BERR | Department for Business Enterprise & Regulatory Reform

REVIEW OF REEF EFFECTS OF OFFSHORE WIND FARM STRUCTURES AND POTENTIAL FOR ENHANCEMENT AND MITIGATION

JANUARY 2008

IN ASSOCIATION WITH

defra

Review of the reef effects of offshore wind farm structures and potential for enhancement and mitigation

Report to the Department for Business, Enterprise and Regulatory Reform

PML Applications Ltd in association with Scottish Association of Marine Sciences (SAMS)

Contract No : RFCA/005/00029P

This report may be cited as follows:

Linley E.A.S., Wilding T.A., Black K., Hawkins A.J.S. and Mangi S. (2007). Review of the reef effects of offshore wind farm structures and their potential for enhancement and mitigation. Report from PML Applications Ltd and the Scottish Association for Marine Science to the Department for Business, Enterprise and Regulatory Reform (BERR), Contract No: RFCA/005/0029P

Acknowledgements

The Review of Reef Effects of Offshore Wind Farm Structures and Potential for Enhancement and Mitigation was prepared by PML Applications Ltd and the Scottish Association for Marine Science. This project was undertaken as part of the UK Department for Business, Enterprise and Regulatory Reform (BERR) offshore wind energy research programme, and managed on behalf of BERR by Hartley Anderson Ltd. We are particularly indebted to John Hartley and other members of the Research Advisory Group for their advice and guidance throughout the production of this report, and to Keith Hiscock and Antony Jensen who also provided detailed comment on early drafts. Numerous individuals have also contributed their advice, particularly in identifying data resources to assist with the analysis. We are particularly indebted to Angela Wratten, Chris Jenner, Tim Smyth, Mark Trimmer, Francis Bunker, Gero Vella, Robert Thornhill, Julie Drew, Adrian Maddocks, Robert Lillie, Tony Nott, Ben Barton, David Fletcher, John Leballeur, Laurie Ayling and Stephen Lockwood – who in the course of passing on information also contributed their ideas and thoughts. We are also grateful to BERR for providing us with the opportunity to undertake what has proved to be an interesting and rewarding research project.

Executive Summary

The purpose of this report is to review the likely reef effects of offshore wind farm (OWF) structures focussing on two aspects of their physical presence: firstly, the likely reef effects on fish, shellfish and other marine biota and secondly, the potential to enhance the reef effect for commercially significant species.

The report begins with a literature review of the factors which control colonisation of structures in the marine environment, and describes the characteristics of the subsequent succession and climax communities. Predictions of the enhanced habitat opportunities for commercially important species (such as mussels, lobster, crab and finfish) associated with OWFs in the UK, were then considered. We used a combination of existing data resources and an understanding of the life cycles, food requirements and physiology of the target species, together with simple mathematical considerations, to assess whether such opportunities might present themselves, either through provision of shelter or rocky substrata on which to settle, and/or adequacy of food supply. We have extended our analysis to include some preliminary observations on the aquaculture potential of OWFs. The report also considers the potential offered by the footprints of OWF, together with their turbine structures and associated scour protection, to enhance the opportunities for local fisheries, either through enhanced habitat opportunities for commercial species or through the development of ‘no-take’ areas.

As a general rule, our analysis shows that for each Round 2 OWF site identified, we are able to recommend, on the basis of predictions from existing data, the development of commercial activities which are likely to yield useful outcomes and identify others which are unlikely to succeed. However, more detailed site based investigations would be needed to verify the predictions before developing any enterprise commercially.

The following table summarises the potentially enhancing/mitigation effects of OWF structures and their associated scour protection for individual species, and provides further comment on potential with regard to fisheries management measures. These tentative assessments can be updated as further information becomes available to ground-truth the predictions.

Table 1: Summarising the potentially enhancing/mitigation effects of OWF structures and their associated scour protection in Round 2 areas

	North-west (Solway to North Wales coast)	The Greater Wash (Wash to Humber)	Thames Estuary
Potentially enhancing effects of artificial reefs			
Cancer pagurus[1,2]	+	+	+
Homarus gammarus[1,2]	+	+	+
Mytilus edulis[1,2,4]	0 to +	0 to +	0 to (+)
Crassostrea gigas[1,2,4]	0 to +	0 to +	0 to (+)
Laminariales[1,2,3,5]	+	+	0
Finfish[1,2,5]	0 to +	0 to +	0 to +
Note: + positive; – negative; 0 neutral			

1 Evidence from baseline surveys (diverse sites and sources); 2 Evidence from Post construction monitoring surveys; 3 Evidence from wind farm analogues e.g. Sarns; 4 Evidence from existing shellfish models; 5 Evidence from literature

Potential for enhancing fisheries resources	
Closure of OWF footprint to extend protection of nursery and spawning areas	There is evidence to indicate that juveniles of some species preferentially use rocky reefs as habitat including, potentially, turbine bases and associated rock armouring e.g. whiting, crabs (post burrow stage) and lobsters. The beneficial effects of closure could be tested at an existing OWF site where known nursery areas extend into the OWF footprint. It may be easier to enforce closure to fishing activity within an OWF footprint rather than outside; currently and in common with structures like oil platforms in the North Sea, exclusion zones operate at some OWF sites around turbines (50m). Closure to some fishing gears could be negotiated with local fishermen, and implemented by a SFC byelaw (within 6 nm) or ministerial (SI) Statutory Instrument (out to 12 nm).
Closure (partial 'no-take') to assist in the recovery/enhancement/management of specific commercially important fin fish species	It is very unlikely that all types of fishing gear need to be excluded from OWF footprints for operational reasons – however, measures to exclude particular fishing gears combined with knowledge of habitat preferences of target species might be used to assist recovery of specific commercially valuable species at some sites, e.g. cod, bass/whiting. There is evidence to suggest that turbines plus reefs may offer direct benefits for these species. This partial closure option does not exclude the possibility of developing for e.g. bass restoration areas to support recreational sea angling at some locations such as in the Thames Estuary. Partial closure of OWFs could be implemented under current byelaws administered by SFCs or negotiated with local fishermen.
Closure of OWF footprint i.e. 'no-take' MPA	Closure of OWF footprints, as part of a wider strategic network of Marine Protected Areas (MPAs) to support fisheries management, could have significant enhancement/mitigating potential for local fisheries. As yet, to our knowledge, there have been no studies in UK waters which have set out to assess the effects of closing an area of sea space, such as the footprint of an OWF, to all exploitative activity other than those carried out at Lundy, where lobsters are more numerous and larger than before the introduction of the no-take zone. However, there is evidence to suggest that not only will stocks of fish increase within the footprint itself, but there will be enhancement effects in the area surrounding the closed area. The potential benefits of OWF footprint closure to simply allow restoration of indigenous biological communities, thereby improving ecosystem health and resilience, also needs to be evaluated.

Data gaps and questions to inform a forward research programme identified in this study include the future direction of OWF design/operation, fisheries management issues in relation to OWFs, potential use of OWFs as feeding and nursery areas for fish, birds and other mobile species, impacts of OWFs and associated reefs with regard to invasive species. A range of questions in relation to the potential for enhancing/exploiting natural populations of crustacea/bivalves or algae, (as opposed to developing aquaculture methods and technologies appropriate for deployment within the OWF footprint), has also been identified. The following paragraphs summarise the main conclusions of this report:

(1) Turbine towers and their associated scour protection constitute surfaces readily colonised by a typical and broadly predictable assemblage of organisms, reflecting zonation patterns observed in adjacent intertidal and sub-tidal rocky shore communities. The physical impact and biological impact of OWFs will be proportional to the level (area/extent) of scour protection utilised and this will need to be assessed on a site specific basis. Site dependent factors such as proximity to rocky shores and hydrographic conditions influence the presence of some species and the absence of others at specific OWF sites. The structures may also extend the distributions of some mobile species such as crabs, lobsters and fin fish, as a result of new habitat opportunities, thus enhancing the productivity of these populations. The use of concrete foundations will enhance niche diversity but the maximum community development will be possible when scour protection is used. The high niche diversity (including interstitial spaces between the rocks) will promote recovery from predation or storm events and promote a more biodiverse community than could be expected from unprotected towers. Community development will relate to season of placement, the type and amount of larval supply to the site and the depth of the site.

(2) At sites where it is unnecessary or unworkable to exclude all fishing gears, some commercial species will probably benefit from the presence of turbine structures and their associated reefs as a result of the provision of enhanced habitat opportunities. For example, in supply of food resource and habitat for some life cycle stages such as juvenile whiting, cod and bass. This may present an important enhancement opportunity for specific commercial species in some areas where populations are under pressure. The potential offered by OWF sites to test the enhancement effect for highly valued species for sea angling, such as bass, could be progressed at sites where commercial fishing using mobile gears has to be excluded on safety grounds. The potential knock on socio-economic benefits for the local economy of managing a fishery specifically for sea angling could also be assessed.

(3) There may be potential to enhance existing crab fisheries where it has been necessary to introduce scour protection at an OWF site, and the increases in yield may well provide a boost to the income of local crab potters. In the cases of both crab and lobster fisheries, the opportunity for designing habitat to maximise the holding capacity of scour protection exists. Generally scour

protection will support both species, but purpose-designed, dual function artificial reefs have a much better chance of maximising return for investment. However it will be necessary to undertake further research to understand better the relationships between lobsters and the nature and extent of scour protection, before significant benefits for lobster fisheries can be realised. Partial 'no-take' areas (or 'fixed gear reserves') need not exclude deployment of fixed gears such as lobster and crab pots, to allow fishers to take advantage of these enhancement effects.

(4) Exploration of the potential for mussel culture appears to be one of the most straightforward economic opportunities which could be progressed within existing OWFs – although, development of appropriate technology for culture in water depths at OWFs will require some further investigation. It is doubtful whether enhancing effects of scour protection will be particularly relevant in the case of mussels, as there is ample food resource to support growth at all sites, except possibly in the Thames Estuary, where further assessment of the resource would be needed. Cultivation of shellfish within an OWF footprint may potentially attract larger numbers of foraging birds at some sites, possibly leading to increased collisions, and so this issue would need to be considered on a site specific basis in the course of the EIA.

(5) The opportunities presented by seaweed culture in the UK have yet to be recognised and an appropriate strategic direction provided for the sector. It appears that there may be significant niche opportunities afforded for seaweed culture by OWFs, because of the avoidance of near coast pollution in some areas, but the feasibility and operability of appropriate technologies for culture need to be tested within an OWF footprint.

(6) At the present time there appears to be very little potential for fin fish culture within OWFs, as shallow water depths and current conditions are not ideal for cage culture of salmon or cod, and current market conditions and labour costs mean that culture of sea bass in UK waters could not compete favourably with Mediterranean mariculture. In future however, it may be possible to culture sea bass profitably in UK waters if climate change forces sea bass culture out of the Mediterranean and suitable technologies can be developed to exploit offshore UK sites. The current moves to culture turbot and halibut on shore suggest that if systems which are fully closed and based on recirculation technology can be profitable, it is unlikely that offshore finfish culture will develop, except in deeper water further offshore than the existing OWFs.

(7) Evidence from a variety of sources indicates that one enhancement effect which requires further investigation, as it is potentially a valuable opportunity for restoration and management of commercially important species, is the possibility of developing 'no-take' MPAs in association with OWF footprints. Demonstrating the benefits of 'no-take' requires long term and detailed monitoring, and where a particular species is being considered, a thorough understanding of its habitat requirements is also needed. The potential benefits

of demonstrating that ‘no-take’ yields benefits to fishers through monitoring are significant, and could be considered for example, at OWF sites where fishing needs to be excluded to ensure operational security. The potentially enhancing effects of scour protection could be assessed initially using existing predictive models, and then ground truthed over time as data becomes available from the ‘no-take’ area.

(8) It has also been suggested that whilst commercial benefits from fisheries and aquaculture are desirable, there is a case for closing an OWF footprint simply to allow restoration of indigenous biological communities, thereby improving ecosystem health and resilience with knock on benefits for wider ecosystems. At the present time it would be difficult to identify UK coastal waters which have been subject to no anthropogenic impacts at all, and some areas are degraded as a result of historical exploitation and unsustainable activities. Because normal OWF operational requirements are believed to have relatively low impacts on either the benthos or water column communities, a better understanding of the potential benefits of allowing areas of sea-bed to effectively lie ‘fallow’, could be obtained from long term closure and monitoring of ecosystem health and function at selected OWF sites. This would enable us to develop a novel understanding of the natural resilience and recovery potential of coastal ecosystems.

