	Steel	Steel
Connection with Seabed	None	Pile-driven	Pile-driven
Application	Virtually all conditions	Most conditions other than deep, soft material	As monopile, but can also be used in deeper water
Advantages	Float out installation	Simple, Versatile	Versatile
Weight (tonnes)	~1050	100-400 (depending on the size of the turbine being supported)	100-400 (depending on the size of the turbine being supported)
Potential for habitat creation	Potentially strong for habitat creation due to increased surface area and boulder protection	Good, depending on scour protection method	With scour protection, may be stronger than the monopile design

4. Scour protection methods

Scour, or erosion, around the base of wind turbines is a major issue for developers, as it can cause serious damage to the wind farm infrastructure, for example the sub-surface cables which connect the turbines to the shore. Scour is a function of current speed, sediment type and the nature of the obstruction, in this case, the wind turbine (Linley *et al*, 2007). Figure 6 illustrates how scour is caused, and the potential impacts it can have on the surrounding sediment. The resulting scour pits can range from 1 to 50cm in depth (Hiscock *et al*, 2002).

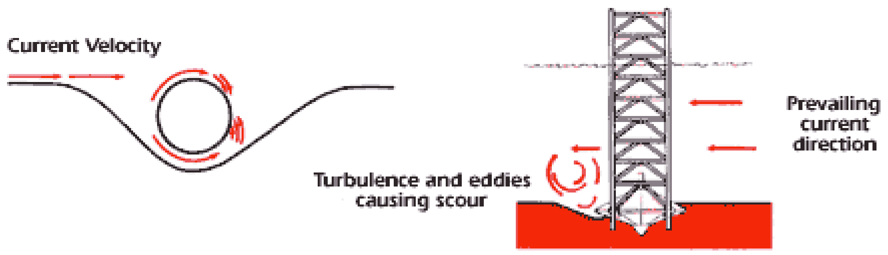

Figure 6 - The formation of scour, taken from Website 5

There are several ways to address this issue, with each potentially affecting the degree and success of habitat creation and use around the wind turbine. The main ways are to either increase the depth of the pile into the sediment, or to lay a protective surface around the base of the turbine. Increasing the depth of turbine foundations means that even if material is removed from the surface around the base of the tower, the turbine itself will remain stable; however cables may still be at risk (Figure 7). To lower the risk to cables, rock armour is placed around the base, in layers of aggregate around 10m out from the base (Linley *et al*, 2007).

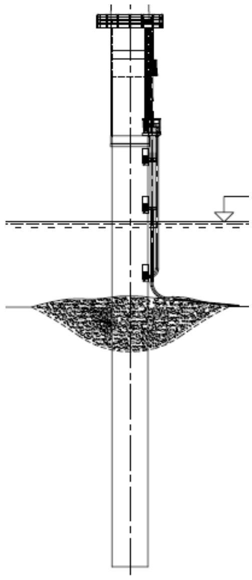

Figure 7 - Approximate scale and extent of rock armour around a monopile turbine foundation, with deeper foundations, taken from Linley et al, 2007. For approximate dimensions see Figure 5

Around the monopile foundations of the Horns Reef offshore wind farm, Denmark, the following dimensions of aggregate protection were employed (Website 2):

1. A 'gravel mattress' arranged to minimise erosion, of 0.5m thick, and made up of gravel with 0.03-0.2m diameter.
2. Additional gravel around the base once the turbine has been erected, 0.8m thick, comprising gravel with a 0.350-0.550 diameter.

Figure 8 - Polypropylene frond mats around a turbine foundation, taken from Linley et al, 2007

A second main method of scour protection is the use of polypropylene fronds (Figure 8), which mimic seaweed by catching and trapping sediment around the base of the turbine, providing protection. The fronds are generally around 1.5m in length, and are embedded securely in concrete mattresses to prevent them being washed away and becoming plastic litter in the surrounding waters (Linley *et al*, 2007). The building of a layer of boulders around the base of the turbine is the third main method of scour protection which is focussed on in this study. The large boulders, usually around two metres in diameter (Mr Ronnie Bonnar of Talisman Energy UK, Pers. Com., 2007), are deposited usually in a dome or pyramid design, to protect both the tower and the seabed from damage.

Regardless of the scour protection method used to prevent damage to the sea bed, there will always be changes in current around the base of the wind turbine. These will affect the potential habitat surrounding the foundations, as different current strengths produce different bed forms, from ripples to sand ribbons and hollows, which in turn may attract or repel different benthic communities (Parkinson, 1999).

As with most elements of an offshore wind farm, whether or not to employ scour protection is an issue considered for each development. For example, for the Beatrice demonstrator programme in the outer Moray Firth, the extent of scour predicted is minimal, therefore no protection has been deployed (Mr Ronnie Bonnar of Talisman Energy UK, Pers. Com, 2007). Periodic seabed surveys will usually be carried out though, to ensure that scouring is still minimal. This can also be the case when predicted scour is anticipated and protective mechanisms built into the design of the foundation, to ensure the levels of scour are as predicted and no increased damage is being caused. New monopiles may have the ability to withstand around a metre of scour by having additional layers of material around their base before damage would be caused (Mr Glen Evertsen of AMEC Wind Energy, Pers. Com, 2007).

4.1 Materials used in scour protection, and potential types of habitat created by their deployment

Materials used in any construction project are an important part of development planning, especially in a harsh environment such as the open ocean. Different materials can also have an impact on the level of colonisation which is able to occur, a fact highlighted by a study on seawall colonisation in Sydney Harbour. Bulleri (2005), found that differential weathering of varying surface materials in the wall lead to a range of surface areas and textures, which has the potential to alter its level of ‘attraction’ to certain species. Chemical cues within man-made materials can also play a part, for example, oyster larvae have been found to prefer certain mixes of concrete to natural surfaces (Bulleri, 2005).

As well as the materials used, the orientation of the foundations is also a key issue. The degree of water movement will vary depending on the level of exposure each ‘face’ of the turbine receives, and this will in turn generate micro-niches. The more complex the shape of the foundations, the greater the range of localised hydrographic conditions, therefore there will be greater potential for different organisms to colonise (Linley *et al*, 2007).

4.2 Comparison with relevant habitats

Different types of scour protection will result in artificial habitats which mimic different natural habitats. For example, the use of the synthetic fronds will result in a habitat similar to a sea grass bed (Figure 9).

Figure 9 - Development of an artificial sea grass bed as the synthetic fronds are buried by drifting sediment, taken from Website 5.

Around this artificial habitat, sand banks develop, bedding in the scour protection further, and creating an environment for colonisation for organisms such as starfish and crabs (Website 5).

If gravel protection is used, then the habitat created will be more comparable to a mobile sub-littoral shingle, as described in the Joint Nature Conservation Committee (JNCC). It states a 'lack of conspicuous fauna' and being strongly affected by tidal streams or wave action, which would result around the base as the currents which would otherwise cause the scour will still be present and washing over the area (Website 3).

Finally, the third of the most common scour protection methods involves the placing of large boulders around the base of the towers to hold the sediment in place. These boulders are often several metres in diameter (Mr Ronnie Bonnar of Talisman Energy UK, Pers. Com. 2007), and the resulting artificial habitat will have many similarities to that of a sea wall, which also often comprise large sandstone boulders.

5. Potential impacts of wind farms

Despite the clear gains in terms of lower carbon emissions and the reduced dependence on fossil fuels, offshore wind farms are not without their controversy and opponents (Bishop and Miller, 2007). The Ministry of Defence has also entered the discussion, blocking the construction of one large wind farm off the Northumberland coast due to concerns about the negative impacts of the turbines on radar equipment, and in recent years the threat of terrorism has also had an impact on developments (UK Offshore Wind, 2001). The following diagrams (Figures 10 and 11) illustrate the extent of the potential risks to the environment from offshore wind farms in the three main phases of the development – exploration, construction and operation.

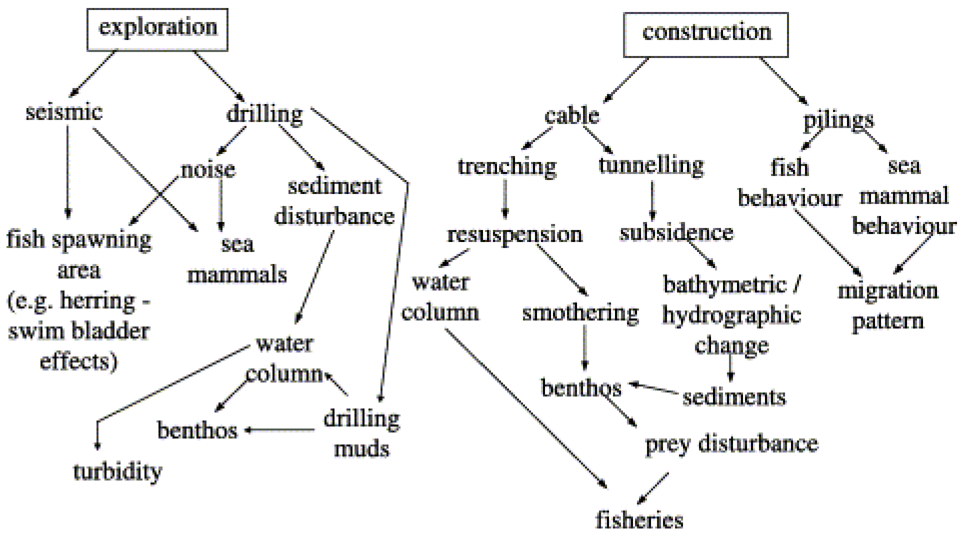

Figure 10 - Environmental consequences of offshore wind farms in the exploration and construction phases, taken from Elliott, 2002

These 'horrendograms' indicate the major processes which can potentially result from the development of an offshore wind farm, and they may impact on the surrounding environment. They act in a similar way to flow diagrams, but with many more interconnections between the individual flow diagrams, serving to show how one aspect of the development, for example drilling, can have a series of primary impacts, such as noise, which then cause secondary impacts, in this case potential impact on sea mammals. Further to this they illustrate that the same impact could be caused by more than one aspect of the development, for example in the construction phase, impacts on the benthos can be a result of cable trenching or tunnelling. The web of potential impacts for the operational phase is even more complex, with again many impacts resulting from more than one aspect of operation.

Despite their complex appearance however, they do allow a certain degree of simplification, as they provide an at-a-glance overview of impacts and how these are related to each other. To attempt to replace the figures with descriptions would not only add unnecessary volume to reports, but also complicate matters due to the many overlapping factors and impacts.

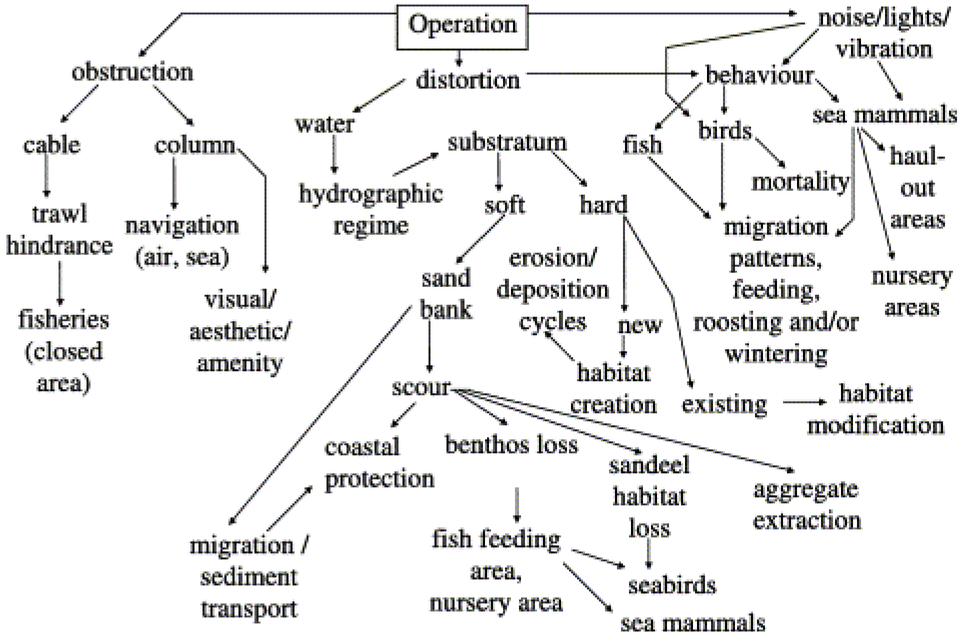

Figure 11 - Environmental consequences of offshore wind farms in the operational phase, taken from Elliott, 2002

It is apparent therefore, that without a clear understanding of the local conditions, poorly planned offshore wind farms could have a highly detrimental effect on the ecosystems into which they are placed. Using these diagrams, it is possible to follow through impacts at each stage, and allow the completion of an accurate Environmental Impact Assessment to determine whether such impacts will have a significant effect upon the area. It is also possible to identify which areas might be the most at risk and need the most attention when it comes to providing mitigation measures to reduce environmental impact.

On a general level, impacting activities can be divided into long and short term (Dolman *et al*, 2003). Activities which cause short term impacts include:

- Seismic exploration to identify the most appropriate location;
- Intense noise from ramming, drilling etc;
- Increased vessel activity from exploration and construction;
- Increased turbidity from cable laying;
- Decommissioning of wind farms.

Activities which cause long term impacts include:

- Presence of structures;
- Operational noise and vibrations;

- Electromagnetic impacts;
- Increased vessel activities for maintenance.

Of all the issues and potential impacts raised through the production of figures such as Figures 10 and 11 and their respective reports, one of the main concerns with the production of a new offshore wind farm is the possible impact on surrounding wildlife, in particular the 'charismatic megafauna', or the birds, fish and marine mammals of conservation interest.

5.1 Impacts on marine mammals

Potential impacts on marine mammals (seals and cetaceans) can be divided into direct and indirect issues (Norfolk Offshore Wind, 2002):

Direct impacts:

- Collision with increased boat traffic;
- Leaving area due to disturbance;
- Starvation, especially of young due to being abandoned by a mother scared away from the area.

Indirect impacts:

- When disturbed, organism may spend more time alert, altering normal behaviour, potentially reducing reproductive/foraging success;
- Stress may reduce immune response, increasing the organism's vulnerability to pollutants and disease.

Since the earliest discussions into the planning of offshore wind farms, the potentially damaging noise generation during construction and operation has been a major issue (Thomson *et al*, 2006), and many studies have been completed into this. In terms of noise, pile driving during construction has the greatest capacity to cause damage, with very high sound pressure pulses taking place up to sixty beats per minute for up to two hours, the length of time it takes to drive in a pile. For mammals, including the most common European species, the harbour porpoise (*Phocoena phocoena*), this noise can be heard over 80km away from the wind turbine, and although there is some level of uncertainty, it is estimated that in some cases the noise may be heard several hundreds of kilometres away (Thomson *et al*, 2006).

However, impacts of noise are very site and species specific, a fact highlighted by two studies on bowhead and humpback whales, which found that although bowhead whales (*Balaena mysticetus*) would alter their traditional migratory path by up to 20km to avoid drilling ships, a study with similar noise levels observed no clear avoidance behaviour from humpback whales (*Megaptera novaeangliae*) (Myrberg, 1990).

Seals have also been targeted for assessment in wind farm impact studies, but there are not currently any data to suggest real risks. Both grey and common seals have been found to be able to hear operational noise from wind farms up to 1km away, but in general they simply avoid the area, which is not as big a problem as it may initially appear. Grey seals (*Halichoerus grypus*) have such large home ranges that they do not rely on the relatively small area of the wind farm, and common seals (*Phoca vitulina*) usually stay in small, localised ranges which do not normally extend to wind farm locations (Dolman *et al*, 2003).

A major problem with quantifying impacts on marine mammals is that there are very few reliable sets of baseline data in terms of numbers and movements in the surrounding waters. The pile installation during the construction phase may induce a startle response in the animals, but operational noise and vibrations will usually not increase background levels from shipping and submarine cables significantly, meaning the impact is generally classed as negligible for seals and cetaceans (Norfolk Offshore Wind, 2002).

Table 2 - Potential impacts of offshore wind farms for marine mammals and the likelihood of their occurrence

Potential impact	Likely to occur around offshore wind farms?	Level of significance
Mortality through collision with increased boat traffic	Unlikely during operation, as collisions with boats are rare. May be an issue during construction due to damage to hearing/orientation	Low, as animals will generally be able to avoid a collision
Leaving area due to disturbance	Species dependant, but a certain level of avoidance would be expected	Relatively low, as long as the wind farm was not on a key migration route or in a major feeding ground
Noise damage	Yes, during construction, with lower levels during operation.	Potentially high during piling operations, but much reduced once installed, thereby reducing the risks.
Disruption of normal behaviour	Yes, in the initial construction phase, but not as likely once marine mammals have become accustomed to the operational levels of noise and activity	Relatively low once operations have been ongoing for a period of time

5.2 Impacts on fish

OSPAR listed in 2004 the following as potential impacts on fish populations from wind farms:

- Disruption of orientation, especially for migratory species;
- Impediment of foraging activities;
- Habitat loss – not just from the actual wind turbines, fish may move out of areas due to increased stress levels;
- Damage to fish eggs;
- Alteration of fish species availability and abundance;
- Alteration of fish community composition and abundance.

Further potential impacts, noted by the environmental statement of the Beatrice demonstrator wind farm (Talisman Energy, 2006), in the Moray Firth, include:

- Disturbance and redistribution of sediments;
- Scouring of sediments around the base of turbines;
- Re-suspension of pollutants within the sediment;
- Accidental release of chemicals and hydrocarbons during installation;
- Physical presence of the structures.

Other studies have shown that intense noise, such as that from drilling operations, may destroy the hair cells of fish's auditory maculae. This leads to the theory that fish congregate around oil rigs and similar structures not for habitat reasons, but because they have been deafened to the point where they would not be able to hunt or avoid predation if they were to enter the open water (Myrberg, 1990). This is, however, still a theory, and has yet to be proven in any studies.

It has also been suggested that the electromagnetic fields generated by the transmission of electricity along conductors may have an impact on nearby fish, in two main ways. Firstly, the fields may interfere with the earth's own magnetic field (Linley *et al*, 2007) and affect migratory species such as salmon being able to navigate, and secondly, it could reduce hunting efforts by those fish which use the magnetic fields emitted by their prey to find food, such as sharks and rays (Linley *et al*, 2007). The orientation of eels (*Anguila anquila*) was found to be particularly badly affected, with eels showing a distinct preference for travelling in a different direction when exposed to the electromagnetic field, compared to the earth's natural field (Talisman Energy, 2006). Given that eels are a migratory species; this could have potentially harmful impacts if they were not able to return to their spawning or feeding grounds. Atlantic salmon

(*Salmo salar*) were also considered an at risk species, but studies here showed that although the fish use the earth's magnetic field to aide their migrations, the presence of the wind farm's electromagnetic field did not significantly alter their movements (Talisman Energy, 2006).

The re-suspension of finer sediment arises through the fluidising of the seabed to allow installation of sub-surface cables. This increased turbidity brings about a large range of problems for fish, including the clogging of gills and the reduction in feeding ability due to reduced visibility. Smothering and other damage to fish eggs and larvae is also a problem, especially for those species which lay their eggs on or in the substratum, such as sand eels, herring and sprat. Burrowing or burying species such as flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*) may also lose areas of their habitat, and beds of cockles (*Cardiidae*), clams (*Mercenaria mercenaria*) and oysters (*Ostreidae*) may be submerged (Talisman Energy, 2006).

In terms of commercial fisheries, there is usually a 500m safety zone designated around the wind farm, into which vessels are unable to go. This will remove a certain area of seabed and water column from their fishing grounds, but according to the environmental statement of the Beatrice demonstrator project, not an amount significant to adversely affect their fishing efforts (Talisman Energy, 2006). Despite this, careful consultation with the local fisheries boards is recommended, to determine the specific details of local fisheries, and what methods are employed by fishermen in the area. Once the wind farm is developed, the safety zone must be adhered to, and anchoring or trawling in the vicinity of the wind farm and its cables should be avoided (BWEA, 2004).

Table 3 - Potential impacts of offshore wind farms for fish and the likelihood of their occurrence

Potential impact	Likely to occur around offshore wind farms?	Likely to cause significant impact?
Electromagnetic field	Yes, and their connecting cables back to land.	Depends on the species, and their level of vulnerability.
Habitat loss	The seabed habitat will be lost to the installation of the turbines.	Potentially no, as the change in habitats due to scour protection may be beneficial to the inhabiting fish species
Alteration of species composition	Yes, due to changes in habitats and conditions	Yes to those species being removed, but no to those entering the area. Overall there may be a benefit to the surrounding environment
Increased turbidity	Yes, during the initial construction phase, for example as cables are installed. Impact should be reduced once operation has commenced	Increased turbidity may impact on fish through egg smothering, blocking of gills and reduction in the ability to feed as effectively. May also release chemical and physical pollutants within the sediments.

5.3 Impacts on birds

Bird mortality is a major factor in environmental assessments. The main causes for concern are a) mortality due to direct in-flight collisions with the turbine's blades, and b) mortality due to avoidance of feeding grounds because of the development of wind farms (Kaiser, 2002). Wind turbines may pose a potential collision risk to birds as they take part in the following activities (Talisman Energy, 2006):

- Daily flights between foraging and roosting grounds
- Evasion or avoidance flights following human disturbance
- Flights towards the turbines, due to attraction to the wind farm area, for food etc.
- Active foraging flights

The risk of collision also depends on a combination of factors, including (Talisman Energy, 2006):

- Species
- Flock size
- Flight behaviours including speed, direction and altitude
- Local inter-site routes
- Weather conditions

- Feeding habits and habitats
- Seasonal variability in flight ability, e.g., may have reduced ability to avoid collision whilst moulting

Migration patterns may also be disturbed, as birds are obstructed or distracted by the turbines whilst moving between their breeding and foraging grounds. However, the few studies which have been carried out suggest this is not actually as big a problem as originally thought. A study in Lely in the Netherlands found that the two diving duck species they looked at adjusted to ambient flight conditions, and altered their flight plans accordingly (Percival, 2001). This report also found that birds in general reduced their activity near the turbines, with fewer being recorded within around 500m of the turbines, and very few being observed in between closely spaced turbines (less than 200m). Very few birds will actually fly between turbines, choosing to instead fly around them, regardless of the number of turbines, or the overall size of the area.

Even when bird movements are high in the area, studies have found that mortality rates are low. In Blyth, where there are around 5000 bird movements daily, there were 31 deaths over 3 years, meaning the mortality rate only 1.34 strikes/turbine/year (Parkinson, 1999).

In general, the closer the wind farm is to the shore, the greater the potential collision risk for birds will be (Talisman Energy, 2006). The risk will also depend on whether there are alternative sites for the birds to move their feeding grounds to.

Table 4 - Potential impacts of offshore wind farms for birds and the likelihood of their occurrence

Potential impact	Likely to occur around offshore wind farms?	Likely to cause significant impact?
Mortality through collision	Dependant on conditions, species and location of wind farm	No – figures indicate a very low risk
Mortality through disruption of feeding grounds	Dependant on the species present and location of wind farm	No – if careful planning means development away from important areas
Disruption of migration routes	Depends on location of wind farm and distance from shore	No – if wind farm is not too close to shore, and major known routes are avoided in planning

5.4 Social impacts/approval

In terms of the human element of impacts to consider, many studies into social attitudes having been carried out, and a survey in Britain came up with the following generalised profiles of those in favour of wind farms and those in opposition (taken from Krohn and Damborg, 1999).

Those in favour of wind energy tend to believe:

- Renewable energy is an alternative to other energy sources
- The climate change argument must be take seriously
- Wind energy is unlimited, unlike fossil fuels
- Wind energy is non-polluting
- Wind energy is safe

Those against wind energy tend to believe:

- Renewable energy cannot solve energy problems
- Wind turbines are unreliable and dependant on the wind
- Wind energy is expensive
- Wind turbines spoil the scenery
- Wind turbines are noisy

In Europe, the two main factors which affect a person’s opinion are distance from shore and contrast (Bishop and Miller, 2007). Using computer visualisation software, their study placed a wind farm gradually further and further offshore, finding the greater the distance, the fewer negative comments were recorded. Studies have also shown that those from older generations had more negative opinions than younger groups, even when they were from similar social groups in terms of education, wealth and country of residence (Bishop and Miller, 2007).

Approval of wind farms is around 80%, when comparing studies from Canada, the UK, the Netherlands and Denmark (Krohn and Damborg, 1999). Many surveys though have found that although some groups of people may object initially, once wind farms have been installed, approval increases as people realise noise and visual impact are not as high as they anticipated.

5.5 Negative aspects of offshore wind power

Although not specifically impacts of offshore wind farms, there are negative factors to wind generated power which must be considered. One such issue is that of cost, as the cost of installing and maintaining the offshore wind farms can be significant, with added costs due to the issues of accessing the towers due to the need to purchase/hire and maintain a boat and trained crew. In poor conditions especially this can be very dangerous for those requiring access. There is also the cost of the electricity which is generated by the turbines. Costing an estimated 4-10 American cents per kilowatt hour (Website 13), although it is generally cheaper than power generated by geothermal technology, biomass burning, hydrogen fuel cells and solar power, it is more expensive than hydroelectric power, as well as power generated by more common means such as nuclear power, coal and natural gas. This therefore raises the complex issue of what the general public would value more – cheap electricity or the environment.

In addition to the costs of the actual installation and electricity generated, with developers looking to move even further offshore, there is the cabling issue to also consider, as cables will have to cover longer distances and potentially be laid in increasingly deep water.

6. Artificial reefs and colonisation/communities

Artificial reefs have been used for the benefit of the local area by enhancing the naturally occurring habitat and community, and therefore ultimately the local ecosystems for many years, with a great deal of success (Perkol-Finkel and Benayahu, 2007). Many man-made structures can take on the status and role of artificial reef, but perhaps one of the largest bodies of work which can be related to the wind farm example is the work on oil rigs, both operational and abandoned, as they are fairly similar in terms of structures to wind turbines.

6.1 Oil platforms as artificial reefs

A study in California showed that the sub-tidal portion of oil platforms could often provide habitat for invertebrate assemblages up to tens of cm thick (Bram *et al*, 2005), and that despite the fact that the environments differ in many ways, there is often some degree of overlap between the platform communities and local rocky habitats.

Bram *et al* (2005) also produced several other useful conclusions:

- Invertebrate growth rates were more rapid than at inshore habitats, but densities were lower;
- The conspicuous absence of macroalgae on the study's ceramic tiles placed for experimentation suggest either that plankton is not settling, or that shading levels were too great and preventing photosynthesis;
- Colonial tunicates were dominant initially, due to their classic opportunist status, along with encrusting bryozoans, both of which became minor taxa later in the succession;
- Amphipods, barnacles and sponges were also common early colonisers;
- Mussels colonised after around 12 months, but recruitment levels were low due to the lack of larvae in the plankton.

A similar study looked at the "rigs to reefs" programme in the southern Arabian Gulf, and found that in general the entire surface area available was colonised, both by encrusting and mobile species, and that both the number of organisms and the biomass decreased with depth to the seabed (around 20m in this study) (Stachowitsch *et al*, 2002). Due to the nature of encrusting organisms developing new colonies over existing, dead groups of organisms, at each depth, the weight of dead material was greater than the weight of living material, explaining the reason for the very thick layers described by Bram *et al* (2005).

Generally, sessile organisms were greater in biomass, and mobile organisms greater in number, and communities differed from the surrounding sea floor, a finding contradicted by Bram *et al* (2005).

6.2 Sequence of colonisation

In a relatively undisturbed environment, colonisation communities will follow a succession which is adapted to meet the long term average conditions of that environment (Patricio *et al*, 2006), whether it is man made or artificial. Patricio *et al* (2006) study focussed on an area of intertidal rocky shoreline near Lisbon, Portugal, and recorded the organisms which moved into specially cleared sections along the shore. They found that in terms of fauna, amphipods, gastropods, isopods and diptera were initially high, along with the classic opportunist oligochaete group, but that these were then replaced after around three months by bivalves and polychaetes. These latter two groups then became the most dominant, accounting for 72-92% of the total biomass. It was also found that they showed inverse temporal trends, that is, when one increased, the other decreased.

6.3 Seasonal variations

Seasonal variations in climate and conditions may result in seasonal changes to the colonising communities, as well as their abundances and biomass. In the western Baltic Sea, the benthic fauna is periodically wiped out from large areas of the seabed due to oxygen deficiency, and as a result, Arntz and Rumohr (1982) carried out experiments to determine whether there were any seasonal variations in the number and biomass of the organisms which re-colonised. Sampling was carried out in June and December on the natural seabed, where it was found that there was a distinct seasonal cycle in organisms on specially-cleared surfaces. In terms of density, the highest peak occurred in August 1978, with 7000 organisms/m^2, compared to winter densities which reached only a third to a half of that value. Biomass again, was higher in summer, an average wet weight of 300g/m^2, compared to winter values of 100g/m^2 (Arntz and Rumohr, 1982).

6.4 Attraction versus production debate

With any artificial reef, there is the debate as to whether the new structures simply attract resources away from natural habitats, or actually produce their own communities and create additional biomass for the area (Perkol-Finkel and Benayahu, 2007). Their success at increasing production will depend on their ability to attract new propagules, and the suitability of the surfaces. Perkol-Finkel and Benayahu (2007) found that regardless of the sequence of colonisation, in the Red Sea, differences between artificial reefs and natural reefs still prevail after one hundred years. This suggests they will support different communities, therefore are probably adding to the surrounding environment rather than detracting from it.

6.5 Artificial reefs for recreation

In recent years, the concept of the artificial reef has been taken another step forward into the domain of recreation. In the UK, the most well known of these is probably the Scylla, a 113m long Exocet Leander class frigate, sunk off Plymouth in March 2004 (Website 11). Before its sinking, all harmful and hazardous materials were removed to make the vessel safe for colonisation, as well as any hazards to divers, such as loose cables, to reduce danger to those using the wreck. The aim of the Scylla was two-fold: to create an artificial reef to improve local biodiversity, and to provide an attraction for divers. It was estimated that the wreck would generate an additional £1 million from diving activity each year for Plymouth and south east Cornwall (Website 11).

The concept of combining ecosystem improvements and recreational diving opportunities has also been developed in America, Australia, New Zealand and Canada, with examples including the second largest sunken ship off British Columbia, Canada, with the HMS Cape Breton, sunk in 2001 (Website 12).

Although this element of artificial reefs exists however, it is unlikely that it would be possible to incorporate the aspect of recreational diving into the benefits of an offshore wind farm, due to the safety factor. Another factor to consider is the cost of the installation of the offshore turbines, and it would be expected that those responsible for them would not want large number of recreational vessels entering their sites in case of accidental damage to their equipment. However, this could be beneficial for any colonising species, as it would be another element of protection for them, preventing divers or their boats' anchors causing them any damage.

7. Oil platforms and similar structures as benefit to fish populations

As previously described, one of the largest bodies of work on man made oceanic habitats has been centred on offshore oil platforms. There have been many documented examples of fish utilising these structures to their benefit, with increased diversity and abundance, as well as large individual fish and the sheltering effect for juveniles or smaller fish. To this end, the role of oil platforms will be discussed, as well as seawalls, selected due to their similarity with the boulder method of scour protection used around many offshore wind turbines.