(9) In general, the opportunities to use OWF footprints for other commercial activities will depend crucially on the site specific physical conditions, the complexity and lay-out of a given OWF, the commercial opportunities presented by the indigenous mix of fish/shellfish species already present in the sea area and finally, on the stakeholder interest in working collaboratively with OWF operators to resolve issues of common interest. It is obvious that against the current background of rapid turnover of ideas associated with new opportunities for commercial development at OWF sites, there is a need for openness amongst stakeholders to explore opportunities constructively and systematically, so that in the longer term potentially significant benefits for all stakeholders can be realised.

Contents

Tables

Figures

Appendices

1 Introduction

The development of renewable energy resources is an integral part of the UK Government's longer-term aim of achieving a 60% reduction in carbon dioxide emissions by 2050, and in common with a number of other industrialized countries, the UK made commitments to reduce carbon dioxide emissions under the Kyoto protocol in 2000. The initial target under the protocol to reduce greenhouse gas emissions by 12.5%, (compared with 1990 levels), by 2008-12, was followed by the introduction of even more ambitious targets to reduce carbon dioxide emissions i.e. by an additional 7.5% (to 20%) by 2010. In parallel with these ambitions, the UK government has also developed a target to increase the proportion of electricity generated from renewable energy sources to 10% by 2010 (see www.offshore-sea.org.uk and www.berr.gov.uk/energy/sources/renewables/index.html) and as indicated in the 2003 Energy White Paper, is working with regional and local bodies to deliver these objectives. Each regional spatial strategy therefore includes a target for renewable energy capacity, derived from assessments of the region's renewable energy resource potential.

In the UK currently there are several potential sources of renewable energy present in or on the oceans including thermal, wave, tidal and wind (www.berr.gov.uk/energy/sources renewables/renewables-explained/wind-energy/page27403.html) see also Pelc and Fujita 2002). Wind-energy currently accounts for 0.45% of the UK's electricity requirements (see www.BWEA.com) with a majority of wind-turbines being land-based. However, social and technological developments have meant that there is growing interest in locating wind-turbines offshore. Thus in April 2001, and following a pre-qualification process, the first round of offshore wind farm (OWF) sites (normally referred to as the 'Round 1' sites) were allocated, with 18 companies being awarded agreements for leases by the Crown Estate (CE). Under the agreements, the companies were given a three-year period in which to obtain the necessary consents for a lease to be granted. Sites were identified within the UK 12-nm territorial limit, at least 10 kms apart, and OWFs were permitted to have a minimum generating capacity of 20MW and a maximum of 30 turbines. The granting of the Agreement for Lease meant that developments had to comply with a number of conditions which included taking account of all the relevant environmental factors, such as proximity to shipping lanes, dredging areas, fisheries, conservation areas, cables and pipelines. Applicants were also required to provide a statement and project plan with reference to their first choice, showing the main stages of development.

In July 2003, and building on the success of Round 1, the Secretary of State for the Department for Business, Enterprise and Regulatory Reform asked the CE to invite developers to bid for site option agreements in the second OWF round ('Round 2'). Arrangements for Round 2 were designed to facilitate development in three strategic areas in territorial waters (i.e. the North west (Solway to North Wales coast), the Greater Wash and the Thames estuary) on a much more ambitious scale than in Round 1. Bids for site options were assessed against a range of criteria, including financial standing of the developers, offshore development and wind turbine expertise, and against the constraints set by the Strategic Environmental Assessment (SEA). (See http://www.offshore-sea.org.uk/consultations/Wind_R2/index.php.). On 18 December 2003, the CE offered 12 companies/consortia options for 15 site Agreements for Lease spread across each of the three strategic Round 2 areas, with each having the development option for seven years, during which the developers have to obtain the relevant statutory consents. Once the necessary statutory consents are in place, developers will be able to convert their Agreements for Lease into full leases.

Offshore wind turbines are large structures that are exposed to the full force of the offshore environment necessitating substantial anchoring. A majority of the offshore wind-turbines currently proposed for Round 2 will be located in shallow water (< 20 m) in areas of predominantly mobile sedimentary sea beds. In such situations erosion at the turbine base is a major consideration and is most often countered either by placement of rock erosion control material (armour) and/or concrete-mattresses or mats at the turbine-base. The rock armour placed at the base of wind-turbines effectively forms an artificial reef which will be colonized by organisms with some, potentially, being of commercial value. Offshore wind power generation is a relatively new field, and although the potential impacts of noise and interactions of OWFs with birds have been well studied, the likely impacts of creating reefs around turbine structures have not as yet been investigated (Pelc and Fujita 2002; Gill 2005). However, research has been conducted into the effects of many other types of offshore constructions, such as breakwaters, artificial reefs and oil/gas related structures, on the marine environment, including the effects of adding hard-substrata to otherwise sedimentary areas.

The purpose of this report is therefore to review the likely reef-effects of OWFs and their effects on fish, shellfish and other marine biota and also to consider the potential to enhance the reef effect for commercial species. The main objectives of the project thus fall under four main tasks:

Firstly, a desk based review of existing information on the likely colonisation by finfish, shellfish and other marine biota of wind farm structures and their associated scour protection will be undertaken. The review will consider both the sequence of colonisation and controlling variables based on information from studies around wind farms and wind farm analogues. Secondly, and based on the outcomes of the review, predictions of anticipated finfish, shellfish and other marine biota colonisation of monopile and other wind turbine base types fixed to the seabed will be made, covering the three Round 2 wind farm areas, highlighting (and explaining) any differences between them. The third objective will be to consider the experience of artificial reef design to promote aquaculture and finally, a work programme of field investigations is suggested to address the gaps in understanding and test the predictions made.

2 Sources of Data

It is important to recognise that offshore wind farms are a relatively new technology, and that the industry as a whole is on a steep learning curve (Pelc and Fujita 2002). This suggests that considerable changes in policy and guidance may be expected, as information is acquired and existing practice is reviewed in the light of new data, with government and the sector itself learning from the experience of the first developers. There are nevertheless large amounts of data available which is appropriate for the task in hand. We have used data resources provided directly by the Department of Department for Business, Enterprise and Regulatory Reform (DBERR), the British Ocean Data Centre (BODC), the Centre for Environment Fisheries and Aquaculture Sciences (CEFAS), Seafish and other data which is in the public domain – such as reports of Sea Fisheries Committees (SFCs). Also the Environmental Statements, baseline surveys and monitoring surveys carried out by UK offshore operators to date have been used together with references therein. However, as only five offshore wind farms (Blyth, Scroby Sands, Kentish Flats, Barrow and North Hoyle) have so far been built in the UK, some of the analysis is supported by data from the Danish wind farm developments at Horns Rev and Nysted. Whilst the literature relating to artificial reef development is vast and diverse, and understanding from this sector has been extrapolated to the current analysis with relative ease, other data sources which would have considerably enhanced our analysis, have proved to be under analysed for our purposes. This particularly refers to sources from the oil and gas sector, where so much of the information which should be useful has not been captured here by other than personal contact or anecdote e.g. video surveillance of oil and gas structures. We anticipate that by highlighting the potential of the data in this report however, further work will be commissioned to ensure its analysis and application for the benefit of the OWF sector in future.

3 Offshore Wind Farms

3.1 Introduction

An offshore wind farm consists of one or more wind-turbines anchored to the seabed, within a space effectively determined by the CE lease. The Round 1 OWFs were permitted to include up to 30 turbines, and as figure 1 illustrates, these are generally evenly spaced across the footprint of the OWF. In the case of North Hoyle for example, turbines are placed 350m apart (north-south) and 800m apart (east-west). The North Hoyle site covers about 10 km2 and subsea cables totalling 38.3km in length are used to connect the turbines together and to carry the electricity generated to shore. The grid connection is into an existing substation in Rhyl, and this transfers the power generated into the national electricity network.

Figure 1: Showing an aerial photograph (left, reproduced courtesy of Anthony Upton (info@anthonyupton.com)) and the site plan of North Hoyle offshore wind farm (right, reproduced courtesy NPower Renewables) located 7km from the N coast of Wales between Rhyl and Prestatyn. The site plan illustrates the five rows of 6 turbine towers (30 in total) and two meteorological masts in around 12m of water.

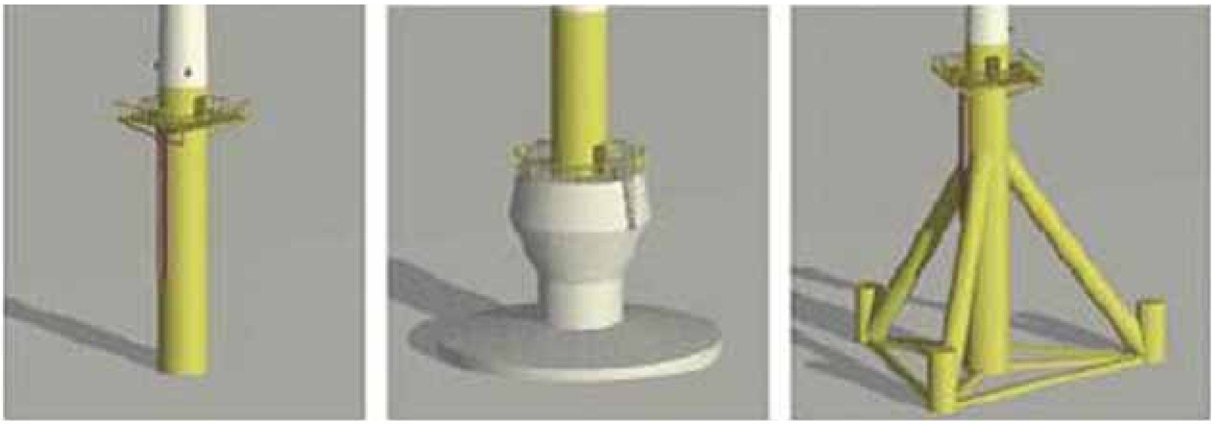
© British Crown and SeaZone Solutions Limited, Data Licence 052003.002 All Rights Reserved. NOT TO BE USED FOR NAVIGATION

Each turbine consists of, from top to bottom, the nacelle or head (which includes the blades), which is supported on a shaft (or turbine tower) that is connected to a foundation piece. Wind blowing over the aerodynamic blades causes them to turn and this rotational energy is used to turn a generator to generate electricity. The foundation, and any surrounding scour control material, is the only part of the turbine which is immersed in seawater and is of primary interest in terms of this review. There are currently three broad categories of foundation-type: monopile, gravity and tripod. Monopiles are currently the most popular foundation type except in shallow situations where concrete gravity foundations are also used. Tripod foundations remain at the design stage but are considered to show the most potential as the technology moves into deeper water.

3.2 Turbine bases – different designs

The current design philosophy for wind farms in water depths up to 20 m is based on the monopile, except in the shallowest waters (up to 5 m) where gravity base structures are more frequently used (see Figure 2). The installation methodology (driving, drilling or combination) will depend on sediment properties and water depth. For deeper waters, tripod support structures are being considered but the optimum design is yet to be established. Floating support structures remain a challenge with regard to cost, and are only relevant to areas lacking shallow water (Henderson et al. 2002).

Figure 2: Wind-turbine foundation design (left to right, monopile, concrete gravity and tripod) (from Henderson et al. 2002).