7.1 Oil platforms

Off California, a study into the relationship between oil platforms and fish found that the platforms tended to have higher abundances of larger fish surrounding them than the natural reefs, probably due to restrictions reducing fishing effort levels (Love and Schroeder, 2006). It also found that there was a higher density of young-of-the-year fish than nearby reefs, with the likely explanation being that the tall platform structures occupy more of the water column, thereby increasing chances of juvenile fish encountering them rather than low-lying natural structures. Despite having a higher density of juvenile fish however, the study showed that in terms of growth rates, there was no significant difference between the daily growth rates of fish at the platforms and natural reefs (Love and Schroeder, 2006).

The study also managed to calculate that for the largest platform in the study, Platform Gail in southern California, if it were to be removed after decommisionning, it would be equivalent to removing 12.57 ha of average larvae producing natural habitat in California for cowcod (*Sebastes*), and 29.24 ha for bocaccio (*Sebastes paucispinis*).

There are many suggestions as to why oil platforms and similar structures, including wind farms, are potentially such good habitats, the following four of which were put forward by Neira in 2005:

- They provide suitable structures for invertebrates to colonise, forming the base of a food web;
- They occupy the whole water column, thereby providing a wide range of habitats, lowering risk of predation and increasing productivity;
- They may act as plankton collectors, concentrating phytoplankton, zooplankton and other organisms which just drift with the current;
- They can act as reference points in an otherwise empty open-water habitat.

In terms of lowering predation, Love and Schroeder (2006), focussed on the predation of painted greenling (*Oxylebius pictus*), a small, benthic fish which inhabits rocky outcrops in southern California. The study compared predation rates at several platforms and adjacent rocky outcrops, and found that on average, natural reef-inhabiting fish suffered a predation rate over 2.5 times that of those fish inhabiting the oil platforms.

Seasonal variations are also a potential issue for colonising fish populations. One Australian study found that in summer, the peak fish concentration around oil rigs off the south east coast was 25.1 fish per 100m^3, compared to 87.3 fish per 100m^3 in winter (Neira, 2005). It was also found that out of the 1526 fish caught for the research, 91% came from only eight families. *Carangidae* (jack mackerel), *Myctophidae* (lanternfish) dominated in both summer and winter, with the other six families being *Bovichtidae* (thornfish), *Monacanthidae* (filefish), *Scomberescoide* (sauries), *Triglidae* (sea robins), *Berycidae* (redfish), *Arripidae* (Australian salmon) and *Bothidae* (flounders) (Neira, 2005).

7.2 Sea walls and wharves

Oil platforms are not the only man-made structures which become habitat for organisms, simpler installations such as sea walls may also be used. These are relevant to this report due to the use of boulders as a method of scour protection, often of similar size and shape to those used in the construction of coastal protection.

One study in Sydney Harbour, Australia, supported the idea that habitat complexity is an important factor in the utilisation of structures, as it compared the number of chitons (*Polyplacophora*) found in crevices and on flat, exposed surfaces along the sea wall. Sampling indicated that numbers of chitons were significantly higher in crevices than on the exposed sea wall at any tidal height (Moreira *et al*, 2007). Other organisms found within these cracks and crevices include barnacles, crabs and molluscs, with the most likely reason being protection in terms of both predation and wave action. When given the choice of habitats, the chitons always moved towards the crevices, rather than staying on the flat exposed faces of the sandstone blocks making up the sea walls (Moreira *et al*, 2007). This suggests that by increasing the heterogeneity of artificial habitats, biodiversity may be increased, improving commercial potential for areas as well. Again though, it is species specific, as Chapman (2006) found that a variety of mobile animals, such as starfish, sea urchins and molluscs were found less frequently on seawalls than natural reefs.

Another feature of the sea walls in Sydney Harbour is the wharves, built to allow boats to moor. Because these are usually built over sea walls, assemblages are already altered, but they have been found to have some additional impact. Blockley (2007) found that the shading can reduce surface temperature in relatively shallow waters, as well as altering light conditions, which meant that on walls under wharves, algae was virtually absent. This could have impacts all the way up the food chain, as without algae, other organisms may not settle.

8. Potential colonisation of wind farm foundations

Colonisation patterns will depend upon the methods of scour protection and foundation used. For example, for the gravel mattress method, the most comparable natural habitat would be rocky subtidal areas such as the shingle reefs, ‘sarns’ in the Cardigan Bay area (Linley *et al*, 2007). According to a Joint Nature Conservation Committee (JNCC) (Website 3), these areas are generally lacking in conspicuous fauna, with highly variable fauna. Typical species composition includes robust polychaetes, bivalves, echinoderms and crustaceans, and, where water flows are lower, anemones, hydroids and bryozoa.
In terms of the turbine itself, details of the predicted community have been published by Linley *et al* (2007) and Hiscock *et al* (2002), indicating which depths certain groups of species could be expected to inhabit (Figure 12)

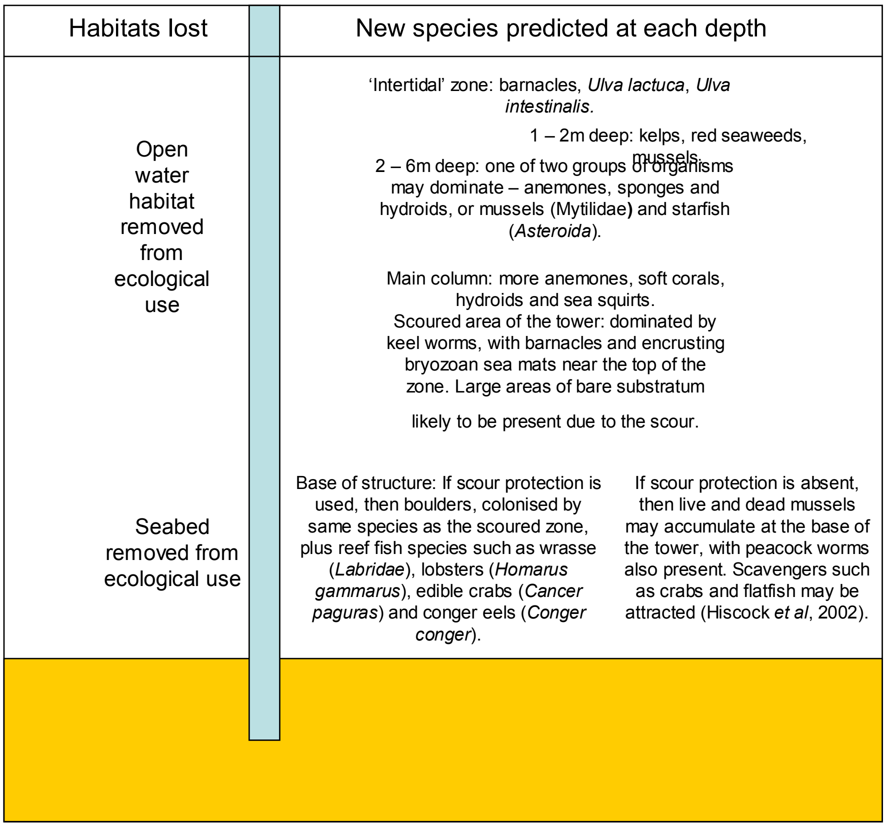

Figure 12 - Habitats lost and predicted colonising communties for an offshore monopile wind turbine, adapted from data in Linley *et al* (2007) and Hiscock *et al* (2002)

Mussel dominance was found to be the case at the Horns Reef offshore wind farm, Denmark, where the biomass of common mussels and barnacles was ten times greater on the tower than around the scour protection, and biomass declined with depth down the turbine (Forward, 2005).

This colonisation of a turbine's foundations should be considered from the early planning stages, as studies have shown that the fouling communities which inhabit the bases can add a large amount of weight to the structure (Parkinson, 1999). If not properly planned, this weight may lead to damage and excessive maintenance for the turbines, which would in turn damage any beneficial colonisation taking place.

8.1 Predicted communities of scour protection

Boulder protection

Where boulder protection is used, barnacles and tube worms again dominate the colonisation, as well as sea squirts. If well planned, then lobster, edible crab and velvet swimming crab (*Necora puber*) may be attracted, plus wreck and reef fish such as wrasse and conger eels (Hiscock *et al*, 2002). The presence of the boulder protection will be comparable to rocky outcrops, which generally have higher levels of biodiversity and abundance than the surrounding sandy seabed. For example, a study into the settlement patterns of juvenile lobsters found that no lobsters were recorded settling onto sandy areas of the seabed, compared to 19 lobsters/m^2 on large cobble and boulder covered areas (Linnane *et al*, 2000).

Gravel protection

According to the JNCC description of the habitat type "sparse fauna on highly mobile sub-littoral shingle", which is the most comparable habitat type for this scour protection method, the species composition is highly variable between seasons depending on currents flushing organisms out, and relatively faunally impoverished (Website 3). It is generally inhabited by low numbers of robust polychaetes or bivalves, with occasional epibiota such as echinoderms and crustaceans including *Liocarcinus* spp. and *Pagurus* spp. At times when currents are reduced, anemones such as *Urticina feline* and small populations of hydroids and bryozoa may also colonise. According to the 2004/5 Comparative Tables, published by the JNCC through their website, the characterising and dominant species of the gravel habitat are *Chaetopterus variopedatus* (the parchment worm) and *Spisula elliptica* (a bivalve mollusc). Both of these are found in large numbers around the UK coastline, and therefore would be expected to form a large proportion of the colonising community in this situation.

Within the extensive 'beds' of parchment worms can be found large populations of *Mysid* shrimps and very small crab species often found inhabiting the tubes left by dead worms. These in turn provide food for species such as seahorses and pipefish, which are able to anchor themselves into the tubes by their tails (Anthoni, 2006).

Synthetic fronds protection

Both anecdotal and photographic evidence indicate that the semi-burial of the synthetic fronds by accumulating sediment mean that this form of scour protection most closely mimics the natural habitat of a sea grass bed (Website 5). Sea grass beds are very important for fish, providing feeding grounds and resources, shelter from predation, nursery areas and refuges for larvae (Kopp *et al*, 2007). They achieve this by creating a 3-dimensional architecture to the seabed, as well as stabilising sediments and harbouring a diverse and abundant invertebrate fauna, which allows them to support a healthy fish community (Pihl *et al*, 2006). One of the largest groups of fish inhabiting sea grass beds, particularly in the Baltic Sea, are the *Syngnathidae* group, which includes the seahorses, pipefish and sea dragons. These are especially successful due to their specially adapted body shape and ability to anchor into the fronds. Gobies are also an important component of the sea grass food web, with their densities being up to four times greater in sea grass beds than surrounding non-grassed areas (Pihl *et al*, 2006).

General points

On the scour protection, algae was a major component, and in comparison to the tower, the biomass around the base was twice as much as on the tower (Forward, 2005). Hiscock *et al* (2002), predicted that if scour protection is not used, the resulting 'scour pits' are usually 1-50cm deep, and have had their finer sediment removed, leaving only large shells and coarse gravel. These areas are generally colonised by tube worms and barnacles, and attract edible crabs and lobster, as well as fish such as ling (*Molva molva*).

9. Current evidence of wind farms as fish habitat

Offshore wind farms may benefit local fish populations by acting as one or both of the following:

- An artificial reef
- A no-take zone in terms of fisheries

9.1 The wind turbines

There have been only a few major studies in terms of offshore wind farms and fish habitat, one focusing on the Horns Reef wind farm, off the coast of Denmark, which compared the wind farm area to a reference area. Forward (2005) found that in terms of benthic community structure, there was no significant difference between the two sites, but there was a substantial increase in sand eel density, rising by 300% at the wind farm during 2004 operations, compared to only 20% at the control site. The rise at the wind farm site was mainly due to increased juvenile sand eels (*Hyperoplus*), and the main two reasons proposed were a reduction in mortality through predation, and a change in the sediment structure, as the median particle size increased as smaller particles were removed during construction. In addition to this, eight new species were found in the wind farm area post-construction. Figures such as these, as well as healthy and diverse communities being found around sites such as North Hoyle and Blyth, suggest that initial fears about electromagnetic fields and noise are not major issues (Linley *et al*, 2007).

A study in the Adriatic Sea also found a beneficial link between offshore floating wind farms and bluefin tuna (*Thunnus thyunnus*), recording that the tuna showed a tendency to congregate around the turbines, showing that they were acting as Fish Aggregating Devices (FADs). Areas around the turbines had catch rates for tuna 10-100 times greater than in the open ocean (Fayram and de Risi, in press). One possible reason for this is that fishing is restricted around offshore wind farms due to risk to the cables, thereby acting almost as a reserve for those species found within it. Marine reserves have been used many times in the past, and are strongly advocated as a tool for the management and protection of coastal fisheries (Garcia-Charton and Perez-Ruzafa, 1999).

Research into commercial fisheries around the Horns Reef wind farm found that when nets were set around the border of the area, there was no negative impact on the fishery, and for cod, there was a considerable increase in the numbers caught, thought to be due to the high densities of small fish and crustaceans inhabiting the area which were not present before (Forward, 2005). This conclusion is subjective however, and based on non-analysed observations, not statistically proven. Another conclusion Forward drew in the 2005 report was that in March 2003, just four months after the wind farm came into operation, there were three fish species of fish found within the area, and that this rose to fourteen species by September 2003. However, it is not known whether or not this alteration in number of species is related to fish returning to the area post-construction, or new fish moving into the area to inhabit the wind farm area, as there are no statistically valid comparisons of numbers of fish at the wind farm site and reference site.

9.2 The scour protection

Although not part of the wind turbine itself, but still an integral part of the development, the scour protection, generally in the form of large boulders, would form an important part of habitat creation around the wind farm. For these areas, habitat complexity is once again an important issue, and there have been many studies which could be of use here. A number of these studies have focussed on tropical reef systems, but there is enough similarity with the wind turbine situation to make their inclusion valid. Friedlander and Parrish (1998) looked at Hawaiian reef systems, and found that transects adjacent to a sand interface, and with high spatial heterogeneity had the highest numbers of both species and individuals, whereas areas far from sand and with low relief saw the lowest values.

Complex habitat structural features, such as boulder arrangements, may:

- Provide shelter from physical stress – provision of shelter by the wind farm will be high, because prior to the turbines being installed, the seabed would have been relatively featureless, with few shelter-providing structures.
- Restrain foraging predators and interfering competitors – the creation of a wide range of niches will provide safety for many species, which would otherwise be predated upon in the open ocean.
- Modify the availability of resources and their rate of acquisition – it has already been suggested that structures such as oil platforms and wind farms can act as plankton collectors, allowing plankton which would otherwise have drifted by to settle and develop (Neira, 2005). These then provide the beginnings of a food web to develop, creating a new community with new resources.
- Provide refuges and barriers, thereby further increasing habitat diversity – by increasing the diversity of habitats on the ocean floor, biodiversity and abundance may also be increased.

In the North Sea, figures from ICIT (International Centre for Islands Technology, part of Heriot-Watt University, Edinburgh), estimate that 0.055-0.62kg/m^3 of fish exist due to the presence of 'reefs' from disused oil rigs. Another estimate is that within 100m of each platform, there are 70,000 pelagic fish, and 9,000 demersal fish making use of the habitat (Parkinson, 1999).

10. Ecological goods and services and the potential impacts of the wind farm

In economic terms, any benefits society gains from the environment are classed as "ecological goods and services", with examples of goods being things such as food and aggregates, and services including sewage breakdown and pollutant dispersal (Frid and Paramor, 2006). To ensure sustainable decision making, it is critical that these goods and services be included in any planning process, as too much human activity being carried out may compromise the ability of the environment to continue in their provision.

Beaumont *et al* (2007) indicated that these goods and services can be divided into four broad categories:

- Production services – products obtained from the ecosystem;
- Regulating services – benefits obtained from the regulation of ecosystem processes;
- Cultural services – non-material benefits obtained from ecosystems;
- Supporting services – necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

Regardless of the size of an ecosystem, the range of goods and services it can provide depends entirely on the species present and their life processes (Frid and Paramor, 2006). For any potential wind farm then, it is imperative to ensure that the development does not damage the surrounding ecosystem so much that these goods and services can no longer be provided at sustainable levels. Each of the above categories has several sub-groups within it, and the creation of an offshore wind farm has the potential to have positive and negative impacts on the ability of the ecosystem to continue to provide its goods and services (Table 5)

Table 5 - Offshore wind farm impacts on ecological goods and services of the marine environment, adapted from Beaumont *et al*, 2007

Goods/Service	Positive impacts of wind farm	Negative impacts of wind farm
Food provision	May increase number and size of certain fish species, and act as a nursery ground, potentially improving adjacent stocks for fishing The prevention of fishing in the area will have an ecologically positive impact	Prevents access by fishermen to area
Raw materials	While wind farm is in place, materials cannot be obtained, thereby indirectly conserving them	Prevents access to surrounding area for dredging, drilling etc.
Gas/climate regulation	Reduces carbon emissions by replacing less clean power generation methods	Increase in boat traffic in the area could increase litter or accidental oil spillage
Disturbance prevention, e.g. floods and storms	Near-shore wind farms may act as an extra level of protection against storms and floods	Near-shore wind farms may alter the way in which currents hit the shore, making current defences useless and necessitating the building of new defences
Bioremediation of waste	No likely positive impacts	May alter currents in the immediate area, changing the capacity for bioremediation
Cultural heritage and identity	Adds another layer to the identity of the coastal region	Some people may feel it detracts from the appeal of the coastal region (although it has been shown this is generally not the case)
Cognitive benefits (education and research)	Allows a greater database of flora and fauna surrounding offshore wind farms, therefore greater understanding	No likely negative effects
Leisure and recreation	May attract new tourists to the area. Studies have shown wind farms in general do not affect people's decision to return to an area With the benefits of the artificial reef, anglers may be attracted to areas just adjacent to the exclusion zone for better fishing, a similar situation may occur with divers	May prevent/reduce some activities such as whale/bird watching, diving and sport fishing in the immediate area
Feel good factor	Positive feeling of using cleaner energy generation method	May reduce some people's enjoyment of the area by reducing aesthetic appeal

Resilience and resistance of environment	Short term disturbances, such as the construction period, may actually increase diversity and therefore strength of the ecosystem	Too much damage may permanently reduce ability of ecosystem to provide goods and services
Nutrient cycling	May create new, more productive habitats	Removal of habitats may temporarily reduce productivity

10.1 Relative impacts of offshore wind farms to other marine activities

To determine the relative impacts of an offshore wind farm development compared to the many other activities which take place within the coastal zone, a matrix was produced by the Marine Life Information Network for Britain and Ireland (MarLIN), and then added to by the Institute of Estuarine and Coastal Studies (IECS). Within this matrix (Appendix One), the probable and possible impacts of all activities on a wide range of aspects of the marine environment were predicted, allowing 'scores' to be allocated for each interaction, ultimately allowing the determination of relative impact values.

Using the values within the table, the development of an offshore wind farm has the impact score of 30, and the other listed activities with values within two either side of this are:

- Shellfish collection, 28
- Artificial reef development, 28
- Culverting lagoon development, 30
- Maintenance dredging, 31
- Oil and gas platform development, 32
- Oil and gas extraction, 32
- Urban development, 32

These further highlight the similarities between oil and gas offshore developments and offshore wind farm developments, potentially supporting the idea that any benefits oil or gas platforms have for fish or benthic communities may also be provided by wind farm installations in similar environments. It also mirrors the same impacts highlighted previously, with the impacts classed as 'probable' being:

- Loss of area from seabed, water column and air space – due to the installation of the turbines into the habitats.
- Loss of substratum – due to installation of turbines and scour protection.

- Changes in water flow rate and currents – due to the obstructive nature of the turbines.
- Visual presence – many people still consider them aesthetically displeasing.
- Abrasion/physical disturbance – mainly during the exploration and construction phases.
- Displacement – conditions in the surrounding environment may change significantly, forcing some species to leave the area.
- Water abstraction – although water is not directly removed from the system, the ecological use of the water column within the wind farm may be reduced for certain species.
- Productivity loss – the removal or alteration of habitats for the installation of the turbines may reduce the levels of productivity, at least in the short term until the area recovers.
- Non-selective abstraction of non-target species – some species previously inhabiting the area may be unable to continue to do so due to the change in conditions.

Many of these issues could potentially be reduced or even resolved through careful design and planning, following advice such as that included at the end of this report. Considering that another marine activity with a similar value from the activities matrix in Appendix One is artificial reef development, then this is evidence that with good management, offshore wind farm developments can mimic the role of artificial reefs in the marine environment.

For statistical analysis of the activities matrix (Appendix One), a cluster analysis was performed, using the Euclidian distance method of similarity coefficient, and then group average linkage to create the dendrogram. This was done by using the Community Analysis Package, produced by PISCES Ltd (2002) (Figure 13)

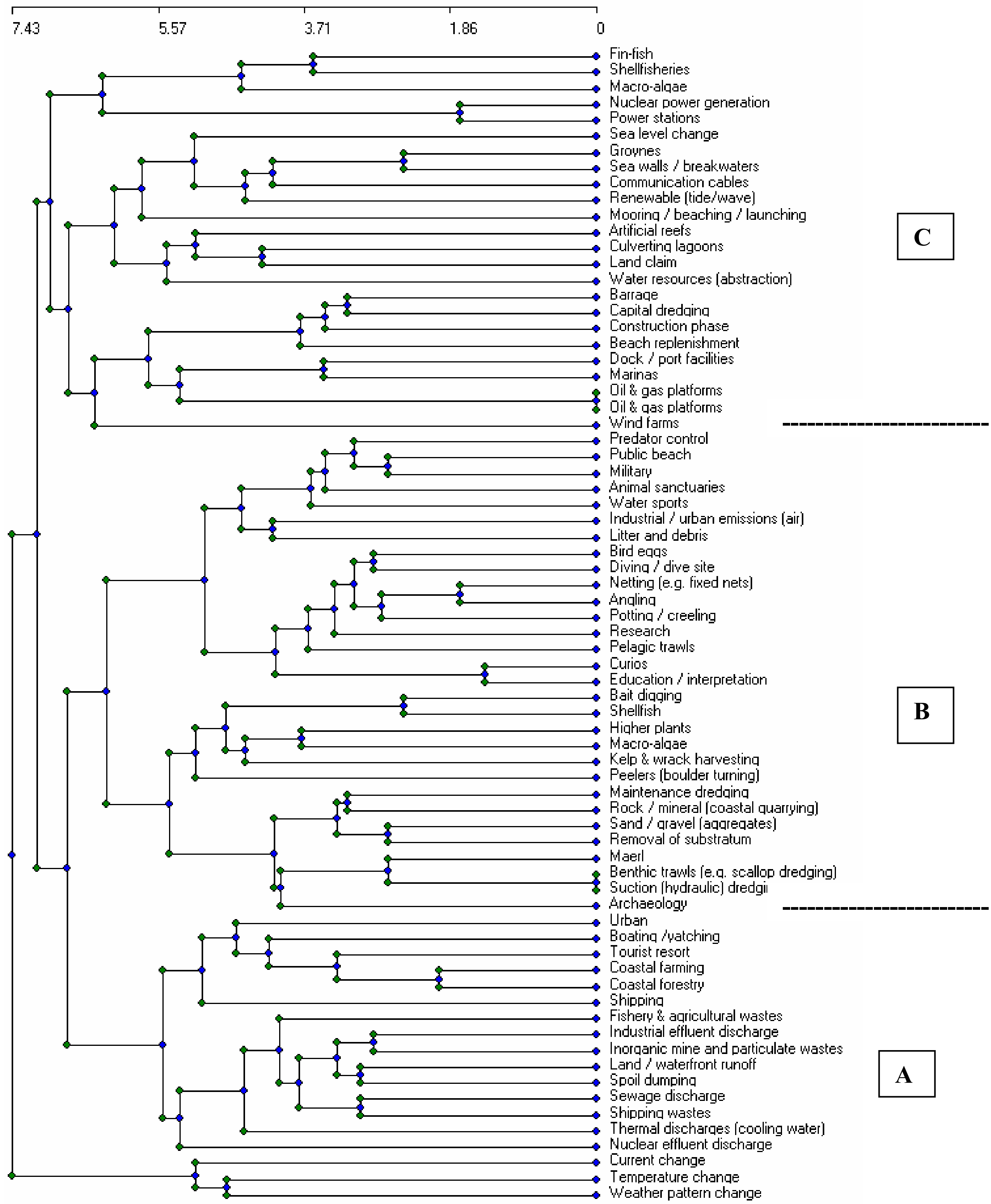

Figure 13 – Cluster analysis of activities matrix (A - waste discharges + waste activities; B - Biological and physical extraction + activities; C- physical structures and physical interference)

This allows statistical comparisons to be drawn between the various activities which take place in the marine environment. The analysis was run by Professor Mike Elliott of the University of Hull, and is an example of one of the methods which can be used to compare the various activities within the marine environment through their profile of impacts.

Using the simplistic approach of calculating the relative impact scores of each activity may allow an overall comparison, but does not allow the exact nature of these impacts to be compared. For example, the removal of sediment by dredging may have a different range of impacts compared to the release of effluent into the coastal zone, but have similar overall total scores. By using the cluster analysis method, these variations within similar values will be maintained, allowing for more accurate and meaningful comparison. Suggestions for the potential future development and improvement of this work will be discussed later in this report.

11. Quantifying habitat loss and habitat creation from an offshore wind farm

For the majority of offshore wind farm developments around the UK coastline, the monopile foundation method is the most commonly used. Therefore it has been decided to concentrate on this design for the calculations contained within this chapter, which aims to put values to the volume and area of habitat lost and created by the installation of a single turbine.

11.1 Loss of seabed/surface area

Probably the most noticeable loss of habitat is that of land lost directly from the seabed, and therefore the impacts upon benthic invertebrates or other bed-dwelling organisms. In general, offshore wind farm development zones tend to be harsh environments of bedrock or very coarse sediments, and so are species poor, mainly dominated by short lived species which appear in summer, some of which being flushed away by autumn storms and resulting in a temporary change in community composition (Linley *et al*, 2007).

The level of impact will depend on the nature of the bedrock and/or sediment the wind farm is to be developed on, but in terms of area, the values are fairly consistent.

At the North Hoyle site off the North Wales coast, there are 30 turbines in an area of $10km^2$. From this, the calculation is very simple.

$$\frac{\text{Area of wind farm}}{\text{Number of turbines}} \qquad \frac{10\ km^2}{30} \qquad = \mathbf{0.3\ km^2\ seabed\ lost\ per\ turbine}$$

These values are consistent with other offshore wind farms, such as Kentish Flats and Gunfleet Sands 2. Also consistent is the distance turbines are set apart, at between 400 and 800m depending on seabed and current conditions. However, this calculation assumes that within the site of the offshore wind farm, the whole area, including the space between the turbines, is lost, which is not the case. Although the areas between the turbines may be subject to slightly altered current conditions, the habitat will not be lost as directly as that removed for the installation of the wind farms. A more accurate and valid calculation focuses on individual turbines.

For each turbine, the specific area of seabed surface area lost depends on the area of scour protection installed around its base, which in most cases is a circle with a radius of 10m out from the base of the turbine. However, this radius will begin at the edge of the turbine, which for this study has been assigned a diameter of 4m. Therefore, to calculate the total amount of seabed area lost, a circle with a diameter of 12m will be used. This gives the total area lost, per wind turbine, as:

$452m^2$

Seabed disturbance from the imbedding of cables linking offshore facilities to onshore sub-stations and the National Grid is also an issue for habitat loss. At the Horns Reef offshore wind farm, off Denmark, for the 19.5km distance between wind farm and land, $20{,}000m^2$ of seabed was affected, either through removal or relocation through the water jetting process (Forward, 2005). This allows a second calculation.

$$\frac{\text{Area of seabed affected}}{\text{Km of cabling}} \qquad \frac{20{,}000\ m^2}{19.5\ km} \qquad \mathbf{= 1025.6\ m^2\ lost/km\ cable}$$

For ease of calculations, this figure can be rounded down to $1km^2$ of seabed surface area lost for every kilometre of cable required. However, this area of seabed may recover if the cables are laid carefully, for example by burying them deep enough to allow a natural layer of sediment to reform over the top of them.

Due to the fact that any proposal for an offshore wind farm must include how many turbines will be included, and the distance offshore, which indicates the amount of cabling required, it is therefore possible to calculate, on a site specific basis, how much potential damage will be caused in terms of surface area affected.

11.2 Loss of water column

The volume of water column removed from ecological use because of the offshore wind farm is highly species specific. For example, it has already been stated that bowhead whales will divert their migratory paths to avoid the developments, and other mammals such as the harbour porpoise and humpback whale also have varying levels of tolerance (Thomson *et al*, 2006; Myrberg, 1990). This means that certain species will be able to travel closer to the wind farm than others.

Volume lost will also vary between periods within the development. Generally, a greater area will be lost during the drilling and construction phase, as this is when the most damaging noise is generated. Once the wind farm is in operation, noise is reduced and most organisms, whether bird, marine mammal or fish, will be able to tolerate a closer proximity.

For example, the Thomson *et al* study (2006) looked at some example fish species, and found that during operation, cod (*Gadus morhua*) and herring (*Clupea harengus*) could detect the noise up to 4km away, and it was audible by dab and salmon up to 1km away. Given that many offshore wind farms have successful fish populations (Forward, 2005), which in some cases are more successful than those away from the development; this suggests that the actual water column area lost is low.

The above however, does not allow a numerical evaluation of the actual volume of water which is lost directly through the placing of a monopile. This can be calculated by knowing the water depth and diameter of the monopiles used for each wind farm (Table 6). For the final column of Table 6, the volume per wind turbine has been taken as a cylinder, with the length being the average water depth for the wind farm concerned, and the diameter the stated diameter of the monopile foundation.

Table 6 - Depth, diameter and minimum water column volume of UK offshore wind farms, based on information from AMEC Wind Energy (2007)

Wind farm	Location	Average water depth (m)	Monopile diameter (m)	Volume per turbine (m^3)
Blyth	Blyth	8	3.5	77
Scroby Sands	Great Yarmouth	7	4.2	97
Kentish Flats	Whitstable	5	4	63
North Hoyle	Liverpool Bay	12	4	151

With the combined total of turbines between the above wind farms being 92, this means the total direct volume lost because of the listed wind farms is 9,484m^3. With these values then, the average water column volume lost purely due to the introduction of a monopile wind turbine foundation is:

103m^3

11.3 Loss of air space

Technically, the volume of air space habitat removed from use is purely the volume of the turbines' structure above the surface of the water. If it is assumed that birds will not enter into the general 'rectangle' created by the turbine tower and its blades, then the calculations would be as follows (with values taken from Manwell *et al*, 2007).

Height of the turbine above water (including blades) = 95m Diameter of tower = 4m Diameter of blade circle = 80m Volume of resulting rectangular prism: **28,800m^3**

However, in terms of bird avoidance, the area no longer used as before is much bigger than this. In general, birds will avoid the turbines by a distance of 400-800m (Talisman Energy, 2006), but this is highly species specific, for example Eider ducks (*Somateria mollissima*) will stop flying between turbines spaced less than 200m apart (Percival. 2001). Some species will move in closer, whereas some will keep a distance of almost 1,500m from the turbines (Talisman Energy, 2006). For near shore wind farms, this may result in a relatively large area of potential flying habitat to be lost, but for farther offshore developments, such as the proposed demonstrator project in the Moray Firth, the Beatrice wind farm, the area lost is very small when compared to the overall site designated for the development. Another consideration in terms of air space lost, and the potential impact on avian populations, is that if the wind turbines are placed at the minimum distance apart, fewer birds would enter the area between turbines. This could, in the long run, further reduce the risk of collision and therefore mortality rates. Therefore, the amount of air space lost will depend on (Talisman Energy, 2006):

- The number of turbines present in the development;
- The proximity of the development to the shore;
- What species are present nearby, and their level of sensitivity.