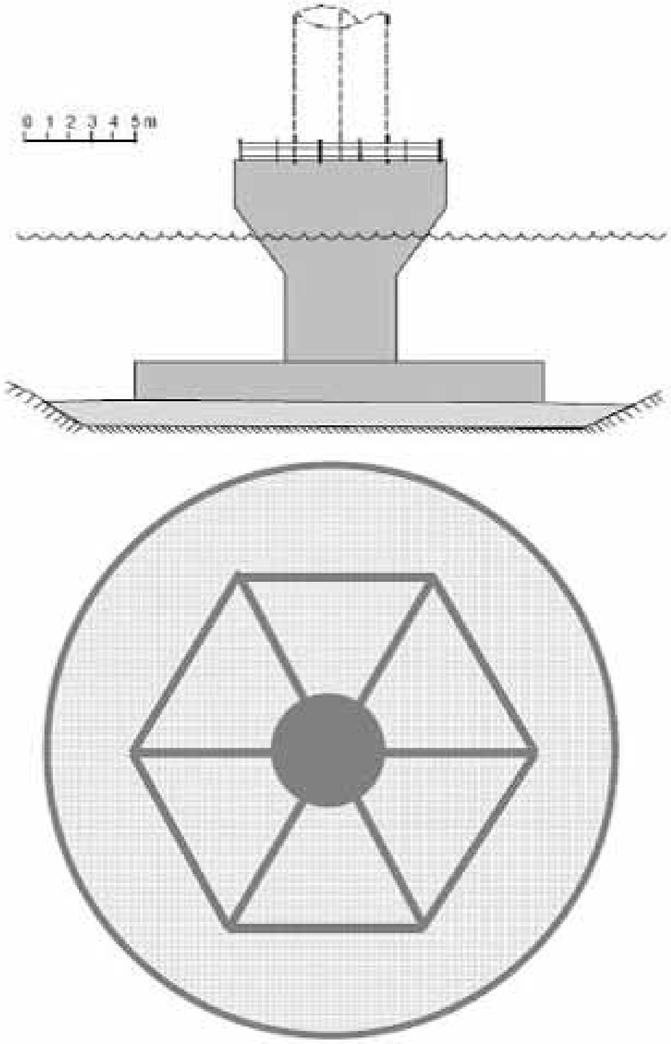


Monopile foundations are relatively simple consisting of a steel tube of 3 – 4 m in diameter (50 mm steel thickness in the case of Horns Rev monopiles) simply driven into the sediment for distances dependent on the sediment conditions (25 m in the case of Horns Rev). Concrete gravity foundations can be more complex particularly where additional mass is gained by adding gravel or rocks to the foundation (see Figure 3).

3.3 Infrastructure (pipelines, cables etc)

The turbines in a wind-farm are generally linked to a substation where the generation voltage is stepped up 5 to 10 times (with a commensurate decrease in the current) prior to transmission, along cables to land. The cables linking individual turbines and those connecting to the shore are normally buried (to a depth of at least 1 m in the case of the Horns Rev Farm, Denmark) in order to give them protection and to reduce the extent to which they may influence sensitive species, although the trenching activity is a disturbance in its own right.

Figure 3: Gravity foundation. Above – side view, Below – plan view showing hex-void spaces for filling with gravel or rocks (reproduced from Energi-E2 2005)



3.4 Site selection criteria for offshore wind-farms

Wind farms are subject to the same financial considerations as any other major civil engineering project and have the objective of generating the cheapest electricity possible. This is achieved through careful site selection and, until recently, this has excluded offshore developments. However, the offshore environment has a number of advantages compared with onshore locations; the offshore wind environment is more reliable, less turbulent and has a higher energy density meaning that, for the same turbine, an additional 50% of electricity can be generated. Secondly, the offshore environment can be considered both relatively remote (in terms of visual amenity) to local population centres, yet close in terms of infrastructural requirements. Basically, offshore turbines allow wind power generation relatively close to population centres as opposed to generation on remote hillsides (Byrne and Houlsby 2003).

Offshore construction has major cost considerations that are related to the depth of the water (i.e. the infrastructure required to support the turbine-head) and the extreme rigours of the offshore environment. This means that currently, the cost for offshore wind turbine support structures may account for 50% of the total investment for an offshore wind farm project (Feld 2004).

In order to minimise costs a majority of wind farms are currently located or planned to be constructed in water less than 20 m deep (Feld 2004) although the proposed Talisman demonstration project aims to site two turbines 25 km from shore in 50 m of water (Talisman 2006).

Exposed, shallow waters are often associated with strong currents and mobile sediments. The rapid movement of sediments introduces an additional problem to offshore electricity generation, that of erosion around the foundation. There are several mechanisms by which this can be countered, including increasing the depth of the piling on which the turbine is supported and the deposit of scour protection material around the base of the turbine. Scour protection can be delivered by either deploying coarse aggregate around the base or by the use of concrete mats or mattresses that trap sediment, the latter technique having been extensively used in the offshore oil and gas industry (see Figure 4 below). The nature of any scour protection material used is of major relevance to the current review, as it will modify the receiving environment and constitutes, in effect, an artificial reef.

3.5 Scour protection used in offshore wind farms

The hydrographic interaction between wind turbines and their receiving environment can induce scour at the turbine-sediment interface. Scour is a major problem facing industry working in the marine environment and is a function of current speed, sediment type and the nature of the obstruction. Scour can result in extensive depressions occurring around the base of turbines that may be of sufficient magnitude (up to 10 m deep) to cause concern and necessitate remedial action.

The problem of scour can be addressed in several ways:

(i) Piling foundation to greater depth

Perhaps the most simple means of overcoming the problem of scour is by piling the turbine foundations to greater depths. Whilst this method may work, the resultant scour can lead to other problems, including difficulties in protecting the emergent cabling from the turbine bases.

(ii) Rock armouring

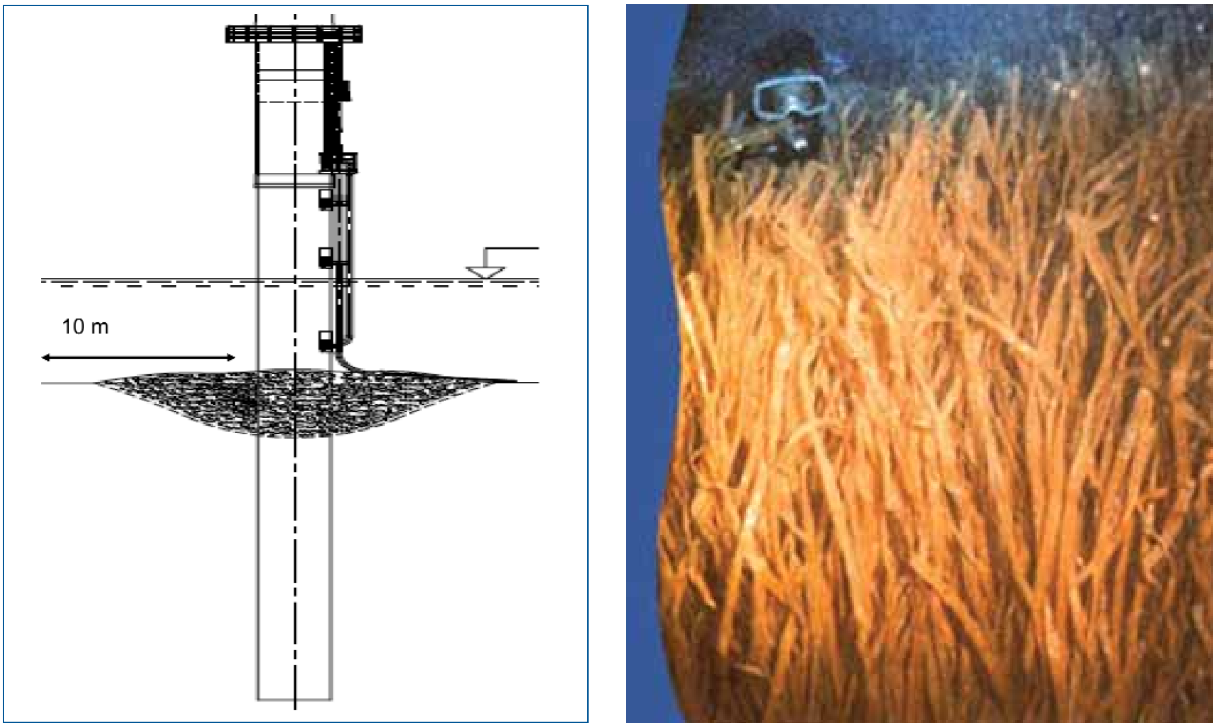
Another approach is to protect the base of the turbine by rock dumping. This involves the placement of one or more layers of aggregate around the turbine base to form a roughly circular reef of 10 – 15 m radius with the foundation at the centre. This approach has been adopted to protect many of the Danish wind turbines e.g. Horns Rev (but not Nysted).

(iii) Anchored polypropylene fronds

The problem of scour is not new and has been a persistent problem to the oil and gas industry in the North Sea, particularly around structures such as pipelines and platform foundations. Observations of the sediment trapping properties of seaweed beds led to the development of a system of scour control that utilises anchored polypropylene fronds of 1 – 1.5 m in length that emulate seaweed. These are secured in concrete to form 'mattresses', which are simply laid on the seabed or onto a textile mat, subsequently secured to the seabed using diver-deployed anchors. The fronds are buoyant and project into the ambient current resulting in localised drag and reduced current velocities. This causes a proportion of suspended sediment to fall out of suspension and accumulate around the fronds. The fronds vibrate in the current which serves to compact the sediment. The sediment tends to accumulate to a point where about 10% of the frond length remains exposed to the water column. Anecdotal observations indicate that the exposed ends of the fronds, some 100 – 200 mm in length, can serve to attract fish.

The main scour protection measures adopted, or proposed, for use in the offshore wind farm industry are very different and are likely in nature, to interact in different ways and to different extents with the receiving environment.

Figure 4: Turbine foundations: rock ballast (left) showing approximate scale and extent of optional rock-scour protection around turbines at North Hoyle (Ben Barton, formerly North Hoyle but now Crown Estate, June 2006, pers. comm.) and frond-mats (right) (reproduced courtesy of Seabed Scour Control Systems Ltd).



4 Offshore Wind-Generation in Europe including the UK

A total of 10 offshore wind-energy projects are currently operational worldwide. Early projects were relatively small scale and located in shallow or sheltered waters. The Blyth offshore turbines (Northumberland, UK) constituted the first truly offshore wind farm exposed as it is to the full force of the North Sea. Currently, Denmark, Germany, Ireland, Sweden and Netherlands in addition to the UK are investing in offshore wind power technology (see Table 2 below). The newly-completed Danish Horns Rev offshore wind farm is currently the largest offshore project in the world.

Table 2: European offshore wind farms (location, date online, output per turbine, number of turbines and total output) (from www.BWEA.com)

Location	Country	Online	MW	No of turbines
Vindeby	Denmark	1991	4.95	11
Lely (Ijsselmeer)	Holland	1994	2.0	4
Tunø Knob	Denmark	1995	5.0	10
Dronten (Ijsselmeer)	Holland	1996	11.4	19
Gotland (Bockstigen)	Sweden	1997	2.5	5
Blyth Offshore	UK	2000	3.8	2
Middelgrunden, Copenhagen	Denmark	2001	40	20
Uttgrunden, Kalmar Sound	Sweden	2001	10.5	7
Yttre Stengrund	Sweden	2001	10	5
Horns Rev	Denmark	2002	160	80
Frederikshaven	Denmark	2003	10.6	4
Samsø	Denmark	2003	23	10
North Hoyle	UK	2003	60	30
Nysted	Denmark	2004	158	72
Arklow Bank	Ireland	2004	25.2	7
Scroby Sands	UK	2004	60	30
Kentish Flats	UK	2005	90	30
Barrow	UK	2006	90	30
TOTAL			**587**	**316**

In the UK, generating electricity from wind-power on a commercial basis (i.e. contributing to the national grid) started in 1991 (see www.BWEA.com). This has expanded considerably and there is now a total of 1445 land and sea-based wind-turbines currently in operation generating about 0.45% of the UK's electricity (again see www.BWEA.com). Basing wind turbines offshore has a number of advantages over their land-based counterparts including access to superior wind-strength, low-turbulence, regularity of supply and relative ease of planning under certain circumstances. During the Round 1 process a number of potential sites were identified and licences for construction granted and since that period, five sites have become operational (North Hoyle, Scroby Sands, Kentish Flats, Blyth and Barrow, with Burbo still under construction) while others are either currently under-construction or approved for construction (see Table 3 and Table 4 below). Under Round 1 the total consented output is approximately 900 MW.

Table 3: Round 1 sites: showing current status, capacity and developer/operator/turbine type (see www.bwea.com/offshore/round1.html) See also Garrad, Hassan and Partners Ltd (2005).

Location	Status	Capacity	Developer/Operator/Turbines
North Hoyle	Operating (Dec 2003)	60 MW	npower renewables (Vestas 2 MW)
Scroby Sands	Operating (Dec 2004)	60 MW	E.ON UK Renewables (Vestas 2 MW)
Kentish Flats	Operating (Sep 2005)	90 MW	Elsam (Vestas 3 MW)
Barrow	Operating (Sept 2006)	90 MW	Centrica/DONG (Vestas 3 MW)
Gunfleet Sands	Approved	30 turbines	GE Energy
Lynn/Inner Dowsing	Approved	60 turbines	Centrica
Cromer	Approved	30 turbines	Norfolk Offshore Wind/EDF
Scarweather Sands	Approved	30 turbines	E.ON UK Renewables/Energi E2
Rhyl Flats	Approved	30 turbines	npower renewables
Burbo Bank	Approved	30 turbines	Seascape Energy
Solway Firth	Approved	60 turbines	E.ON UK Renewables
Shell Flat	Submitted	90 turbines	ScottishPower/Tomen/Shell/Elsam
Teesside	Submitted	30 turbines	Northern Offshore Wind/EDF
Tunes Plateau*	Submitted	30 turbines	RES/B9 Energy
Ormonde*	Submitted	30 turbines	Eclipse Energy

*These two projects were outside the original Round 1 process but conform to its terms, Ormonde is an innovative wind-gas hybrid project.

Table 4: Round 2 sites: showing location, projected maximum capacity and developer involved (www.bwea.com/offshore/round-2map.html) See also Garrad Hassan and Partners (2005)

Location	Maximum capacity (MW)	Developer
The Greater Wash		
Docking Shoal	500	Centrica
Race Bank	500	Centrica
Sheringham	315	Ecoventures/Hydro/SLP
Humber	300	Humber Wind
Triton Knoll	1,200	npower renewables
Lincs	250	Centrica
Westermost Rough	240	Total
Dudgeon East	300	Warwick Energy
The Thames estuary		
Greater Gabbard	500	Airtricity/Fluor
Gunfleet Sands II	64	GE Energy
London Array	1,000	Energi E2-Farm Energy/Shell/ E.ON UK Renewables
Thanet	300	Warwick Energy
North west (Solway to North Welsh coast)		
Walney	450	DONG
Gwynt y Mor	750	npower renewables
West Duddon	500	ScottishPower
TOTAL	**7,169 GW**	

Developments in the period between Round 1 and Round 2, in terms of turbine output, mean that BERR expectations for Round 2 represent a 10-fold increase on current capacity with projections of 5% of the UK's electricity being generated offshore (Table 5). The number of turbines required to meet this objective is dependent on their individual output but they will occupy an area of seabed of approximately 600 km2.

Table 5: Installed offshore and onshore wind farm capacity together with projects under construction consented and in planning. (source: www.BWEA.com)

	Onshore MW	Offshore MW
Currently installed	**1,761.56**	**303.80**
Under construction	**752.80**	**582.00**
Consented not built	**1,642.00**	**2,088.00**
Projects in planning	**7,957.58**	**2,733.00**
	12,113.94MW	**5,706.00MW**

If all wind farms currently consented and in planning were to be constructed and operational by 2010, it appears that the UK will be some way off realising the goal of more than 10% of power requirements produced from renewables by

2010, especially as other renewable sources not included in this figure are relatively insignificant. By far the largest proportion of the projects in the above categories are still in planning, and the lead times are unpredictable and sometimes protracted, especially where there is opposition to the project. Also there is no guarantee that all wind farms which are consented will be built, or that all those which submit applications will receive consent.

During Round 2 three broad areas were identified for potential development. These were the Thames Estuary, The Greater Wash (Wash to Humber) and the North-west (from Solway to the North Wales coast) (see Figure 5 below).

Figure 5: The location of Round 2 application sites within the broader Round 2 offshore wind farm areas i.e. The Thames estuary, The Greater Wash (Wash to Humber) and the North West (Solway to North Welsh coast). (Figure reproduced courtesy of BWEA; see www.bwea.com/offshore/round-2map.html)

The general biological and physical characteristics present in the Round 2 OWF strategic areas have been extracted from SEAs (See http://www.offshore-sea.org.uk/consultations/Wind_R2/index.php) and environmental baseline studies at the proposed OWF sites within the Round 2 application areas (see inventory in Appendix v) and combined with other data resources to provide the basis for the analyses presented in this report. The general characteristics of the Round 2 areas are summarised for reference purposes in Appendix i, and have provided us with general background information to contextualise the analyses shown in this report. Monitoring information has been obtained from built OWFs in the UK and elsewhere in Europe (e.g. Denmark), and this has also included a variety of post-construction monitoring surveys at individual sites.

Table 6: Summarising the characteristics of built OWFs in the UK (Burbo almost complete). Data extracted from Environmental statements and monitoring studies (see Appendix v and personal contact as per key shown below).

	Turbines	Location depth	Water	Wind/ waves	Scour protection	Substrate
Barrow[1] DONG/Centrica	30 turbines Up to 108 MW	10 km off Walney Is. nr Barrow-in-Furness	12-18m	Wind: 5.6m/sec Wave: 0.9/sec (exposed to SW mainly	None	Fine sands overlying clayey mud with tillate
Blyth AMEC	2 turbines of 2MW	1km off Blyth Northumberland	3-4m	Wind: 10m/sec	None	Bedrock with gullies up to 0,75m deep
Burbo Bank[2] (Elsam) (in construction)	30 turbines 90 MW	6.4 km off North Wirral & Liverpool, Lancs	1-8m	Wind – 9m/sec Waves – exposed SW/NW	12-15m diameter; 1-2m high. Installation underway*	Med/coarse sands with abundant shell and sandbank
Scroby Sands[3] (E-on)	30 turbines 60 MW	2.5 km off Great Yarmouth, Norfolk	2-9m	Wave <6m; tidal range 2.5m;	Aggregate to sea bed level only (TBC)	Highly mobile mixed sands and gravel
Kentish Flats[4] (Elsam)	30 turbines 90 MW	8.5km off Whitstable Herne Bay, Kent	0-6m	Wind – 8.5m/sec Waves – exposed to SE	None	Clay silts and silty sands
North Hoyle[5]: Npower renewables	30 turbines 60 MW	7.8 km off Prestatyn, N. Wales	7-11m	Wind – 5-10m/sec Waves – exposed to W (mainly SE to NW quadrants)	None	Sandy with some gravel and mud

1 Trine Sorensen, Dong Ltd, April 2007, pers. comm.; 2 Soren Vestergaard, Dong Ltd, April2007, pers. comm.; 3 Tony Nott, Scroby Sands, April 2007, pers. comm.; 4 Steve Bellew, NTL, April 2007, pers. comm.; 5 Ben Barton, (formerly North Hoyle) Crown Estate, Sept 2006, pers. comm.

The alteration of the seabed which results from the introduction of wind farms is likely to have a variety of consequences as the species present in the water column colonise the new structure, and as a result of changes induced in the receiving environment. The nature of the new communities will be dependent on a range issues including the nature of the supply of propagules and the environmental conditions at the OWF site. This means that the impacts, including fishery-related changes, are likely to be very site specific.

5 Factors Controlling Colonisation of Offshore Structures

Whenever a new material is deployed in the sea it is rapidly colonised by animals and, if exposed to sufficient sunlight, plants as well. The development and maintenance of biological communities is complex, involving both pre- and post-recruitment processes. This issue of the relative importance of pre- and post-recruitment processes in determining community structure, is a hotly debated concept in marine ecology (Caley et al. 1996; Menge 2000) and critical to understanding the likely colonization and utilization of new substrata such as turbine towers and the erosion control material placed at turbine bases.

5.1 Pre-recruitment, settlement and post-recruitment processes determining community structure

5.1.1 PRE-RECRUITMENT PROCESSES

There are numerous and diverse reproductive strategies adopted by benthic organisms. However, a majority of them reproduce by releasing gametes into the water column which, if to be viable, must fuse with an appropriate counterpart to produce a propagule (larva). The propagule spends a varying amount of time (species and condition specific) drifting/swimming in the water, before finding a suitable site on which to settle and attach to the substratum. Many species have very short lived propagules however, and unless they occur on hard substrata or very nearby they are unlikely to colonise structures built in sediment areas. Once attached, the propagule grows into the adult phase ready to continue the cycle.

The release of gametes into the water and/or the water-borne (planktonic) phase results in the dispersion of the propagule, the extent of which is a function of the duration of the planktonic phase of the species in question, and the current regime into which it is released. In temperate waters most organisms breed when the food supply in the water column is abundant (late spring through summer) in order to maximise the survival rate of the resultant larvae. This results in a seasonal settlement of larvae and a subsequent juvenile year-class (cohort) that may compete for resources including food and shelter.

5.1.2 FACTORS CONTROLLING SETTLEMENT

Dispersive larvae develop in the water column until such time as they become competent to settle. The species-specific duration of this phase is determined by a number of factors including water temperature, food supply and the quality of the individual larvae concerned (Keough 1983). Once competent to settle many larvae change their behavioural patterns, for example, by swimming downwards towards the seabed. Once on the seabed, larvae are limited in their ability to settle by current speed, and the threshold value for species varies. Where the current speed enables the larvae to settle they are then faced with the active ‘decision’ as to whether to settle. Different species have adopted a range of strategies to ensure that the competent larvae maximize their chance of settling on a suitable substratum. In the case of barnacles, for example, the most important settlement cue is the presence of conspecifics (Miron et al. 1996) presumably on the basis that the presence of the same species indicates that the environment is suitable, while competent larvae of other species, such as the American lobster, search for a suitable shallow, rocky substratum (Cobb and Wahle 1994).

In shallow coastal environments, where the water column is normally very well mixed, physical factors, such as water temperature, control the range of a majority of species. However, further offshore, where currents reaching structures may be isolated in time and/or space from parental populations, this may not apply. The effect of limitations in supply and negligible local recruitment is to limit aspects of the development of the community, to reduce species richness and potentially limit the productivity of the environment. Even where there is sporadic larval supply the inability of species with extended larval phases to recruit locally, will limit their ability to exploit the new habitat (Goldson et al. 2001). Under such circumstances the structure is likely to be dominated by those species that can arrive in the water column, for whatever reason, or which are robust in the sense that individuals arriving in very small numbers can establish communities that can then self-recruit.

5.1.3 POST RECRUITMENT PROCESSES

Once settled, juveniles are subject to many dangers which result in an initial high mortality rate, which tends to decrease exponentially as the cohort grows. Dangers include predation, physical burial and damage as well as intra-specific competition resulting in insufficient nutrition. The extent of the impact of these post-recruitment processes varies according to the nature of the environment and temporally. These processes combine to control the extent to which recruited individuals thrive and go on to reproduce.

Physical burial occurs where individuals are exposed to high levels of sedimentation, for e.g. as a consequence of current induced sedimentary re-suspension or proximity to a supply of sediment. Smothering necessarily afflicts small organisms to a greater extent than larger ones that are more able to extend feeding and respiratory organs above the sediment. Abrasion occurs in environments where currents are sufficiently strong to entrain and carry particles. Highly abrasive environments are very stressful and thus generally associated with low species diversity. Intra-specific competition occurs when the density of a given species exceeds the site- and time-specific environmental carrying capacity for that species. The carrying capacity for aggressive species, such as European clawed lobsters, is necessarily numerically lower than that for species with a less aggressive and more communal behavioural patterns such as spiny lobsters. The degree to which a given habitat can be modified to increase the environmental carrying capacity for a given species is an active area of research.

5.1.4 COLONISATION PROCESSES IN OFFSHORE WIND FARMS

Wind farms tend to be located in areas that are shallow, both to reduce emplacement costs, and exposed to the full force of the wind to maximise energy output. Such areas tend to consist of either bedrock, for example at Blyth, UK or mobile, coarse sediments that characterise much of the benthic environment at Round 2 sites (and similar Danish sites such as at Horns Rev). The hard-substratum benthos associated with these harsh, exposed environments tends to be species poor and dominated by short-lived ephemeral species that appear during the relatively calm summer, only to be removed during autumnal storms (as was seen during the first winter that turbine towers were in place at Horns Rev). In this sense communities associated with wind-turbines are likely to be analogous to those found in rocky subtidal areas such as the 'sarns' found in Cardigan Bay, Wales, UK (Hiscock 1986).

At the opposite extreme to the highly exposed conditions, are those where sedimentation is occurring i.e. where the current slows and can no longer carry its sediment load. Scour control mats and fronded mattresses, which are routinely used in the offshore industry to prevent scour, work by inducing sedimentation through baffling water currents. The use of such devices around wind-turbine bases, as opposed to rock and/or gravel has considerable reef-effect implications and is likely to result in a benthic environment that more closely reflects the baseline conditions and reduce the reef-effects of the resultant structure.