11.4 Creation of seabed/surface area

As stated, the amount of habitat available for colonisation depends on foundation type, water depth and dimensions of foundations. For the UK, all major offshore wind farms use the monopile foundation method, and from this, the surface area which will be created can be calculated (Table 7). For the final column, the surface area per turbine has been calculated by taking the surface area of a cylinder, created by the average water depth as its length, and the diameter as the diameter of the cylinder.

Table 7 - Depth, diameter and surface area of UK offshore wind farms, based on information from AMEC Wind Energy (2007)

Wind farm	Location	Average water depth (m)	Monopile diameter (m)	Surface area per turbine (m^2)
Blyth	Blyth	8	3.5	107
Scroby Sands	Great Yarmouth	7	4.2	120
Kentish Flats	Whitstable	5	4	87
North Hoyle	Liverpool Bay	12	4	175

Although technically, the area covered in scour protection is 'lost' in direct terms, the hypothesis being tested here is that habitat is actually created, as the surface type is altered, usually from relatively bare seabed, to either fronds and sediment, or a gravel or boulder base. As previously stated, scour protection is set out in a 10m radius around the base of the wind turbine, which for these calculations has been taken to have a diameter of 4m. To calculate this area, the total seabed area lost, from the total circle diameter of 24m ($452m^2$) is taken, and from this, the area covered by the base of the wind turbine itself ($12.5m^2$) is subtracted, giving an area of scour protection of $439.5m^2$. Combining this information with the data from Table 6, the total area created by the following major offshore wind farms can be calculated (Table 8).

Table 8 - Total area generated by the development of an offshore wind farm, based on information from AMEC Wind Energy, 2007

Wind farm	No. of turbines	Total turbine area (m^2)	Total scour protection area (m^2)	Total area created by the wind farm (m^2)
Blyth	2	214	879	1,093
Scroby Sands	30	3600	13,185	16,785
Kentish Flats	30	2610	13,185	15,795
North Hoyle	30	5250	13,185	18435

In these selected wind farms, there is a total of 92 wind turbines, which, including both their 10m radius of scour protection and the monopile itself, generate a total of

52,108m^2 of area potentially available for colonisation. Using these data then, overall, the average area of potential habitat generated per turbine in a monopile offshore wind farm development is:

566m^2

Synthetic frond protection

The type of habitat created is just as important an issue as the quantity which arises from the development, and the main variation between offshore wind farms is the method of scour protection used around the bases of the turbines. Although boulder protection and the plastic fronds offer equal protection to the structures, they will potentially attract very different communities. For example, with the plastic fronds, sediment gathers until only the final 10-20cm remains visible above the sediment surface, with these tips becoming inhabited by fish, in a way similar to a bed of sea grass, and thereby creating a very different habitat environment to that of the rock armour (Linley *et al*, 2007). The additional area created by these frond tips will be negligible compared to the area of the scour protection; therefore it can be assumed that the area of sea grass-similar habitat per offshore wind turbine will be purely the area around the base of the turbine designated for scour protection, i.e. the 10m radius out from the base of the turbine:

439.5m^2

Gravel scour protection

The most commonly used scour protection method in the UK is gravel protection, usually consisting of a layer of stones with a mean diameter of 5cm. Assuming a single layer of stones of this size, it would take 2,313 stones to cover the area of protection (439.5m^2). The surface area of each individual stone is 78cm^2, making the total surface area of gravel habitat 1,804m^2. However, given that approximately half of this area will be unavailable for colonisation due to being embedded in the sediment, or obscured by a lower layer of sediment, the area of gravel habitat open for colonisation would be 902m^2.

For a more accurate determination of the surface area around the whole of the scour protected zone, the details mentioned in Chapter 5 can be used.

Average size of gravel (Mr Glen Evertsen of AMEC Wind Energy, Pers. Com., 2007) = 0.05m diameter
Surface area of circle with the same diameter = $0.19m^2$
Depth of gravel mattress (Website 2) = 1.3m
Area of scour protection (Linley *et al*, 2007) = $439.5m^2$
Surface area of cylinder created (excluding base) = $537.5m^2$
Number of gravel faces which would fit into this area = 2,828
Surface area of gravel open for colonisation (50% of the surface area of the total number of stones visible):

$1{,}102m^2$

This would be the minimum surface area available for colonisation, as there would also be the surface of the spaces between the stones, open for smaller organisms to move into. However, over time these spaces would fill with drifting sediment, making them uninhabitable, reducing the available surface area back to simply the open top layer. Also, these spaces would be relatively small, due to the size of the gravel, which would also limit those species able to utilise the habitat.

Boulder scour protection

Boulder scour protection is generally employed in deeper waters, or where the level of scour is anticipated to be relatively high. For boulder scour protection, it has been assumed for this study that a 5m high pyramid of boulder protection will be employed around the base of the turbine, in a pyramid design. This is due to the fact that the majority of offshore turbines are built in water deeper than this, with future wind farms being planned for waters in the 15-20m deep range. It has also been assumed that the average diameter of the boulders used is 2m, similar in size to those used in coastal defences such as sea walls, and that the standard scour protection has been employed, with an area of $439.5m^2$.

To calculate the minimum surface area which would be created, it has also been assumed that the boulders would form a dome around the tower, and a similar method as used above can determine the surface area of the external layer of boulders available for colonisation.

Average size of boulder = 2m diameter
Surface area of circle with the same diameter = 3.14m^2
Depth of scour protection = 5m
Diameter of scour protection (Linley et al, 2007) = 24m
Surface area of dome created = 517.5m^2
Number of boulder faces which would fit into this area = 164
Surface area of boulders open for colonisation (50% of the surface area of the total number of boulders visible):

1,029m^2

Although this surface area, again a minimum value, is fractionally smaller than that created by the gravel scour protection, impact of spaces between the boulders silting up will be to a lesser extent due to the size of the spaces initially. Therefore it would be expected that the spaces between the boulders would remain in an ecologically usable condition for a longer period of time than those between the smaller, gravel-sized stones.

11.5 Creation of water column

It is physically impossible to increase the volume of water column available; therefore there is no direct increase in water column habitat. Instead, there will be an alteration in the form of water column habitat available, changing the open ocean into a more sheltered habitat type. Evidence has shown that the abundances of fish increase in similar areas, such as oil rigs, compared to the open ocean (Love and Schroeder, 2006), suggesting that even though the volume of habitat does not increase, its usefulness in ecological terms may do so, especially as it traps passing plankton and organisms become developed on the wind farm turbines.

It can be stated then, that despite no increase in habitat, the change in habitat will result in an increase in carrying capacity and ecological usefulness for the area, due to increased food and shelter.

11.6 Creation of air space

As with the water column, it is impossible to physically create air space, so again the issue of changing its ecological use is the main indicator of habitat loss or gain. Studies have shown that the general response of birds is to avoid the area (Percival, 2001), and due to this it can be stated that carrying capacity will be reduced, therefore having no beneficial effects for birds.

Another aspect for consideration here however, is the potential benefit the removal of birds from the system could have for fish inhabiting the area surrounding the offshore wind farm. This is due to the reduction in predation from diving birds which would otherwise be feeding in the area, but have been forced to other zones by the turbine installation. Therefore, the removal of air space, despite being negative for birds, could create an additional positive aspect for fish or other prey species.

11.7 Net habitat loss and gain from an offshore wind farm development

By combining all of the data regarding habitat area lost and gained, it is possible to establish the net change in habitat with the development of an offshore wind farm, and whether that value is positive or negative (Table 9). For each of the values, this is the minimum surface area created, and will depend on the number of layers deployed around the base of the turbine, as well as the exact diameter of the material used. For the gravel, an average diameter of 5cm has been used, with 2m average diameter being used for the boulder calculations.

Table 9 – Net average habitat loss and gain per monopile foundation turbine for an offshore wind farm, depending on scour protection methods used

	Seabed/surface area (m^2)		Water column m^3	Air space
Habitat lost	452		103	28,800
Habitat gained (with each scour protection method; minimum value)	Gravel	1,102	0	0
	Boulders	1,029		
	Fronds	439.5		
Net change	**Gravel**	**+ 650**	**- 103**	**-28,800**
	Boulders	**+ 577**		
	Fronds	**- 12.5**		

Although the calculations indicate a negative change in water column, i.e. a loss in habitat, this may be misleading. Despite being a direct reduction in water column available for organisms, the ecological usefulness of the area may be increased, for example by providing shelter and acting as a fish aggregating device. Therefore, the area's carrying capacity will have been increased, indicating that the actual result is beneficial for the surrounding environment.

The same is true for the change between the sandy seabed and the synthetic fronds habitat. According to the JNCC habitat hierarchy, the sandy seabed is most comparable to “offshore circalittoral sand”, which generally has a community comprising polychaetes, amphipods, bivalves and echnioderms (Website 10). However, within this habitat type, abundance and diversity are generally low, and therefore with the change to the synthetic fronds will arise a more diverse species community. It can be assumed again then, that the carrying capacity of the area would be increased, even though the surface area does not.

Although numerically there is a large loss in habitat per turbine for birds in the surrounding area, careful planning of the location of the wind farm can reduce the impact of this, and it has already been shown that even in areas of relatively high bird density, the number of mortalities is very low. If the wind farms were to be installed in areas with low levels of bird movements, and away from conservation zones, which is generally the rule, impacts could be reduced to negligible.

In terms of actually creating habitat, then the most benefit is gained from a change in the seabed from open ocean seabed to either gravel or boulder scour protection. This is due to the significant increase in surface area which is achieved by the three-dimensional structures created by the boulders and gravel, which cannot be created by the installation of the synthetic frond mats, which are simply placed around the base of the turbine, directly onto the sea floor.

The dominating value within Table 8 is the loss of air space as a result of the development of an offshore wind farm. This may be somewhat misleading, as values have already shown that the mortality rates to birds from an offshore wind farm are much lower than originally predicted. Therefore, the focus should not be on this value of a loss of 28,000m^3 of air space, but more on the habitat change and creation in the seabed and water column environments.

For any of the aspects considered within the calculations of this report, the only area considered is that directly affected by the development, such as the installation of the towers, the scour protection and the cabling linking the turbines to the shore. However, because the scour protection around the turbines is only a 10m radius out from the base, and the usual gap between turbines is around 400m, a large percentage of the overall wind farm area is not directly covered or altered by the turbines or their surrounding protection. Within this non-developed area, it would be expected that minimal scour occurs, with only a slight alteration in normal flow and current activities, meaning that discounting short term impacts through increased turbidity, and operational noise and electromagnetic field levels, there will be very little change in the habitats between the wind turbines.

Despite not being included in Table 7, in order to stress the differences between the different methods of scour protection, there is also the surface area of the tower itself to consider. Here, again, the information from Blyth, Scroby Sands, Kentish Flats and North Hoyle offshore wind farms has been combined, producing an average water depth of 8m and average pile diameter of 3.9m (AMEC Wind Energy, 2007). This creates an average surface area for a monopile turbine foundation of:

$$\mathbf{97m^2}$$

Regardless of the scour protection method used then, this can also be considered as habitat creation, as shown by the predicted colonisation communities up the surface of the tower.

Combining this with the net changes in habitat, the following values are generated:

- Gravel protection – a habitat gain of **747 m^2**
- Boulder protection – a habitat gain of **674 m^2**
- Synthetic frond protection – a habitat gain of **84.5 m^2**

Through the colonisation of the tower itself by settling organisms and collected plankton, then the ecological usefulness of the surrounding water should also increase, as fish will be able to feed the entire height of the turbine. Therefore, the installation of the wind turbine and its related scour protection will be able to provide surfaces and shelter both horizontally and vertically, creating habitat for both pelagic and benthic organisms.

12. Measuring success at habitat creation

12.1 General considerations

For any habitat creation programme, whether intentional or indirect, as an offshore wind farm would be, it is important to be able to determine its success. Perhaps more importantly, it is also essential to be able to tell if a project is failing, and actually causing more damage than good to the surrounding environment. If the latter is the case, then it would determine whether further work was needed to prevent additional environmental damage. Within this, the concepts of habitat restoration, enhancement, mitigation and compensation are all relevant. Mitigation can be defined as "the act of making any impact less severe" (Elliott *et al*, 2007), which is what the aim of turning the wind farm foundations into artificial reefs is. However, it could also be seen as compensation, or "to make up or make amends for damage". Both mitigation and compensation strategies generally involve a certain level of habitat restoration or creation, and in some case, habitat enhancement, defined as "to raise in degree, heighten, intensify, or to increase the value, importance or attractiveness" of an area. All of these concepts are tied by subjective opinions however, for example, assuming that a three-dimensional habitat is will perform better ecologically than a two-dimensional habitat (Elliott *et al*, 2007). Objective methods of determining success or habitat creation are therefore required. Love and Schroeder (2006) proposed three main ways of determining the ecological performance of an oil rig compared to the natural habitat:

- Compare number of larvae produced;
- Comparison of health/growth rates;
- Comparison of mortality rates.

These could easily be adapted to compare performances of a wind turbine and its adjacent habitats, allowing a numerical evaluation of habitat creation and success. Another method to monitor success is to use the well established association between habitat complexity and biodiversity. Many studies have determined that spatial and temporal heterogeneity of ecosystems is vital for successful ecological processes to occur, and complex habitat structure has been linked to fish assemblage structures such as species composition, species richness and diversity (Garcia-Charton and Perez-Ruzafa, 1999).

12.2 Physical methods

One method to measure habitat complexity is a comparison of linear distance and step distance, i.e. the actual distance between two points, following the exact contours of the habitat. A simple way of doing this is to lay chains along the studied transect, but there are also complex calibrated step measuring systems, which are passed over transects, measuring the rugosity of the habitat. Different degrees of accuracy can be gained by using different sized wheels (Figure 14).

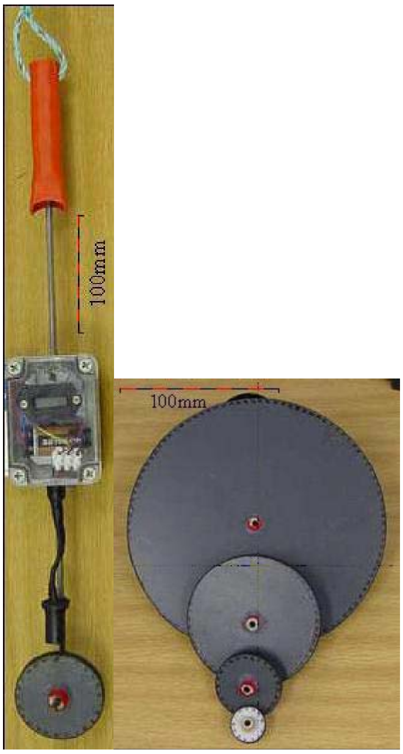

Figure 14 - Step distance measuring device, with detachable wheels for varying degrees of accuracy, taken from Wilding and Rose, poster

This method is more accurate than the previously most commonly employed method of visually assessing the habitat complexity, which is not accurate enough for scientific analysis, and has the added unreliability of being subjective.

12.3 Statistical analysis

In terms of statistical analysis, there are a number of indices which can be used, for both habitat and fish assemblage characteristics. These can then be compared and correlated. This information can determine which factors most influence successful colonisation and use of habitat, and therefore allow better use of materials and design in future wind farm developments.

<u>For habitat characteristics (Brokovich *et al*, 2006):</u>

- Rugosity index
- Cover complexity index
- Vertical relief index
- Average transect depth
- Percentages of each surface component

- Distance from shore/nearby features

Fish counts:

- Visual counts along set transect.