Under ideal conditions the hard substrata offered by structures such as wind-turbine bases would readily and rapidly become heavily colonised by a diverse and abundant fauna and/or flora, and such colonisation is dependent on both the presence of a sufficient number of larvae and suitable environmental conditions (Hiscock et al 2002). Generalised predictions can be made, reliant on existing experience of fouling on structures in similar locations, but detailed predictive modelling of biofouling is not yet possible as we have a poor understanding of site specific variables.

5.2 Community development

Many communities, whether terrestrial or aquatic, show a very well defined succession from the initial arrivals to the development of climax communities. Early colonisers are characteristically short lived and highly fecund with very efficient dispersal methods to enable them to exploit new habitats. In marine systems the situation is complicated by the prevalence of extreme conditions in many environments meaning that some habitats are continually being colonised as if for the first time. This happens in environments that are, for example, in sedimentary wave exposed locations where the seabed is less than about 5m below CD, and so are blasted by very strong water currents that may contain abrasive material (sand and gravel). Under such circumstances a climax community is not given the opportunity to develop except for rapid settling fast growing species, which may manage to settle on the structure above the seabed.

Nevertheless, and irrespective of site specific differences in exposure, hydrographic regime, proximity of potential sources of propagules, Hiscock et al (2002) using the Marine Nature Conservation Review (MNCR) database and results from a variety of studies of benthic and epibiotic communities associated with rocky substrata and artificial structures such as jetties and oil platforms, were able to predict the zonation characteristics and likely communities which would appear on turbine towers over time when placed on the seabed in more than 15m of water. The early colonisers in the intertidal zone are barnacles, *Ulva lactuca* and *Ulva intestinalis*, whereas kelps, red seaweeds and mussels as well as encrusting sea mats dominate at 1 to 2m below CD. Hiscock et al (2002) suggested two possible options for the shallow subtidal (2 – 6m below CD) – either dominance by mussels together with predatory starfish or dominance by communities characterised by plumose anemones (*Metridium senile*), hydroids (such as *Tubularia* spp.) and solitary sea squirts such as *Ascidiella* spp. In the case of well developed mussel beds, Hiscock also noted that where live mussels become detached from the structure, they would attract scavengers such as starfish, plaice and flounder. These predictions of the likely early colonisers have subsequently largely been verified as a result of post construction monitoring surveys at Blyth and North Hoyle OWFs, where most of the key elements of the predicted colonising community were present (see Mercer 2001, Bunker 2004) and see also http://www.hornsrev.dk/Engelsk/default_ie.htm). The larvae of most of the colonising species are present in the water column at different times of year, so that actual colonisation observed is largely dependent on when the new habitat is introduced into the water column.

Even under conditions that are sufficiently stable to allow colonisation to continue the early colonising barnacles and mussels may establish with such vigour that they remain the dominant fauna. Under such conditions the development of more diverse communities may be dependent on the presence of predators that are effective in grazing the early colonisers from the substratum and select against secondary colonisers which may defend themselves chemically (e.g. Lindquist et al. 1992). Many shallow, temperate water, hard substratum communities consist of expanses of urchin 'barrens' or high densities of macroalgae, particularly kelp (Konar 2000). The factors involved in the transfer from one system to another remain unclear but possibly involve urchin pathogens or parasites and physical removal of algae by storms, but can be affected by the dynamics and levels of exploitation of lobsters.

On an artificial reef in Portugal, Boaventura et al. (2006) recorded the following succession: barnacles, bryozoans and serpulids dominated the samples between zero and three months to be replaced by Porifera, Hydrozoa, Anthozoa, other sessile Polychaeta, Decapoda, Gastropoda and Bivalvia after three to six months. Relini (1994) reported that the climax-community had not been reached on an artificial reef deployed in the oligotrophic north-western Mediterranean after five years but that slow growing sponges and macroalgae were increasingly dominant. Closer to home, Brown (2005) described the succession on a range of materials (including concrete, rubber and steel) on the west coast of Scotland and concluded that whilst material is an important factor determining early colonisation, after 12 months of immersion the colonisation of all materials becomes increasingly similar (tunicate dominated). On the Poole Bay artificial reef a succession of animals and plants was seen over the first 18 months (Jensen et al. 1994) after deployment, with a community similar to that of local rocky patch reefs being seen five years after deployment (Jensen et al. 2000). Consequently it appears that biological successions move to climax communities at different rates according to the local hydrographic regime, larval supply and the frequency of extreme events. This means that predictions as to the precise nature of the climax community are likely to exhibit considerable site and time heterogeneity (reviewed in Richmond and Seed 1991).

Community development is a complex multifactor process that varies in both time and space, and so modelling and predicting subtidal habitat colonisation and the ultimate community composition is difficult and it may be preferable, where possible, to examine proximal habitats and their associated communities for guidance.

5.3 Layout of turbines

The layout of turbines within an OWF is dependent on a number of competing factors. On the one hand, the operator needs to minimize the overall footprint size of the farm to reduce stakeholder conflict, minimize the land-area on which rent is paid and to minimise infrastructural requirements such as connecting cables. On the other hand, the density of turbines needs to be minimised to ensure that each is effectively independent and faces a non-turbulent air stream of maximum energy density. The necessary compromise between these conflicting objectives results in turbines that are generally 500 – 1000m apart on the axis of the prevailing wind. This distance may increase if turbines increase in size.

The degree to which each turbine is independent, from a biotic perspective, will differ between species with large, motile species such as cod being able to move quickly between different turbines and utilize the entire wind farm matrix. Other valuable species, particularly lobsters, will also move over such scales, during their normal perambulations (Cobb and Wahle 1994; Smith et al. 2001) the degree to which they take up long-term residence being dependent on a number of factors, many of which are unknown but include seasonal factors (Smith et al. 1999), reproductive movements, inter specific competition and the availability of food. Experience from Poole Bay (Jensen et al. 2000) and Horns Rev suggests that *Cancer pagurus* (edible crab) will be among the early colonisers.

The layout of the wind turbines in an OWF will be dictated by a number of factors, particularly their spacing in order to maximize energy capture. However, consideration should ideally also be given to spacing issues, from a biological perspective. For example, there is some evidence to suggest that in order to maximize productivity, artificial reefs should be deployed in a fractal pattern to maximize complexity at the largest scale (Lan et al. 2004). Although it is recognised that technical and operational challenges are currently very pressing for the OWF sector, discussions at a stakeholder workshop (Mee 2006) suggested that design optimisation focussing on biodiversity and/or fisheries benefits at the earliest possible stages of site planning and development, could potentially benefit all stakeholders. These ideas have also consistently been promoted by Seafish (Craig Burton, Sea Fish, March 2007, pers. comm.). Perhaps as the sector becomes better established, operators may be able to focus on these additional challenges, especially in instances where there are potentially financial benefits or significant savings in management time from dealing with conflict with fisheries.

5.4 The effect of reef shape, profile and height

There are many physical attributes of the reef structures created by the physical presence of the turbine towers, and any surrounding scour-protection material, which influence reef behaviour and performance. These factors include reef-height, shape and profile.

Any structure deployed in the marine environment will, immediately, interact with the local hydrographic regime. This interaction results in the creation of turbulence which is a function of the size and profile of the obstruction and the strength of the current. The disturbance of laminar flow and the generation of turbulence offers considerable potential to fish which are able to both reduce their energy expenditure by swimming in turbulent flows and exploit food particles that are swept up from the seabed or capture disorientated prey (Brock and Kam 1994; Rilov and Benayahu 1998). Some fish species may thus benefit from high-profile structures creating the habitat type that they require (Wilhelmsson et al. 2006a).

The orientation of man-made structures in relationship to the prevailing current direction can also influence their impact and colonisation. Where there is a strong residual current differential exposure is likely to occur around the reef with some sides being more exposed than others. The degree to which this effect affects colonisation and utilisation of the reef structures is largely unknown. However, Martin (2005) has reported significant differences between the sea- and landward sides of offshore breakwaters, and (Fowler et al. 1999) reported that pouting use the Poole Bay reef as a shelter from current flow. Man-made structures with complex shapes are likely to offer a greater range of localised hydrographic conditions with subsequent potentially beneficial effects for biodiversity.

6 The Impacts of Offshore Wind Farms

The interaction between offshore structures and their receiving environment is critical to the utilisation of such structures by novel and potentially commercially valuable species. The emplacement of wind turbines will lead to two main types of disturbance, firstly that from the construction process and secondly the ongoing running of the wind farm. In terms of the likely reef-effects of turbines, the long-term interactions are of most relevance. The nature of the interactions and the subsequent indirect effects of these, frequently on non-reef related organisms, are complex (Elliott 2002) but the current status of knowledge of the environmental impacts of location, operation and removal/disposal of OWFs have recently been collated in a status review by OSPAR (2006) and the outcomes of this review are interpolated into the summary provided below.

During construction of OWFs the main potentially significant impacts identified were increased turbidity and smothering from resuspended sediments, construction plant movements, noise and pollution incidents. With regard to the physical presence of structures, loss of seabed habitat, introduction of new substrate (for scour protection or foundations), barrier effects (physical barrier created by presence of turbines to fish migration/movements etc), hydrodynamic sediment transport and water quality and finally, socio economic impacts were all identified as potentially significant. The main potentially significant operational impacts identified were chronic noise and vibration, electro-magnetic fields (EMFs) and those resulting from general maintenance activities (Energi-E2 2005). Further information is provided on each main type of impact in the subsequent sections.

6.1 Influence of electromagnetic fields (EMFs)

OWFs require connection to the local or national electricity grid in order to deliver the power they are generating. This requires that individual wind-turbines in the farm be connected to a central hub (sub-station) which is then connected to the appropriate electricity grid. In the case of the Horns Rev offshore wind farm (Energi-E2 2005) the wind-turbines are interconnected with a 36kV cable, which is then connected to the transformer platform. The transformer platform is connected to land by a 150kV cable (Energi-E2 2005).

The transmission of electricity along conductors generates a magnetic field around that conductor which is proportionate to the current being delivered. The magnetic fields induce electric fields. The magnetic field (B field) and induced electric field (iE field) both have the potential to affect sensitive organisms in two main ways, firstly by interfering with the earth's magnetic field which is used by species such as salmon and eels in navigation and, secondly, by interference with the natural magnetic fields emitted by the prey items of magnetic-field sensitive predators, such as sharks and rays and many other elasmobranchs.

The influence of electromagnetic fields has received considerable attention recently from COWRIE (Collaborative Offshore Wind Research Into the Environment), who have commissioned and published two reports (CMACS 2003; Gill et al. 2005). The detail of these two reports will not be repeated here, (www.thecrownestate.co.uk/35_cowrie) but for the purposes of this report, it is worthwhile noting that their conclusions were that there has been a lack of a consistent assessment of the likely effects of EMF on sensitive species and, indeed, that sensitive species have yet to be properly identified.

The degree to which the reef-effects of offshore wind turbine bases are influenced by EMFs will depend on the nature of the colonising community and the, as yet unknown, importance of EMF sensitive species within that community. Further research on this aspect is planned for completion by 2008, focussing on the impacts of EMFs on elasmobranchs, (funded by COWRIE) (Dr. Andrew Gill, Cranfield University, Feb 2007, pers. comm.), but in the absence of more comprehensive evidence for significant impacts, the fact that apparently healthy and diverse communities are present on existing OWF structures at North Hoyle (Bunker 2004) and Blyth (Mercer 2001) provides evidence that this is unlikely to be a significant factor preventing maintenance of colonising communities on turbine bases in the longer term. However, where the habitat enhancement effect for individual species depends on the survival of specific prey items, we will have to await further research in this area. Burial of the cable to at least 1 m in sediment is considered an effective method of mitigation as magnetic fields from cable trace, wind turbines, and the transformer station may be expected to reach geomagnetic field-strength levels only in the immediate vicinity of these structures, at distances no more than 1m (Energi-E2 2005).

6.2 Noise (operational and construction)

The development of offshore wind-turbines will add to underwater noise levels in two ways: firstly, the acute, short-term, intensive sound generated during piling, and which, though restricted to the construction phase of a project, is likely to have a significant impact on reef associated communities and secondly, the low-intensity, long-term sounds generated during the normal operation of the OWF, which include the sounds generated by the turbines themselves, boats and general disturbance created during maintenance etc. The effects of these latter noises are to a large extent unknown, but they appear to have minimal impact on reef communities other than vertebrates, as discussed below.

Sound, in the form of pressure waves, is efficiently promulgated underwater. Many marine organisms, particularly vertebrates, have a highly developed auditory capability and use it to facilitate hunting, predator avoidance and in communication. Sound waves are mediated with little effect through liquids and animal tissue. However, when sound waves pass through a water-air interface some of their energy is released. This means that very loud sounds, which pass through an organism containing an air sac, such as the swim-bladder found in most teleost fish or mammalian/bird lungs, may cause damage. As a consequence the majority of bony fish and all marine mammals, including human divers, are at risk from injury or death when in close proximity to very loud underwater noises.

The construction of OWFs will in many cases involve weeks or months of daily pile-driving activity (where steel-piles are the foundation-type) which is likely to influence proximal fish populations. However, of most relevance to the current review is the possible influence of chronic turbine-induced noise on reef-dwelling organisms (Wahlberg and Westerberg 2005).

Sound is more likely to directly influence organisms with an auditory capacity including fish. Should this occur, however, the indirect effects on non-auditory invertebrate species might be considerable particularly where important invertebrate predators, such as cod and wrasse, are affected. Underwater noise occurs naturally and at many frequencies, from natural sources such as wave action and seismic activity. Man has been responsible for a substantial increase in the amount of noise pollution in the sea through a number of activities including shipping and oil/gas operations.

Under operation, the wind turbines and the transformer will emit noise to the air and through the tower and foundation to the water. Measurements of noise from a wind turbine on the Horns Rev farm have shown that the airborne noise makes a negligible contribution to the underwater noise level, with a majority of the underwater noise being vectored to the water by the wind turbine foundation. Under operation, the underwater noise from the offshore wind turbines is not higher than the ambient noise in the frequency range above approximately 1 kHz. In the frequency range below approximately 1 kHz, the underwater noise emitted from the offshore wind turbines is higher than the ambient noise. Under operation, the turbines will emit vibrations to the surroundings and this might have an impact on the bottom fauna, fish and mammals in the vicinity of the foundations. Marine animals are used to noise from both natural (waves, seismic activity) and man-made sources (shipping, acoustic surveying etc), to some extent, and have evolved to adapt to varying ambient noise levels. However, the amount of noise associated with operational OWFs has been recorded as being considerable. For example, Mercer (2001) recorded noise at the base of one of the Blyth offshore turbines as being sufficient to cause discomfort to divers operating close by and, in addition, noted that vibration could also be seen at the turbine base. It seems likely that this level of noise would disturb fish although it is not clear whether this is typical of wind farms anchored in sediment (rather than bedrock as is the case for the Blyth turbines). The effect of chronic disturbance occurring through the normal operation of turbines remains largely unknown (Wahlberg and Westerberg 2005).

The exploitation of offshore structures by marine mammals may be affected by the sound made during operation (Madsen et al. 2006). Marine mammals such as bottlenose dolphins, harbour porpoises (Reid et al. 2003) and common and grey seals are likely to be in the proximity of Round 2 sites (McConnel et al. 1999;

Matthiopoulos et al. 2004) and may interact with them. The impacts of operational noises depends on the frequency of the sound produced and the relative sensitivity of the species involved (reviewed by Gill 2005). A further review on this subject should be available from COWRIE during 2007.

6.3 Interaction with the water current regime

As soon as an artificial substratum is placed on the sea bed it will interact with the existing current regime in some way. Such interactions lead to areas of both elevated and depressed current exposure on and around the structure mediated through a range of hydrological phenomena including contraction of water flow, the formation of horseshoe and lee-wake vortices and the occurrence of reflection and diffraction waves (Sumer et al. 2001). The interactions between the artificial substratum and the water flow regime will, at least at some scales, increase localised turbulence as determined by the size of the structure and the rate of water flow (Guichard and Bourget 1998). Turbulent water is a complex environment that can also result in localised current speed elevations that can in turn, have important implications for sea bed erosion (Sumer et al. 2001). At the local level, this is likely to result in scour around most turbine foundations – potentially extending to up to 25m away from the structure (HR Wallingford 2005), with subsequent related effects on organisms around and on the turbine structure. Increased current velocities are likely, for example, where the current is forced around the edges (toes) of the structure while decreased current velocities may occur where the reef acts as a baffle to the movement of water (Sumer et al. 2001; Wilding 2006).

Water currents are critical to marine communities as they deliver food, oxygen and larval recruits and remove waste products (Nowell and Jumars 1984; Snelgrove and Butman 1994). The supply of juveniles to reef structures and the flow rate over suitable settlement substrata is an important factor determining settlement patterns (Snelgrove and Butman 1994) as juveniles will have current speed thresholds above which they cannot settle (Abelson et al. 1994; Breitburg et al. 1995). It is, therefore, not surprising that water current exposure is a highly significant factor determining the development of the community around man-made structures (Qiu et al. 2003). Areas of an artificial reef subjected to higher current speeds can expect an increased food supply and plenty of oxygen, compared with areas exposed to lower current speeds and are thus usually associated with increased biomass per unit area and diversity of reef encrusting organisms (Baynes and Szmant 1989).

The baffling of water currents around artificial structures, and subsequent deposition of water-borne detritus may also occur. This has been demonstrated on the Loch Linnhe Artificial Reef where an extensive impact monitoring programme is underway. Wilding (2006) for example, has shown that the major benthic impact is mediated through the deposition of phyto-detritus, but that such changes are very localised (<1 m).

6.4 Antifoulants, suspended solids and the release of historic pollutants

Offshore structures are designed to operate under well defined mechanical loadings which are a factor of their size, construction type, materials and exposure. One aspect that is critical in the design of the metal pile foundations of many turbines is their hydrostatic resistance. This is a function of their size and the hydrographic regime in which they are sited. Most offshore structures attract substantial accumulations of biomass on their surfaces. Whether this is beneficial or otherwise depends on the perspective, but any accumulation of fouling organisms will increase the hydrostatic drag to which the structure is exposed and this is considered detrimental by engineers attempting to minimise the cost of their structures. Fouling communities can be prevented from accumulating on some structures by the use of antifouling paint, a solution commonly used in the protection of the immersed sections of boat hulls. Antifoulant paints work by slowly releasing toxic components, such as heavy metals, which kill any settling organisms. The chemical prevention or periodical physical removal of fouling communities is a major cost in many maritime industries.

Under the licensing conditions for OWFs, the licence holder must ensure that all protective coatings, paints etc. are licensed for use in the marine environment and approved by the Health and Safety Executive. Information on the actual preventative measures adopted by existing wind farm operators, is scarce, but physical removal appears to be the most popular option for controlling fouling (adopted at Burbo and North Hoyle) whilst the deep-water demonstration twin-turbine proposal for the Beatrice oil platform (North Sea) will be protected from corrosion by a glass flake-epoxy based coating with zero added biocide activity (Talisman 2006). Many OWF operators remove or plan to remove fouling organisms from the turbine monopiles seemingly on an ad-hoc basis, (Ben Barton, formerly North Hoyle wind farm (now Crown Estate), Sept 2006, pers. comm.). Removal of fouling communities is also adopted at some offshore oil and gas facilities because of concerns about additional drag and consequences for metal fatigue. Removal on approximately a two year cycle allows inspections of welds and appears to be relatively common practice across the sector (Robin Gilliver, BHP, Sept 2006, pers. comm.). Although there are many hours of video inspection footage in existence from Southern North Sea platforms, which could potentially be analysed to provide a better understanding of the dynamics and diversity of communities on offshore structures in the longer term, these have yet to be analysed. Nevertheless, Whomersley and Picken (2003) investigating fouling communities on offshore platforms were able to show that despite initial significant differences in fouling communities in different geographic locations (north and south N Sea), these differences became less significant over an 11 year period and that a relatively stable community tended to develop (see also Forteath et al 1982).

Depending on the different approaches of OWF operators, where there is periodic removal of encrusting organisms on the turbine base, this will normally result in a community that is essentially permanently in the early-colonisation phase. Early-stage community development of new substrata is largely dependent on the supply of propagules to the new structure which is dependent on local hydrography and season. However, it is worth noting that if we need to use fouling communities on offshore platforms as definitive predictors of exactly which species are able to colonise OWF turbines in the same geographic area, we may need to await the development of the climax community at a given site, which on the basis of Whomersley and Picken's data appears to take about 5 to 6years (Whomersley and Picken 2003).

The biomass removed during cleaning operations (or indeed, through natural processes such as storm activity) will fall to the seabed. The direct impact of this material will be dependent on a number of factors, but is likely to be minimal in dispersive current regimes that typify many proposed and existing OWF sites. Cleaning operations are likely to be associated with temporary localised accumulations on the seabed, of mussel and barnacle debris and living shells (see also Hiscock et al 2002). This food source will attract scavenging fauna including crabs, lobsters, starfish, whelks, urchins and numerous species of fish. In addition, accumulations of shell-debris may offer additional habitat in their own right (e.g. Love et al. 1999) and, where conditions allow, may establish living communities on the seabed that may make a significant contribution to local recruitment patterns (Wilhelmsson et al. 2006).

Many of the proposed offshore wind farms sites are in close proximity to existing conurbations that have, historically, been a major source of pollutants that are transported through estuaries and deposited in marine sediments (Bryan and Langston 1992). Disturbance of these sediments, which can include those relocated during dredging operations (Rees and Walker 1984), can release these contaminants into the water column. The construction of wind farms will disturb the sediments to considerable depth, particularly along buried cable routes and through piling activity – nevertheless, this should have minimal long-term effects on reef-communities.

6.5 Propagation of invasive species

Some species are physically isolated as their dispersive phase (propagule) is insufficient to bridge gaps between suitable habitats. This includes hard-substratum-dependent species along sections of sedimentary coastline. OWFs offer opportunities for species, including invasive species, to propagate along shorelines. Species invasions have numerous negative implications for native flora and fauna and they are generally considered undesirable (Grosholz 2002). The introduction of a series of hard-substratum 'stepping-stones', has allowed the invasive alga Codium fragile to spread 300 km along the Italian coast for example (Bulleri and Airoldi 2005; Bulleri et al. 2006). However, despite our growing knowledge of the potential implications of invasion by alien species, there is no information at present to suggest that reefs associated with OWFs will provide uniquely beneficial opportunities not currently available to alien species to assist their invasion in UK waters. A range of structures including wrecks, pipelines, oil and gas platforms, buoys, coastal defences and rocky outcrops all provide comparable opportunities for invasives, and the risks associated with development at a specific OWF site would normally be assessed in the course of an EIA in consultation with the regulators and their advisors.

7 Existing Offshore Structures as Wind Farm Analogues

The development of OWFs represents a continuation of man's modification of the coastal zone, a process that has been ongoing for centuries. The earliest structures built in the sea included breakwaters and piers used to protect shipping and facilitate trade. In more recent times coastal engineering works have increased in scale to match population growth and our expansion along the coastline and, currently, large sections of coastline are modified particularly where coastal erosion is a problem. The oceans have also been extensively used as a receptacle for solid materials, such as dredging waste, and the wreckage of countless ships litters the world's oceans. Many of these substrata are analogous to OWFs in the sense that they add a novel hard substratum to the seabed and create a new reef environment.

The deliberate construction of reefs is well established practice, and has resulted in a considerable volume of both anecdotal observations and scientific research. Some of these purpose-built reefs (artificial reefs) are analogous to the scour protection material used, or proposed for use, around turbine bases. In particular, this includes artificial reefs and breakwaters. Whilst the UK oil and gas industry is largely based offshore, and there are similarities to OWFs in some sea areas, the receiving environment and operational conditions are on the whole rather different from that proposed for wind turbine structures. These aspects are discussed in more detail below.

7.1 Artificial reefs

Artificial reefs have been defined in a number of ways but perhaps the most relevant to reefs built in the UK is the definition developed by the European Artificial Reef Research Network (EARRN), later adopted by the Oslo-Paris Commission (OSPARCOM), of an artificial reef as a 'submerged structure placed on the sea bed deliberately, to mimic some characteristics of a natural reef. It could be partly exposed at some stages of the tide' (Anon 1998). This places wind farm structures outside the formal definition of an artificial reef on the basis of purpose. However, in all practical regards OWFs are artificial reefs.