Analyses:

- Shannon-Weiner Index
- Margalef's Species Richness Index

For the most accurate statistical analysis, a number of methods should be employed, ensuring a higher level of validity for any conclusions drawn. It will also allow comparisons to be made with a wider range of similar habitats and situations.

12.4 Monitoring requirements

For any development, constant monitoring is important. Not only does it allow success to be measured, it can also give an early warning sign for any potential damage which is being caused to the environment. However, it must be ensured that any reference sites which are selected as comparison sites have the same ambient conditions, so that any conclusions drawn are valid. At the Horns Reef wind farm, this became a problem, as the reference locations were not initially able to be statistically compared, making it difficult to monitor progress at the wind farm site (Forward, 2005). A further complication for monitoring plans is that natural variations must be identified, so that changes in the environment due to, for example, storm surges, fishing, climate change and nutrient blooms may be separated from changes related specifically to the development of the offshore wind farm (Hiscock *et al*, 2002).

For the North Hoyle offshore development, the following were listed as a baseline for a monitoring programme in June 2003 (Website 4):

- Sediments monitored and classified.
- Suspended particulate matter levels measured.
- Benthic fauna sampling and identification.
- Diver surveys to monitor colonisation, performing grid counts on both the upstream and downstream sides of the tower, as well as collecting samples for identification verification.
- Annual trawl surveys in the surrounding area to monitor possible impacts on commercial stocks, plus a procedure for fishers to make known any problems, for example, reduced catches.

The 'horrendograms' illustrated in Figures 10 and 11 can also play a role in the design of monitoring programmes, as they allow those planning the sampling and analysis to see on one diagram the general areas they must consider. This can then be linked into the Environmental Statements to determine the relative importance of each monitoring scheme. For example, if the web of aspects and impacts shows that cabling must be laid through trenching, which would affect turbidity, and this is supported by studies in the Environmental Impact Assessment, then more effort can be put into ensuring that local benthic communities are not significantly adversely affected. Monitoring schemes can be highly expensive, and require a large amount of funding, generally from those bodies developing the offshore wind farm site. Therefore they must be carefully designed to target those areas and impacts which need the most attention, and not wasted. In other words, ensure the distinction is clear between “what information is needed” and what information it would simply “be nice to have” (Elliott, 2007).

13. Guidelines for future wind farm developments for maximum habitat creation

13.1 General considerations

As with any other aspect of developing the offshore wind farm, the design of the foundations will require careful planning, incorporating all the other aspects of the wind farm, for example economics, social acceptance, and whether new plans will potentially interfere with legitimate users and uses of the area, such as commercial fishermen. Therefore, it is vital that any new guidelines for the design of turbine foundations meet with the six tenets of environmental management (Table 10), as described by Elliott (2002).

Table 10 - The six tenets of environmental management,

Tenet	**Would the tenet be met by the design of a new, more environmentally-beneficial wind farm foundation?**
Environmentally sustainable	New designs must be able to contribute to surrounding ecosystems, and show benefit to the environment in the long term.
Technologically feasible	Even if a new design would be the perfect habitat for a particular group of species, if it is not possible to manufacture it, then it is pointless.
Economically viable	Should a design exceed the budget for foundations, then it will be impossible to install and make the wind farm viable
Socially desirable/tolerable	This is probably the easiest of the tenets to achieve, as it would be expected that most designs which would increase the benefit to the environment would be supported by the public.
Legally permissible	The plans for the foundations would have to be submitted and approved as part of the planning application, and therefore must fit any currently applicable legal criteria.
Administratively achievable	There is not much administrative work which would be affected by the changing of wind farm foundation designs

In addition to those in Table 10, a seventh tenet was added by Elliott *et al* (2007), stating that plans must also be politically expedient, or that the politicians of the current government must be willing to support them. This is particularly important in offshore wind farms, given that government grants may be provided to support their development. However, getting political support for a more environmentally effective solution to the scour protection issue should be possible given that green issues are currently high on the agenda of most political groups.

13.2 Potential application of modelling methods

The design of the foundations, and particularly the scour protection, which is potentially the easiest aspect to modify, to act as artificial reefs may be enhanced through modelling tools, for example the Deployment of Artificial Reef Communities, or DARC model (Lan and Hsui, 2006). This model is based on biologists' observations of biodiversity, and biomass, and allows engineers to design an artificial reef more effectively, determining the optimum materials and designs for maximum benefit to the surrounding environment. Two general conclusions from DARC are that a minimum reef area of 2-5km^2 is required to reach equilibrium and permit propagation, and that the optimal distance between artificial reefs is between 300 and 500m (Lan and Hsui, 2006). As most current major wind farms are covering areas of at least 10km^2 (Forward, 2005), and are due to cover larger areas with Round 2 developments, and within this area the turbines are usually built between 350m and 800m apart (Linley *et al*, 2007), they are able to meet this criteria and therefore should be able to be classed as beneficial to the environment under DARC.

Using tools such as DARC, along with expert judgement and the background data available, however minimal, it will be possible to put together a plan for each individual offshore wind farm in development. Managing to achieve design optimisation at the earliest stages of planning possible will bring about better colonisation prospects for target organisms at a later date, potentially benefiting all stakeholders (Linley *et al*, 2007).

13.3 Relation of wind farm area to surrounding ocean floor

One important conclusion from Patricio *et al* (2006) was that if a disturbed area is small compared to a surrounding non-disturbed area, then complexity will increase first, followed by biomass. However, if the reverse situation arises, biomass recovers first, followed by complexity (Patricio *et al*, 2006). In terms of wind farms, it may be said that compared to the surrounding ocean they are relatively small, which means they should see an initially small but complex community build up around them, with biomass increasing over time.

By observing which species currently exist in the area proposed for development, or even deciding at an early stage which species would be valuable to the area if attracted, it would be possible to 'target' certain groups of benthic species, which would ultimately attract a specific food chain into the foundation area. For example, if there is an existing crab or lobster potting fishery in the area, then the use of boulders and large cobbles to prevent scour would be the most beneficial, as it would mimic the natural habitat of such species, thereby potentially increasing local populations. This not only benefits the crab and lobster populations, but could increase financial gains for local fishermen and dependant businesses in the nearby coastal zone. As there is the general exclusion zone surrounding offshore wind farms also to be considered, then the areas would be able to act as indirect nature reserves, allowing the renewal and recovery of stocks, ensuring that in the long term neither the fishermen nor their target species were to suffer.

An extension of this could be the modification of foundation designs to match the surrounding natural habitat. For example, in shallow, sandy areas, the synthetic fronds could be deployed, as they support the build up of sediment around them, sometimes even becoming completely buried in areas with large amounts of sediment movement (Website 5). In coarser sediment areas, then gravel would be used, leaving the boulder protection for areas near natural rocky outcrops, or where predicted scour is at such a high level that they are required for high levels of protection. This would mean that the foundations and their scour protection were virtually acting as habitat improvement, not just mitigation of the construction and operational impacts, and would further contribute to the indirect nature reserve effect described above.

13.4 Alternative scour protection methods

Where higher level scour protection is required, then there are other options available than just boulders, which may be better at habitat provision by creating a wide range of crevices, which are where the highest levels of colonisation are generally found (Moreira *et al*, 2007). Examples of such options, illustrated in figure 15, are:

- Dolos blocks – weighing up to 20 tons each, and developed in South Africa mainly to build sea defences for coastal towns. Built from un-reinforced concrete, but may sometimes contain steel fibres for additional strength, which are added when the concrete is poured into the moulds.
- Tetrapods – developed in France, and again common in sea wall construction.

- Concrete jacks – consist of three long cement stakes, meeting in the middle. They can range in size, depending on constructors' needs, from 35kg to ten tonnes or more. They have many applications in the marine environment, from scour protection, to bridge piers and breakwaters.
- X blocs – again, consisting of un-reinforced concrete, and common in the construction of coastal defences. Designed in 2001, it is one of the newest additions to this type of material.

Figure 15 - Alternatives to boulders, from left to right - Dolos block (Website 7), tetrapod (Website 8) and concrete jack (Website 9)

These concrete shapes can be placed around the structures, and over the initial months after deployment are bedded down by the natural movements of the water until finding their resting place. Any of the above options would give a greater surface area and a wider range of habitats in comparison to the boulders. When used for sea walls and coastal defences, they are generally numbered on the outside of the pile, so that any movements can be traced, to give advance warning of potential collapse. Although collapse around the base of the wind turbine would be unlikely, this method could be employed to monitor any shifts in the sediment beneath the pile, or to ensure that levels of scour had not significantly altered.

For an even larger surface area, there are specially designed 'reef ball' modules (Figure 16), available in a range of sizes, including the 'goliath', 1.83m wide by 1.52m high, and of comparable size with the large boulders commonly used for scour protection, which are generally around 2m in diameter. These artificial boulders have been used in 50 countries to restore habitats, in both temperate and tropical environments, with great success, allowing rapid colonisation due to their design (Website 6). The afore-mentioned goliath reef ball has a surface area of 21.4m^2, just under double that of a boulder with a diameter of 2m (12.6m^2). They also have between 25 and 40 holes drilled into them, spaced randomly, which would satisfy the need for heterogeneity and habitat complexity for an area to perform successfully as an artificial reef (Perkol-Finkel *et al*, 2006).

Figure 16 - Reef Ball modules showing early colonisation, taken from Website 6

With a larger surface area, the reef balls would also be able to potentially dissipate energy greater around the area, providing more protection. They have also been proven to act as beneficial fish habitat, with a module of the goliath size having an estimated carrying capacity of 385kg of fish/year (Website 6). The surface area of the top of the goliath reef ball is 2.6m^2, meaning that in the 439.5m^2 area of scour protection around the base of the turbine there would be up to 169 reef balls in a single layer. It would be possible then, for this single layer to support approximately 65,000kg of fish per year, and when new offshore wind farms are anticipated to have upwards of 75 or even a hundred plus turbines (Centrica Energy, 2007), this amounts to a very high carrying capacity, much greater than would be expected from the open ocean floor. It must also be included that those values would not incorporate the wind turbine towers in their estimations, meaning that even larger populations could potentially be attracted to the area. As with any new proposed designs for wind farm foundations, economics must be considered. Compared to placing standard boulders around the base of the turbines, purchasing and installing the reef ball systems will be more expensive. If this cost is prohibitively high, then this will restrict the use of such materials, and therefore is something which requires further investigation into relative costs of installation, and potential gains, including increased revenue from recreational activities which 'use' the fish, or from commercial fisheries in the area which may be improved.

As has already been described in chapter 5, one way to avoid damage to the base of the turbine is to install the piling deeper into the sediment (Linley *et al*, 2007), thereby reducing the potential damage to the structure, even if scour does remove the upper layer of surrounding sediment. New designs of offshore wind turbines are beginning to take this into account, allowing for around a metre of sediment removal before any damage may be caused. This would reduce the need for such a large layer of scour protection of any method, or in low risk areas, such as the planned developments for off the Norfolk coast, none would be needed at all. As the foundations can take up an estimated 35% of the total installation costs of the wind farm (Villalobos *et al*, 2004), this could be advantageous economically as well as environmentally. No scour protection would mean the area of seabed lost would be purely the area of the base of the turbine, and the surrounding environment would not change significantly, with the main difference being potentially coarser sediment due to removal of the finer sediment. This could result in a reduced level of environmental impact, although the carrying capacity would not be greatly affected, meaning that the generally bare and sparsely populated open ocean floor would remain the dominant habitat.

13.5 Other factors to consider

Because one of the key points of an artificial reef is that it should produce new communities, rather than simply attracting existing life away from natural habitats (Perkol-Finkel and Benayahu, 2007), the timing of the construction of the offshore foundations is key. For example, for maximum benefit to the surrounding ecosystem, the foundations should be laid at the right time of the year to collect planktonic propagules which would otherwise drift by and potentially never settle and develop. Also, by orientating the foundations correctly, and placing the materials used in the correct fashion, a variety of hydrodynamic conditions will be created, which means a greater range of microniches available for colonisation (Linley *et al*, 2007).

To further increase habitat heterogeneity, which has been proven to be of high importance when attempting to attract high biodiversity (Perkol-Finkel *et al*, 2006), it would be beneficial to incorporate different methods of scour protection into the one offshore wind farm. For example, by encasing the bases of some turbines with boulder protection, and then surrounding others with the synthetic fronds and 5cm diameter gravel. This would enable a much wider array of species to be attracted to the development, enhancing the overall wind farm ecosystem.

13.6 Link back to ecological goods and services and potential impacts of an offshore wind farm

Referring back to the 'probable' impacts of an offshore wind farm according to the activities matrix (Appendix One), those which could potentially be reduced or prevented completely are:

- Loss of area from the seabed, water column and air space – although directly area will still be lost, the ecological usefulness and carrying capacity of the area can potentially be increased.
- Loss of substratum – despite the original substratum being lost to the turbines, by changing the substratum type through carefully designed scour protection would increase the habitat heterogeneity of the area and could potentially improve the area's biodiversity and levels of abundance.
- Productivity loss – if carrying capacity and ecological usefulness are increased, then productivity should also increase, bringing about benefits to the area.
- Non-selective abstraction of non-target species – if scour protection was carefully designed, then the loss of any species from the surrounding area could be reduced or even prevented, as well as the creation of new communities around the protected area.

If all of these impacts were prevented, the overall 'score' for developing an offshore wind farm would be reduced from 30 to 18. To see what the new comparable activities would be at this level of impact, again, those falling within two points either side of this value are listed:

- Sea level change through climate change, 17
- Groyne deployment for coastal defence, 18
- Water resources – abstraction, 19
- Marine netting fisheries, 20
- Potting or creeling, for example for lobster, 20
- Recreational angling, 17
- Waterfront land runoff, 18

Although many of these still have impacts on the marine environment, they are generally considered less damaging than, for example, the development of oil and gas exploration or abstraction. This can therefore provide evidence to indicate that with careful planning and consideration for ecological aspects, the installation of an offshore wind farm does not necessarily need to be an environmentally damaging operation. However, it is clear that in some ways the concepts behind the matrix are in need of further development, especially in terms of scale, as it is unlikely that any impact an offshore wind farm could have would reach the same scales as those resulting from sea level change through climate changes. This will be discussed in Chapter 14.

14. Conclusions

14.1 General conclusions

From the previous discussion of ways in which the negative environmental impacts of an offshore wind farm development could be reduced, and potentially even be made positive, the following answers to the original questions in this study can be produced:

- The construction and operation of offshore wind farms do have some environmental impact, such as disruption of the seabed and noise pollution, but many of these impacts are to a lesser extent than originally predicted. In particular, the potential risk to nearby avian populations has been shown to be much less than feared and publicised by certain groups. Furthermore, those impacts which do still exist may be reduced through good planning.
- Despite the loss of the existing seabed habitat to make way for the installation of the turbines, this loss is relatively small when compared to the remaining undisturbed habitat surrounding the wind farm.
- Through careful design of the required scour protection, new habitats can actually be created, which may be beneficial not only to the surrounding ecosystems and environment, but also potentially to local fishermen. These new habitats may act as artificial reefs, with the ability to enhance what would previously have been a relatively bare open ocean seabed.

This careful design has many aspects, but the main factors which should make the greatest difference in terms of habitat creation and environmental benefit include:

- A range of scour protection methods to be used within any individual offshore wind farm, including synthetic fronds, gravel and large boulders. This will mimic a broader range of natural habitats and increase habitat heterogeneity, which has been proven to aid increased biodiversity and abundance.
- Ensure that a large range of hydrodynamic niches are created for a wider range of species. This will allow both fast-flowing current and shelter preferring species to find habitats within the scour protection.
- Maximisation of surface area to allow maximum levels of colonisation of benthic organisms, which will then allow the development of a food web, leading up to supporting a diverse species community. Ensuring diversity within this could further increase colonisation, for example a range of smooth and pitted surfaces.