In a recent comprehensive review of artificial reefs worldwide Baine (2001) identified more than 300 structures of widely varying material, with concrete, rocks, stones and boulders the most common materials, but tyres, trees and wrecks all used and contributing artificial reef effects in the context investigated. Baine also reviewed the purposes for which artificial reefs have been constructed, and these included functions such as support for fisheries management, habitat creation/protection, waste management, sports diving and seaweed culture amongst others. Artificial reefs have been used in fisheries management for a number of purposes including provision of additional habitat (Blaxter 2000; Sayer 2001), habitat restoration (Caddy 1999) and in combination with access and/or effort restrictions (Wilson and Cook 1998; Pitcher et al. 2000). In Europe, and specifically in the Mediterranean, many artificial reefs have been constructed to manage (prevent) illegal fishing on seagrass meadows (Guillen et al. 1994; Sanchez-Jerez and Ramos-Espla 2000), while in Japan the approach has been to use artificial reefs to enhance existing fisheries. In Japan fishery-enhancement artificial reefs range in size from massive structures designed to force deep, nutrient-rich water upwards to increase primary production leading to increased fisheries, to smaller units, designed to provide a substratum for algal and mollusc culture and to act as fish attracting devices (Morikawa 1996).

One of the most contentious issues within the artificial reef scientific community is the issue of whether artificial reefs merely aggregate or actually increase fishery biomass (Pickering and Whitmarsh 1997; Bortone 1998; Svane and Petersen 2001). Artificial reefs can only increase fishery biomass where there is habitat limitation for a given species, and where the resources utilised by the fishery on the new habitat would not have been used by that, or another fishery, in another location. This is a very difficult concept to demonstrate but it seems unlikely that an exploited species, where individuals are constantly removed from their habitat by fishing, will be habitat-limited, at least in terms of the habitat for fishery-sized individuals (Bohnsack et al. 1997). Estimates of productivity change following artificial reef construction are rare, and often conceptually muddled (Bohnsack and Sutherland 1985) and published economic appraisals of changes in productivity as a consequence of artificial reef deployment are equally rare. Simard (1996) concluded that in spite of the massive investment Japan has made in artificial reef technology, only octopus productivity actually increased as a direct consequence of the construction of artificial reefs.

In terms of fisheries much recent artificial reef research has focussed on the potential for augmenting crustacean species, particularly the aggressive European (Bannister and Addison 1998; Jensen et al. 1998) and American lobsters (Castro et al. 2001) and gregarious species such as the slipper and spiny lobster (Spanier 1994; Arce et al. 1997) using artificial reef technology. Crustacea such as lobsters, have a number of advantages over many finfish species in terms of sea bed farming (ranching) potential, most notably as a result of their relatively high degree of habitat fidelity (Jensen et al. 1994a) and the commercial availability of *Homarus gammarus* juveniles, at least within the UK (Whitmarsh et al. 1995). Most research into lobster ranching and artificial reefs has focussed on aspects of habitat selection and limitation (Barry and Wickins 1992) and the elimination of habitat bottlenecks (Beck 1995; Arce et al. 1997) with a view to increasing the carrying capacity of an environment and thereby the associated fishery size (Eggleston et al. 1992; Rose 2005). Economic models have indicated considerable potential for the use of artificial reefs in augmenting UK lobster fisheries (Whitmarsh et al. 1995) where the cost of the artificial reef is not borne by the lobster ranching venture (Bannister and Addison 1998; Rose 2005). However, the potential of an artificial reef based fishery is dependent on the suitability of the site to host the target species.

Almost any man-made structure placed in the marine environment is rapidly and quickly colonised by marine organisms. The degree of change depends on the nature of the pre-existing biological assemblage and the nature of the new material placed on the seabed. Regardless of their primary role, man-made structures placed on the seabed are often said to increase habitat complexity and this aspect is considered of primary importance in the subsequent biodiversity and biomass increase that is often recorded following placement (Luckhurst and Luckhurst 1978). However, Bulleri (2005) cautions against claiming that artificial reefs can enhance local biodiversity by increasing habitat complexity, thereby attracting new species, suggesting that effort should be directed at minimising the changes to patterns of distribution of organisms where possible. Connell and Glasby (1999) noted that the changes associated with artificial reefs are not necessarily beneficial if the changes in species composition and abundance lead to the degradation of other components of the system, and can even lead to undesirable effects on vulnerable or endangered species as a result of fragmentation of the natural environment, introduction of exotics etc.

In further analysis carried out on urban structures in Sydney harbour, Glasby and Connell (1999, 2001) and more recently Petersen and Malm (2006) and Rule and Smith (2005), have all noted mounting evidence that artificial reefs attract a different species assemblage to natural substrates. This effect may be further strongly influenced by materials used and the orientation of reefs with respect to current, for example (Glasby and Connell, 2001). All these authors have questioned assumptions about introduction of structures and their consequences for local biodiversity, especially in areas where international shipping potentially introduces non-native or invasive species into the local system, and artificial reefs potentially act as ‘stepping stones’ to allow them to become established.

Habitat complexity is difficult to quantify and qualify with a host of characteristics (surface texture, rugosity, degree of lacunosity and angularity) being potentially relevant (Gee and Warwick 1996). Habitat complexity is a scale-dependent concept such that the same habitat can exhibit wide extremes of complexity, depending on the scale of the observer. Currently, one of the best methods of measuring scale-dependent complexity is to determine the scale-specific fractal dimension of the surface. This procedure, which compares the distance between two points along a surface as a function of the ‘step’ length used, allows a direct comparison between different surface topographies and a scale-dependent measure of complexity (Mandelbrot 1982). The measurement of fractal dimension has been used to quantify different substrata, from scales ranging through sand, biotic substrata such as algae (Gee and Warwick 1994) to corals (Bradbury and Reichelt 1983). The scale of the complexity offered by a given habitat is of pivotal importance in determining which animals, or size of animals, can exploit the space offered. In some cases, for example encrusting organisms, additional habitat complexity can simply increase the effective area for colonisation while, for motile organisms, habitat offering complexity of the correct scale confers protection from predation in the form of hiding places and places in which to rear and protect young.

Recently settled (early benthic phase – EBP) crustacea are extremely vulnerable to predation, and many species adopt a cryptic behaviour pattern in order to reduce their chances of being predated. In the case of crustacea, such as crabs and lobsters (Linnane et al. 2001), this can include hiding among stones and cobbles or burrowing into sediment. Physical constraints may determine the environmental carrying capacity for a given species or life-stage of that species. In circumstances where there is a lack of suitable habitat, for say EPB or juvenile crustacea, then the environmental carrying capacity for relevant species can be substantially increased by rectifying that deficiency. Consequently, an appreciation of the scale-dependent aspect of habitat complexity is essential in predicting the likely utilisation of the complex habitat that may be offered by the boulder material that is currently placed, or planned to be placed, around wind-turbine bases in order to protect against erosion.

In the UK there are many structures that could be considered to function as artificial reefs, even where this is not their primary purpose. Whilst many of these will offer a habitat only tangentially related to the type of habitat likely to be offered by wind farms, two, the Poole Bay and Loch Linnhe Reef Complex, exhibit considerable similarities and will be briefly reviewed here.

7.1.1 THE POOLE BAY ARTIFICIAL REEF

The Poole Bay Artificial reef was deployed in 1989 (see Figure 6), primarily, to assess the environmental suitability of cement stabilised blocks that contained a large proportion of coal ash. Each reef unit, of which there are eight (totalling 50 tonnes), is ca. 1 m high and 4 m diameter and consists of conical heaps of blocks (Collins et al. 1990). Colonisation of the reef was rapid and within weeks lobsters, edible crabs and shoals of pouting were observed in and around the structure (Jensen et al. 1994b). Epibiotic colonisation developed so that by the end of 5 years the Poole Bay reef held many of the species found on local reefs in Poole Bay. A single 60 mm total length lobster was caught in a prawn pot suggesting that the reef may have provided habitat suitable for the post-burrow, early cryptic phase of the lobster life cycle (Dr. A. Jensen, NOC, Feb 2007, pers.comm.).

The reef site was the focus for a long term (18 month) tagging and telemetry study of lobsters which quantified activity patterns in relation to environmental factors (Smith et al. 1999, 2000, 2001). In addition to these studies long term data sets that described the community development since 1989 and the block chemistry exist, and these provide useful information to assist in identifying appropriate material and suitable configuration around turbine bases. Later developments were additions of tyre structures and their concrete controls to evaluate the environmental acceptability of tyres as an artificial reef material (Collins et al. 2002).

Figure 6: Artist's impression of the Phase one of the Poole Bay Artificial Reef (left) together with (right) a recent (2006) underwater shot of a diver and epibiotic community on the Poole Bay reef. (Illustration and photo courtesy of Dr. Antony Jensen, National Oceanographic Centre, Artificial Reef Group, Southampton).

7.1.2 THE LOCH LINNHE ARTIFICIAL REEF

The Loch Linnhe Artificial Reef was designed to emulate the scale of artificial reef considered necessary to make a significant contribution to fishery enhancement in coastal waters. The reef complex consists of a main matrix of 30 reef units, each of approximately 4000 concrete blocks (120,000 blocks in total). The reefs are made using either solid blocks or blocks containing two voids; the resultant reefs weigh 200 or 140 tonnes respectively (total 7000 tonnes) and are deployed in water of between 12 and 30 m depth (Figure 7). Each reef unit is 4-5 m in height and has a diameter of 10-20 m (Figure 8) and closely resembles the scale of the ballast used at the bases of some wind-turbines. Construction of the reef complex was completed in 2006. The reef complex is unique as it covers a broad-range of hydrological conditions with some reef-modules being exposed to strong tidal currents whilst others are located in much calmer conditions. Associated with the gradient in current exposure, is a gradient in sediment type with the reefs in the NE sector lying on cobble strewn silty-sands, whilst at the opposite end, the reefs lie on muddy sediments. These environmental gradients and varying habitat complexities allow the proper scientific investigation of the role of a variety of factors determining how such man-made interventions interact with a range of receiving environments, particularly in relationship to fishery species.

Figure 7: The layout of the Loch Linnhe Artificial Reef showing the main complex (30 modules) overlain by bathymetry. (Figure reproduced courtesy Dr. Tom Wilding, Scottish Association of Marine Sciences).

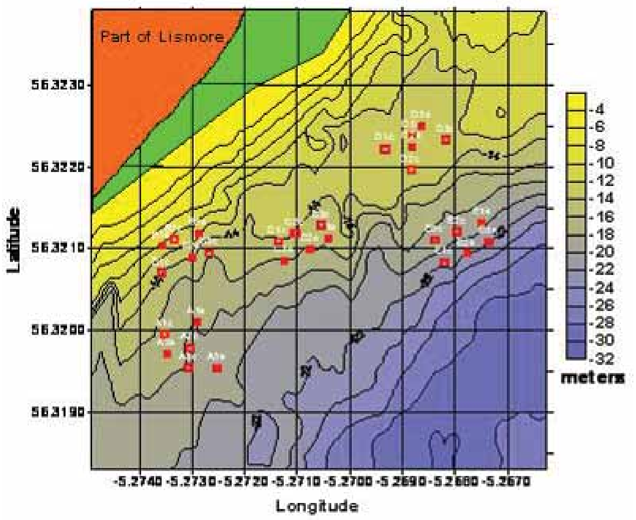
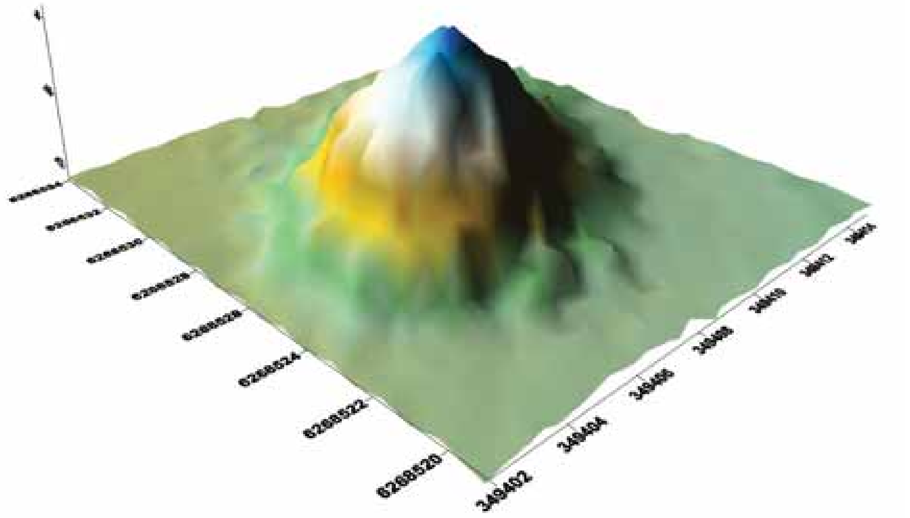