- The use of specially designed materials, such as reef balls, to maximise habitats and abundance.
- The matching of dominant scour protection methods to the existing local ecosystems and communities.
- Good planning in terms of timing, to ensure that the turbine foundations are in place to capture plankton and allow development of the earliest stages of the desired food webs.

The combination of all these factors should ensure that the construction of offshore wind farms need not necessarily have a detrimental impact on their surrounding environments, and actually have the potential to contribute to the environment. Their application could also potentially make the development of future, larger offshore wind farms easier to gain consent for, as their environmental argument would be strengthened.

Many of the conclusions drawn within this study are based on information which is still in its early days of development. Therefore some aspects suffer from a level of uncertainty. Because of this, it is essential that the described monitoring techniques are used, and the information gathered put to use developing the field and determining which of the methods and guidelines described would be the most environmentally beneficial.

14.2 Critique of methods used

Although the conclusions drawn from the work within this report are valid, there are potential factors to consider which would allow even higher levels of accuracy to be achieved. For example, the calculation of the minimum surface areas generated by each scour protection method could be improved through the creation of a three-dimensional model, which would also take into account the surface areas of the niches created between gravel and boulders, as well as being able to instantly recalculate given precise dimensions, as it is unlikely that all wind farm developments will always use exactly the same size of boulders for protection, as well as requiring different depths or diameters to suit their needs. It could also take further into account the size of the spaces between the boulders or gravel, from which a more accurate estimation of the species and number of organisms which would inhabit those spaces could be made. This would allow a better insight to the communities and ecosystems which would develop, and how other aspects could potentially be managed to further improve the situation.

The activities matrix and cluster analysis (Appendix One) could also have their problems, which would need to be improved on for future, more valid use. For example, with only three options (no expected impact, possible impact and probable impact), the analysis was not able to be at its most accurate. Also, the concept of relative impact 'scores', to relate the impact of an offshore wind farm to similarly impacting activities may allow comparison by overall values, but does not allow the profile of impacts to be compared, which would group activities even more closely. Currently, the model makes no distinction, for example, between those activities which impact heavily on the biological environment and those which are basically very large inputs into the marine environment. Possible ways to improve the accuracy and validity of both the matrix and its resulting cluster analysis will be discussed later in this section.

For the calculations completed in Chapter 11, an average for each wind farm was calculated, and then this value itself averaged for the total number of turbines considered. Using this method may have reduced the accuracy of the calculations, as the range of water depths (5 to 12m), means that there will be a much larger range of surface areas and volumes created or removed by each individual wind farm. However, this slight discrepancy could be removed through the development of accurate models, as described later in this chapter, which, as well as taking on board information regarding the receiving environment, would also include data on water depth and the diameters of the foundations used.

14.3 Suggestions for future work – gathering of new data

As with all environmental projects, reliable and quantitative data is essential to ensure that the correct decisions are made. As the wind farm industry is still relatively young, there are very few sets of fully quantified data to support or refute any claims of foundations and towers acting as artificial reefs (Elliott, 2002). This problem of a lack of data means that quantitative estimates of colonisation and new communities are very difficult to produce. Many of the values used within this report have been best estimates by researchers, using comparable situations and experiments, and therefore their accuracy may not always be significant.

Where studies have been carried out, some have been shown to contradict predicted impacts. For example, one of the operational impacts predicted by the 'horrendogram' in Elliott (2002) was the loss of sand eel habitat, and yet at the Horns Reef installation off Denmark's coast, there was found to be a significant increase in sand eel populations compared to a slight drop at control sites (Forward, 2005). The same has been found for bird impacts, with mortality rates being found to be much lower than anticipated (Parkinson, 1999).

With so many early concerns about offshore wind farms being shown to be significantly lower than originally thought, what is needed is a highly detailed study of the colonisation and impacts of a test wind farm, using the concepts described in this report, with different methods of scour protection, along with carefully planned timing and design of the protection deployment. By doing this, it will be possible to determine which factors best contribute to a successful colonisation and community development, and take these forward to future offshore wind farms.

This gathering of data would need to be targeted to those areas where the highest levels of uncertainty could exist. For example, the sand eel population increasing around the Horns Reef wind farm could lead to an increase in predators of the sand eels, thereby altering the species composition of the area in an unexpected way. It could also impact upon the number of birds in an area, if their prey species blooms in abundance, resulting in a greater avian population, and potentially increasing the risk of collision.

14.3 Development of accurate and relevant models

Potentially the best way to get the best results from the monitoring would be to develop a numerical model which links the scour protection methods used around the turbines directly to the types of habitat they mimic, and determines how much of each habitat would be created, depending on the size of wind farm proposed. By combining this information with the results of the detailed colonisation studies, then a more accurate calculation of the environmental gains and losses could be achieved. This could be done for each individual wind farm, supported by studies as to which habitat types are already present, allowing the production of an even more accurate environmental statement, matching the area's environmental needs, reducing damage to the surrounding habitats, and easing the decision as to whether the wind farm is granted development consent or not. The above problem of species compositions being altered could also potentially be included into the models, for example, predicting any possible rises in bird populations due to increased abundance of their food species. By modelling the habitat types which are being created, and predicting the new inhabiting species, it will also be possible to predict any influxes of new species, such as larger marine predators, for example seals or other marine mammals.

14.4 Improvement of the activities matrix and cluster analysis

The concept of the activities matrix and subsequent statistical analysis by cluster analysis (Appendix One) could also be adapted and improved, several options which would increase its usefulness and validity. The cluster analysis run on the data would be more accurate if there were a wider range of options for the level of impact. For example, instead of only 0 = No expected impact; 1 = Possible impact and 2 = Probable impact, there could be an additional level of 3 = Certain impact, such as alteration of sediment through dredging, which is not probable, it is a certainty. Extending the range to these four levels of impact would further increase accuracy in the clustering and validity of the analysis. The addition of the temporal and spatial scales would also be beneficial. Currently, the loss of area from the seabed is classed as a probable impact of both the installation of an offshore wind farm, and sea level change due to climate change. However, it is clear that in terms of area, sea level change is a much wider-ranging impact, compared to seabed loss from a wind farm, which is a relatively small area compared to the surrounding ocean. Therefore it would seem inappropriate to have the two listed as having the same level of impact.

Another way the matrix could be adapted to analyse the impacts of various marine activities would be to analyse the diversity of the impacts each activity causes, and potentially link this in to the types of activity. For example, the question could be asked whether the most damaging activities are those which have the highest abundance of physical impacts in their impact profile, or do chemical impacts cause the most damage, as they may indirectly alter the biological factors as well?

The cluster analysis could also be able to show the result of mitigation, and how this reduces the impact of offshore wind farms in both absolute and relative terms, as described previously.

14.5 Inclusion of other foundation methods and scour protection materials

The monopile foundation, despite currently being the most commonly used method, especially around the UK coastline, is not the only option for offshore wind farm developers. With a move further offshore into deeper water, the tripod method in particular may become more prevalent. Therefore, it would be beneficial to repeat the calculations and work done in this report, which was based on the shallower monopile designs, for tripod or gravity caisson designs. Also, as more research is carried out in the area, new materials may become dominant over the steel currently used, which would potentially have an impact on predicted communities.

Another factor which could be investigated is the impact of the maintenance which is carried out on the turbines. Currently, sand or high pressure water blasting are the most commonly used methods for the removal of organisms should the layers become too great, and this could impact on the whole wind farm community through the removal of the lower levels of the food web. Only when its resilience to disturbances is tested, will the strength and longevity of the colonising community be proven, and whether it has developed its own ecosystem or taken away from that of the surrounding area.

15. References

Ackermann, T. and Soder, L. (2002) An overview of wind energy status, 2002. *Renewable and Sustainable Energy Reviews* 6 pgs. 67-127

AMEC Wind Energy (2007) Information provided by Glen Evertson via personal email.

Anthoni, F. (2006) Invasion of the parchment worm. Found online at www.seafriends.org.nz/indepth/invasion.htm. *Accessed 24/08/2007*

Arntz, W. E. and Rumohr, H. (1982) An experimental study of macrobenthic colonisation and succession, and the important of seasonal variation in temperate latitudes. *Journal of Experimental Marine Biology and Ecology* 64 pgs. 17-45

Beaumont, N. J., Austen, M. C., Atkins, J. P., Burdon, D., Degraer, S., Dentinho, T. P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, A. H., Starkey, D. J., Townsend, M. and Zarzycki, T. (2007) Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. *Marine Pollution Bulletin* 54 pgs. 253-265

Bishop, I. D. and Miller, D. R. (2007) Visual assessment of offshore wind turbines: the influence of distance, contrast, movement and social variables. *Renewable Energy* 32 pgs. 814-831

Blockley, D. J. (2007) Effect of wharves on intertidal assemblages on seawalls in Sydney Harbour, Australia. *Marine Environmental Research* 63 pgs. 409-427

Bonnar, R. (2007) Personal communication through email, re the scour protection used around wind farm foundations. *Received 15/08/2007*

Boyle, G. (2006) UK offshore wind potential – how offshore wind could supply a quarter of UK electricity by 2024. *Refocus* 7 pgs. 26-29

Bram, J. B., Page, H. M. and Dugan, J. E. (2005) Spatial and temporal variability in early successional patterns of an intertebrate assemblage at an offshore oil platform. *Journal of Experimental Marine Biology and Ecology* 317. 223-237

Brokovich, E., Baranes, A. and Goren, M. (2006) Habitat structure determines coral reef fish assemblages at the northern tip of the Red Sea. *Ecological Indicators* 6 pgs. 494-507

Bulleri, F. (2005) Experimental evaluation of early patterns of colonisation of space on rocky shores and seawalls. *Marine Environmental Research* 60 pgs. 355-374

BWEA (2004) British Wind Energy Association Recommendations for Fisheries Liason. Found at www.bwea.com. *Accessed 19/06/2007*

BWEA (2005) British Wind Energy Association Briefing sheet – Offshore wind. Found at www.bwea.com/pdf/briefings/offshore05_small.pdf. *Accessed 18/07/2007*

Chapman, M. G. (2006) Intertidal seawalls as habitat for molluscs. *Journal of Molluscan Studies* 72 pgs. 247-257

Centrica Energy (2007) Lincs Offshore Wind Farm Environmental Statement – non-technical summary. Available online at www.centrica.co.uk/renewables

Dolman, S. J., Simmonds, M. P. and Keith, S. (2003) Marine wind farms and cetaceans. Whale and Dolphin Conservation Society report no. IWC/SC/55/E4, presented at the 2003 International Whaling Commission. Found at www.wdcs.org *Accessed 18/08/2007*

Elliott, M. (2002) The role of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. (Editorial) *Marine Pollution Bulletin* 44 iii-vii

Elliott, M. (2007) Lectures delivered as part of MSc Estuarine and Coastal Science and Management, at the University of Hull.

Elliott, M., Burdon, D., Hemingway, K. L. and Apitz, S. E. (2007) Estuarine, coastal and marine ecosystem restoration: Confusing management and science – A revision of concepts. *Estuarine, Coastal and Shelf Science* 74 pgs. 349-366

Evertsen, G. M. (2007) Personal communication through email, re the scour protection used around wind farm foundations. *Received 20/08/2007*

Fayram, A. H. and de Risi, A. (in press) The potential compatability of offshore wind power and fisheries: an example using bluefin tuna in the Adriatic Sea. *Ocean and Coastal Management*

Flin, D. (2005) Offshore wind: all at sea. *Energy Focus* 4. Found at www.energy-focus.com *Accessed 17/08/2007*

Forward, G. (2005) The potential effects of offshore wind power facilities on fish and fish habitat. Algonquin Fisheries Assessment Unit, Ontario Ministry of Fisheries Resources. Found at ozone.scholarsportal.info *Accessed 18/08/2007*

Frid, C. and Paramor, O. (2006) Marine Biodiversity – the rationale for intervention: Building the evidence base for the Marine Bill. DEFRA report on www.defra.gov.uk. *Accessed 05/07/2007*

Friedlander, A. M. and Parrish, J. D. (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. *Journal of Experimental Marine Biology and Ecology* 224 pgs. 1-30

Garcia-Charton, J. A. and Perez-Ruzafa, A. (1999) Ecological heterogeneity and the evaluation of the effects of marine reserves. *Fisheries Research* 42 pgs 1-20

Hiscock, K., Tyler-Walters, H. and Jones, H. (2002) High level environmental screening study for offshore wind farm developments – Marine Habitats and Species Project. Report from the Marine Biological Association to the Department for Trade and Industry New and Renewable Energy Programme.

Houlsby, G. T., Byrne, B. W. and Martin, C. M. (2001) Novel foundations for offshore wind farms. Research proposal to EPSRC

Jager-Waldow, A. (2007) Photovoltaics and renewable energies in Europe. *Renewable and Sustainable Energy Reviews* 11 pgs. 1414-1437

Kaiser, M. J. (2002) Predicting the displacement of common scotor *Melanitta nigra* from benthic feeding areas due to offshore wind farms. Executive summary of COWRIE funded report.

Kopp, D., Bouchon-Navaro, Y., Louis, M. and Bouchon, C. (2007) Diel differences in the sea grass fish assemblages of a Caribbean island in relation to adjacent habitat types. *Aquatic Botany* 87 pgs. 31-37

Krohn, S. and Damborg, S. (1999) On public attitudes towards wind power. *Renewable Energy* 16 pgs. 954-960

Lan, C.-H. and Hsui, C.-Y. (2006) The deployment of artificial reef ecosystem: modelling, simulation and application. *Simulation Modelling Practise and Theory* 14 pgs. 663-675

Linley, E. A. S., Wilding, T. A., Black, K. D., Hawkins, A. J. S. and Mangi, S. (2007) Review of the reef effects of offshore wind farm structures and potential for enhancement and mitigation. Report from PML Applications Ltd. to the Department of Trade and Industry. Contract no. RFCA/005/0029P

Linnane, A., Mazzoni, D. and Mercer, J. P. (2000) A long term mesocosm study on the settlement and survival of juvenile European lobster *Homarus gammarus* in four natural substrata. *Journal of Experimental Marine Biology and Ecology* 249 pgs 51-64

Love, M. S. and Schroeder, D. M. (2006) Ecological performance of OCS platforms as fish habitat off California. Marine Science Institute, University of California. MMS Study 2004-005. MMS Co-operative Agreement Number 1435-01-03-CA-72694

Manwell, J. F., Elkinton, C. N., Rogers, A. L. and McGowan, J. G. (2007) Review of design conditions applicable to offshore wind energy systems in the United States. *Renewable and Sustainable Energy Reviews* 11 pgs. 210-234

Moreira, J., Chapman, M. G. and Underwood, A. J. (2007) Maintenance of chitons on sea walls using crevices on sandstone blocks as habitat in Sydney Harbour, Australia. *Journal of Experimental Marine Biology and Ecology* 347 pgs. 134-143

Myrberg, A. A. (1990) The effects of man made noise on the behaviour of marine animals. *Environment International* 16 pgs. 575-586

Negra, N. B., Todorovic, J. and Ackermann, T. (2006) Loss evaluation of HVAC and HVDC transmission solutions for large offshore wind farms. *Electric Power Systems Research* 76 pgs. 916-927

Neira, F. J. (2005) Summer and winter plankton fish assemblages around offshore oil and gas platforms in south-eastern Australia. *Estuarine, Coastal and Shelf Science* 63 pgs. 589-604

Norfolk Offshore Wind (2002) Cromer Offshore Wind Farm: Environmental Statement

OSPAR Commission (2004) Problems and benefits associated with the development of offshore wind farms. Biodiversity Series.

Parkinson, K. M. (1999) Environmental consequences of offshore wind power generation. Dissertation submitted as part of MSc Estuarine and Coastal Science and Management, University of Hull.

Patricio, J., Salas, F., Pardal, M. A., Jorgenson, S. E. and Marques, J. C. (2006) Ecological indicators performance during a re-colonisation field experiment and its compliance with ecosystem theories. *Ecological Indicators* 6 pgs. 43-57

Percival, S. M. (2001) Assessment of the effects of offshore wind farms on birds. Report written as part of the Dept. of Trade and Industry's Sustainable Energy Programme, by Ecology Consulting.

Perkol-Finkel, S. and Benayahu, Y. (2007) Differential recruitment of benthic communities on neighbouring artificial and natural reefs. *Journal of Experimental Marine Biology and Ecology* 340 pgs. 25-39

Perkol-Finkel, S., Shashar, N., and Benayahu, Y. (2006) Can artificial reefs mimic natural reef communities? The roles of structural features and age. *Marine Environmental Research* 61 pgs. 121-135

Pihl, L., Baden, S., Kautsky, N., Ronnback, P., Soderqvist, T., Troell, M. and Wennhage, H. (2006) Shift in fish assemblage structure due to the loss of sea grass *Zostera marina* habitat in Sweden. *Estuarine, Coastal and Shelf Science* 67 pgs. 123-132

Reynolds, P. (2006) Energy and the new power play. ***BBC News Online***. *Accessed 12/09/2007*

Sinden, G. (2007) Characteristics of the UK wind resource: long term patterns and relationship to electricity demand. *Energy Policy* 35 pgs. 112-127

Stachowitsch, M., Kikinger, R., Herler, J., Zolda, P. and Geutebruck, E. (2002) Offshore oil platforms and fouling communities in the southern Arabian Gulf (Abu Dhabi). *Marine Pollution Bulletin* 44 853-860

Still, D. (2001) Offshore wind at Blyth. *Renewable Energy* 24 pgs. 545-551

Talisman Energy UK Ltd. (2006) Beatrice Wind Farm Demonstrator Project: Environmental Statement.

Teske, S. (2000) (Editor in Chief) Greenpeace Study: North Sea offshore wind – A powerhouse for Europe: technical possibilities and ecological considerations.

The Energy Review (2002) at www.cabinetoffice.gov.uk

Thomson, F., Ludemann, T., Kafeman, R. and Piper, W. (2006) Effects of offshore wind farm noise on marine mammals and fish. Report funded by COWRIE (Collaborative Offshore Wind Research into the Environment). Found at www.offshorewind.co.uk *Accessed 13/07/2007*.

UK Offshore Wind (2001) Anatomy of a wind farm project – part 2. *Refocus* 2 pgs. 39-40

Villalobos, F. A., Houlsby, G. T. and Byrne, B. W. (2004) Suction caisson foundations for offshore wind turbines. Proceedings – 5th Chilean Conference of Geotechnics, Santiago. Found at www.civil.eng.ox.ac.uk/people/gth/c/c81.pdf *Accessed 02/09/2007*

Voogt, M. H. and Uyterlinde, M. A. (2006) Cost effects of international trade in meeting EU renewable energy targets. *Energy Policy* 34 pgs. 352-364

Wilding, T. and Rose, C. (poster) The Loch Linnhe Artificial Reef – Measuring habitat complexity. Scottish Association for Marine Sciences and Newcastle University, joint project running from 2000-2012

Websites

Website 1 - http://www.csgnetwork.com/surfareacalc.html - Surface area calculator. *Accessed 26/07/2007*.

Website 2 – http://www.hornsrev.dk/Engelsk/default_ie.htm - Details of the construction of the Horns Reef offshore wind farm, Denmark. *Accessed 05/07/2007*.

Website 3 – http://www.jncc.gov.uk/marine/biotopes/biotope.aspx?biotope=JNCCMNCR00001942 – JNCC biotope description of biotope SS.SCS.ICS.SSh. *Accessed 04/08/2007*.

Website 4 – http://www.npower-renewables.com/northhoyle/index.asp. Details of the baseline monitoring methods for the North Hoyle offshore wind farm. *Accessed 04/07/2007*

Website 5 - http://www.scourcontrol.co.uk/ScientificDevelopment/tabid/106/Default.aspx. Details of the synthetic fronds method of scour protection. *Accessed 22/08/2007*

Website 6 - http://www.reefball.org/. The Reef Ball Foundation, with technical specifications of the reef modules. *Accessed 30/08/2007*

Website 7 – http://www.mieliestronk.com/sauitvind.html. Diagram of the Dolos block. *Accessed 02/09/2007*

Website 8 – http://www.perdanga.lt/index_.php?4;111351746. Diagram of the tetrapod structures. *Accessed 02/09/2007*

Website 9 – http://en.wikipedia.org/wiki/Xbloc. Diagram of the X-bloc. *Accessed 02/09/2007*

Website 10 – http://www.jncc.gov.uk/marine/biotopes/biotope.aspx?biotope=JNCCMNCR00002085. JNCC biotope description of biotope SS.SSa.OSa. *Accessed 10/09/2007*

Website 11 – http://www.national-aquarium.co.uk/scylla/index.asp. Details of the Scylla artificial reef. *Accessed 11/09/2007*

Website 12 – http://www.divingbc.com/cape_breton.htm. Details of the Cape Breton artificial reef. *Accessed 11/09/2007*

Website 13 - http://science.howstuffworks.com/wind-power2.htm. Details of a wind turbine. *Accessed 12/09/2007*

Appendix One

		ENVIRONMENTAL PRESSURES																															
		Physical																		Chemical							Biological						
																											Modification					Extractio	
Coastal & Maritime Activities/Events	Sub-activities / events	Loss of Area (seabed)	Loss of Area (water column)	Loss of Area (airspace)	Substratum loss	Smothering	Changes in suspended sediment	Desiccation	Changes in emergence regime	Changes in water flow rate	Changes in currents	Changes in temperature	Changes in turbidity	Changes in wave exposure	Noise disturbance	Visual presence	Abrasion / physical disturbance	Displacement	Water abstraction	Synthetic compound contamination	Heavy metal contamination	Hydrocarbon contamination	Radionuclide contamination	Changes in nutrient levels	Changes in salinity	Changes in oxygenation	Introduction of microbial pathogens / parasites	Introduction of non-native species	Productivity loss	Productivity gain	Loss of carrying capacity	Selective extraction of target species	Selective extraction of non-target species
Aquaculture	Fin-fish	2	2	0	0	2	2	0	0	2	2	0	2	0	1	1	2	0	0	2	0	0	0	2	0	2	2	2	2	2	2	0	0
	Macro-algae	2	2	0	0	1	1	0	0	1	2	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1	2	2	2	2	2	2	2
	Predator control	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0
	Shellfisheries	2	2	0	0	2	2	0	0	2	1	0	2	0	2	2	2	0	1	2	0	0	0	2	0	2	2	2	2	2	2	2	2
Climate Change	Current change	2	2	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	1	0	2	2	1	1	1	0	0
	Sea level change	2	2	0	0	0	0	2	2	2	2	0	0	2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	Temperature change	0	0	0	0	0	0	2	0	0	2	2	2	0	0	0	0	0	1	0	0	0	0	2	0	2	2	2	2	2	1	0	0
	Weather pattern change	0	0	0	0	0	0	2	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
Coastal defence	Barrage	2	2	0	2	2	2	2	2	2	2	0	2	2	2	2	2	2	1	1	1	1	0	2	2	2	0	0	1	1	2	0	0
	Beach replenishment	2	1	0	1	2	2	2	2	2	0	0	2	2	2	2	2	2	0	1	1	1	0	2	0	2	0	0	1	0	1	0	0
	Groynes	1	1	0	1	1	2	2	0	2	2	0	2	2	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Sea walls / breakwaters	2	1	0	1	1	2	2	2	2	2	0	2	2	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
Collecting	Bait digging	1	0	0	2	2	2	2	0	0	0	0	2	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
	Bird eggs	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
	Curios	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	Higher plants	0	0	0	2	0	2	0	0	2	0	0	0	0	2	2	2	2	0	0	0	0	0	2	0	0	0	0	2	0	2	2	2
	Kelp & wrack harvesting	0	0	0	2	0	2	2	0	2	1	0	2	2	2	2	2	2	0	0	0	0	0	2	0	2	0	0	2	0	2	2	2
	Macro-algae	0	0	0	2	0	0	2	0	2	0	0	0	0	2	2	2	2	0	1	0	0	0	0	0	0	0	0	2	0	2	2	2
	Peelers (boulder turning)	1	0	0	0	2	0	2	2	2	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
	Shellfish	0	0	0	2	2	2	2	0	0	0	0	2	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2
Development	Construction phase	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	0	1	1	1	1	2	2	2	0	0	2	0	2	0	0
	Artificial reefs	2	2	0	0	1	2	0	0	2	2	0	2	2	0	0	0	0	0	1	1	1	0	2	2	2	0	0	2	2	0	0	0
	Communication cables	2	0	0	0	1	2	0	0	2	1	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

	Culverting lagoons	1	2	0	0	0	2	2	2	2	2	2	2	1	0	0	0	0	1	0	0	0	0	2	2	2	0	0	1	1	2	0	0
	Dock / port facilities	2	2	1	0	2	2	0	0	2	2	1	2	2	2	2	2	2	1	2	1	2	1	2	1	2	2	2	2	0	2	0	0
	Land claim	2	2	1	2	2	2	2	2	2	2	0	2	2	0	0	0	0	1	0	0	0	0	2	2	2	0	0	2	0	2	0	0
	Marinas	1	2	2	0	2	2	2	1	2	1	1	2	2	2	2	2	2	0	2	1	2	0	2	0	2	2	2	1	0	2	0	0
	Oil & gas platforms	2	2	2	0	2	0	0	0	2	1	0	2	0	2	2	2	0	0	2	2	2	0	2	0	2	0	0	1	0	2	0	0
	Urban	1	1	2	0	0	2	0	0	0	1	0	2	0	2	2	2	0	1	2	2	2	0	2	2	2	2	0	1	0	1	0	0
Dredging	Capital dredging	2	0	0	2	2	2	2	2	2	2	0	2	2	2	2	2	2	0	1	1	1	1	2	1	2	0	0	2	0	2	0	0
	Maintenance dredging	1	0	0	2	2	2	0	0	0	2	0	2	0	2	2	2	2	0	1	1	1	1	2	0	2	0	0	1	0	1	0	0
Energy generation	Nuclear power generation	2	2	1	0	1	2	0	0	0	2	2	2	0	2	2	0	0	2	2	1	0	1	2	1	0	2	0	2	0	2	0	0
	Power stations	2	2	1	0	1	2	0	0	0	2	2	2	0	2	2	0	0	2	2	2	1	0	2	1	0	2	0	2	0	2	0	0
	Renewable (tide/wave)	2	2	0	0	1	1	1	1	2	2	0	1	2	1	1	0	0	1	2	0	1	0	0	0	1	0	0	1	0	1	0	0
	Wind farms	2	2	2	2	0	0	0	0	2	2	0	0	2	2	2	2	2	0	1	1	1	0	0	0	0	0	0	2	0	1	0	0
Extraction	Maerl	1	0	0	2	2	2	0	0	2	0	0	2	0	2	2	2	2	0	0	0	0	0	2	0	2	0	0	2	0	2	2	2
	Rock / mineral (coastal quarrying)	1	1	0	2	2	2	0	0	0	1	0	2	0	2	2	2	2	1	2	2	2	0	2	0	2	0	0	2	1	2	0	0
	Oil & gas platforms	2	2	2	0	2	0	0	0	2	1	0	2	0	2	2	2	0	0	2	2	2	0	2	0	2	0	0	1	0	2	0	0
	Sand / gravel (aggregates)	1	0	0	2	2	2	0	0	2	1	0	2	1	2	2	2	2	0	1	1	1	1	2	0	2	0	0	2	0	2	0	0
	Water resources (abstraction)	0	1	0	0	0	0	1	1	2	1	0	0	0	0	0	0	0	1	0	0	0	0	2	2	2	0	0	2	0	2	0	0
Fisheries / Shellfisheries	Benthic trawls (e.g. scallop dredging)	1	0	0	2	2	2	0	0	0	0	0	2	0	2	2	2	2	0	1	1	1	0	2	0	2	0	0	2	0	2	2	2
	Netting (e.g. fixed nets)	0	1	0	0	0	0	0	0	0	1	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2
	Pelagic trawls	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2
	Potting / creeling	1	0	0	0	2	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2
	Suction (hydraulic) dredging	1	0	0	2	2	2	0	0	0	0	0	2	0	2	2	2	2	0	1	1	1	0	2	0	2	0	0	2	0	2	2	2
Recreation	Angling	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0	0	0	0	2	0	2	2	2
	Boating /yatching	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	2	0	0	2	1	2	0	2	0	2	2	2	0	0	0	0	0
	Diving / dive site	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0
	Public beach	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0
	Tourist resort	0	0	0	0	0	2	0	0	0	0	0	2	0	2	2	2	0	2	2	2	2	0	2	0	2	0	0	0	0	0	0	0
	Water sports	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0
Uses	Animal sanctuaries	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
	Archaeology	0	0	0	2	2	2	0	0	0	0	0	2	0	2	2	2	2	0	1	1	1	0	2	0	2	0	0	0	0	0	0	2
	Coastal farming	0	0	0	0	2	2	0	0	0	0	0	2	0	2	2	2	0	0	2	1	2	0	2	0	2	1	0	1	0	1	0	0
	Coastal forestry	0	0	0	0	2	2	0	0	0	0	0	2	0	2	2	2	0	0	2	1	2	0	2	0	2	0	0	0	0	0	0	0
	Education / interpretation	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	Military	1	1	1	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0
	Mooring / beaching / launching	2	1	0	0	2	2	0	0	2	1	0	2	0	2	2	2	2	0	2	1	0	0	0	0	0	1	1	0	0	0	0	0
	Research	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	2	1	0	1	1	1	0	1	0	0	1	1	2	0	2	2	1
	Shipping	0	0	0	0	1	2	0	0	0	0	0	2	0	2	2	2	2	2	2	2	2	0	2	0	2	2	2	2	0	2	0	0
Wastes	Fishery & agricultural wastes	0	1	0	0	2	2	0	0	0	0	0	2	0	0	0	0	0	1	2	0	0	0	2	0	2	2	0	2	2	1	0	0
	Industrial effluent discharge	0	1	1	0	2	2	0	0	0	0	0	2	0	0	0	0	0	1	2	2	2	0	2	0	2	0	0	1	1	2	0	0
	Industrial / urban emissions (air)	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	0	0
	Inorganic mine and particulate wastes	0	1	0	0	2	2	0	0	0	0	0	2	0	0	0	2	0	1	1	2	1	1	2	0	2	0	0	1	1	2	0	0
	Land / waterfront runoff	0	0	0	0	2	2	0	0	0	0	0	2	0	0	0	0	0	0	1	1	1	0	2	2	2	0	0	1	1	1	0	0
	Litter and debris	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	Nuclear effluent discharge	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	0

	Sewage discharge	0	1	0	0	2	2	0	0	0	0	0	2	0	0	0	0	0	1	2	2	2	1	2	0	2	2	0	0	2	1	0	0
	Shipping wastes	0	0	0	0	1	2	0	0	0	0	0	2	0	0	0	0	0	1	2	2	2	0	2	0	2	2	2	1	1	1	0	0
	Spoil dumping	0	0	0	0	1	2	0	0	0	0	0	2	0	0	0	1	0	0	1	1	1	1	2	0	2	0	0	0	0	1	0	0
	Thermal discharges (cooling water)	0	1	0	0	0	2	0	0	0	1	2	2	0	0	0	0	0	1	2	2	1	0	0	1	2	1	1	1	1	1	0	0
Other	Removal of substratum	0	0	0	2	2	2	1	1	1	0	0	2	1	2	2	2	2	0	1	1	1	0	2	0	2	0	0	2	1	2	0	0

Key: 2 Probable effect; 1 Possible effect; 0 No expected effect