Figure 8: Acoustic (multibeam sonar) image of one of the reef modules making up the Loch Linnhe Artificial Reef complex. (Figure reproduced courtesy Dr. Tom Wilding, Scottish Association of Marine Sciences)



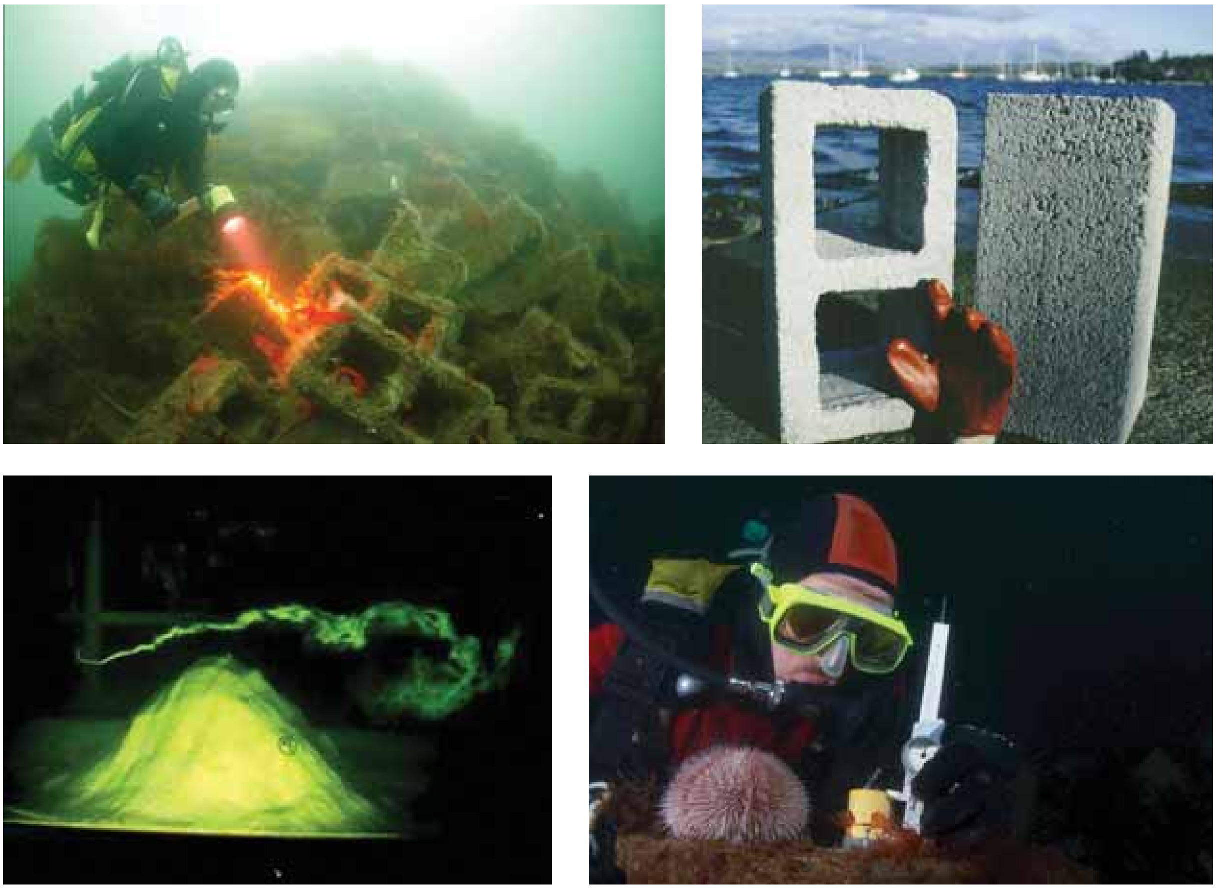
There is an active programme of research associated with the Loch Linnhe Artificial Reef all of which is highly relevant to OWFs. This programme is currently focussing on:

- Monitoring the impacts of reefs on the receiving environment (Wilding 2006)
- Modelling and measuring habitat complexity offered by artificial reefs (Rose 2005)
- Modelling and measuring fluid flows around artificial reefs (Aston 2006)
- Comparisons of productivity between natural and artificial reefs (Beaumont 2006)
- Visual counts of fish and other megafauna around the reef structures (Hunter 2006).

The opportunities for longer term investigations at both Poole Bay and Loch Linnhe artificial reefs are particularly valuable to support further investigations of reef effects within OWFs. An understanding of the changes in species composition of artificial reef communities is still required to provide greater insight into the long term viability and success of future projects associated with OWFs, particularly where natural seeding of structures to support commercial operations is being considered. Perkol-Finkel and Benayahu (2005) undertook a ten year monitoring programme of artificial reef communities, which showed a distinct shift in the community composition over the ten year period. This outcome, they suggested, strongly indicated the need for a complex and heterogeneous structure to support the development of diverse communities. With reference to further comparative studies on a shipwreck, Perkol-Finkel et al (2006) also pointed out, that long term studies are really needed to ensure that the state of biological equilibrium attained at a given artificial reef – often in not less than a decade – equates in some measure with the ultimate goal of the artificial reef deployment in the first place.

Other aspects which can usefully be addressed at these research sites include the investigation of impacts resulting from deployment itself, by considering effects on hydrographic regime, tidal currents, sediment deposition and dynamics etc. When coupled with pre-deployment studies, these allow a holistic and detailed understanding of the physical factors and their interaction at the reefs deployment site (Wilding and Sayer 2002). Further information on the recommended forward programme of research is provided later in this report.

Figure 9: The 4-5 m high reef modules (top left) are constructed using 4000 concrete blocks (either containing voids or solid) (top right). Research in progress includes the visualisation of fluid-flows around physical models (bottom left image courtesy Zoe Aston University of Newcastle) checked with by measuring fine-scale current flows, in situ, by monitoring the dissolution rate of calcium sulphate (bottom right). (Photos courtesy Dr. Tom Wilding, Scottish Association of Marine Sciences).



7.2 Breakwaters

In the UK a majority of the artificial reefs are constructed for the purpose of protecting shorelines by mimicking natural reefs. Some of these structures are massive, for example the Happisburgh-Winterton coast defence works extends many kilometres along the East – Anglian coastline (Hamer et al. 1998) (Figure 10).

Other breakwaters include the offshore (permanently submerged) Torness artificial reef. The Torness artificial reef was constructed using 210,000 tonnes of rock debris excavated from the site of the nuclear power station at Torness Point. The reef consists of 60 modules deployed in an area measuring 1000 m by 150 m. Each module is between 3,000 and 5,000 tonnes in weight and consists of an assortment of rock sizes with a targeted maximum of 75 kg (approximately 0.30 m3) although larger rocks have been recorded following deployment making it 'coarser' than much of what is proposed for deployment around wind-turbine bases. Not withstanding this, (Bentley and Todd 1999) reported higher abundances of cod around the artificial reef units, probably as a consequence of increased food availability.

Figure 10: Part of the Happisburgh – Winterton coastal protection works (courtesy of Van Oord UK Ltd)

7.3 Sarns

Sarns consist of long (>10 km), narrow ridges of poorly sorted glacial outwash and moraine that lie in predominantly shallow water. In the UK they are only found in Cardigan Bay, Wales. This environment (with respect to the boulder size and hydrographic regime) closely mirrors that likely to occur at the turbine bases located in many of the Round 2 sites. Sarns, being shallow (0 – 20 m) are both exposed to storms and to erosion as tidal streams are accelerated over their tops during certain states of the tide. Ephemeral species associated with this harsh, changing environment include epibenthic algae, particularly phaeophytes, with fauna being comparatively both less abundant and diverse. On the sarn crests the alga *Chorda filum* has been reported to be common whilst in slightly deeper water the algae *Laminaria digitata*, *L. saccharina* and *Halidrys siliquosa* and their epiphytes are also recorded as common. The most notable fauna are mussels *Mytilus edulis*, starfish *Asterias rubens*, *Cancer pagurus* and *Homarus gammarus*, fish such as the corkwing wrasse *Crenilabrus melops* and dogfish *Scyliorhinus canicula*. The sarns also support numerous other epibenthic species, notably sponges, barnacles, and byrozoans (for a full species list see Hiscock 1986).

7.4 Oil platforms and rigs

The most ubiquitous offshore constructions, particularly in the North Sea are oil platforms and the immersed sections of oil platforms consist of a superstructure of steel and concrete, superficially similar to the foundations proposed for many wind-turbines. Whilst a considerable amount of research has been conducted into the potential reef-effects of such structures, the majority of this work has focussed on the US experience (Gulf of Mexico), particularly in relation to the disposal of redundant structures specifically to assist the sport fishing industry (Kaiser 2006). The large-scale abandonment of such structures ('Rigs-to-Reefs') in the North Sea is a hotly debated subject (Baine 2002).

Platforms which are located in the general Greater Wash area in comparable water depths to OWFs include Waveney (Perenco), Guinevere A (ExxonMobil, Pickerell A and B (Perenco), Amethyst BID and CID (BP) and the Rough Platforms (BG). Similarly in the general area of the North-west Round 2 area, again in comparable water depths, are the Douglas platforms (BHP), the Morecambe platforms (HRL), Hamilton (BHP) and Lennox (BHP). Whilst these oil platform structures are superficially similar to wind-turbine foundations there are some important differences related to the receiving environment, operation and design. North Sea platforms have, at least in the past, discharged considerable organic material into the sea (waste food, sewage, contaminated drill-cuttings etc.) and are, in this and many other ways, operationally very different to wind farms. In addition, whilst the individual pylons making up the oil platform may be similar to those proposed to support wind turbines, they are built into relatively complex structures which offer considerably more to fish and other organisms sheltering among them. So, whilst oil-platforms (operational or otherwise) have often been associated with aggregation of fish, and the problems of removing fouling communities are well known to operators, the absence of peer reviewed articles or data which has been analysed in an appropriate format (e.g. Video inspection surveys) to assist this study, there is little predictive guidance other than through personal contact or anecdote, which is directly applicable to the current analysis.

Nevertheless, it is clear that BHP, for example, regularly remove fouling communities from offshore structures because of the concern regarding drag, but data has not been retained on the extent or nature of the fouling communities which could be utilised here for predictive purposes. Recent papers (Soldal et al. 2002, Jorgensen et al, 2002, Lokkeborg, 2002) do however quantify fish presence around platforms and provide some idea of survey techniques which could be used around OWFs in the future. Also Forteath et al.(1982) provided examples of platform locations where new hard substrata, often significant distances from the nearest source of epibiotic larvae and/or propagules, were successfully colonised by fouling communities and Whomersley and Picken's (2003) data demonstrates unequivocally that propagules of most common fouling species are able to remain viable in the plankton long enough to colonise structures considerable distances offshore, and in all cases further offshore than the locations of Round 2 OWF sites currently being developed.

Therefore, despite the lack of published data describing oil platform fouling communities, existing published articles from a variety of sources provide adequate evidence to predict the likely colonisation of OWFs by common species, including some which are potentially commercially significant. However, the number of publications should increase in the future as industry/academic collaboration by groups such as the SERPENT project develop.

8 Artificial Structures as Mitigative Measures

Artificial reefs are increasingly regarded as attractive management measures in that they contribute to ecosystem conservation, fisheries sustainability and assist in zoning marine areas thereby reducing conflicts between users. They have been established for the purposes of mitigating impacts on biodiversity (Bohnsack and Sutherland 1985, Ardizzone et al. 1996), fisheries management (Nakamura 1985, Polovina 1991, Bohnsack et al 1994, Boaventura et al, 2006)) and enhancing economic profitability (Whitmarsh and Pickering 1995, 1997) and the use of artificial reefs for fisheries production is one of the oldest and key motivations for their construction (Jensen 2002). Such a use is usually dependent on ecological processes such as recruitment, intraspecific competition and trophic interactions among the various species present. More recently however, environmental and conservation concerns have been instrumental in the development of new functions for artificial reefs, and objectives such as water quality improvement and ecosystem restoration have also been pursued.

In the context of offshore wind power development, there is considerable interest in the utilization of the new habitats created by artificial substrata (i.e. scour-protection placed at the base of wind turbines) to promote biodiversity benefits (Copley 2006), and to mitigate against habitat losses and/or environmental degradation occurring as a consequence of man's intervention in the coastal zone (Pickering et al. 1998). However as Copley, (2006) noted, these are rarely the primary goals of introducing hard substrata into the marine environment – usually there are other reasons, often related to amenity e.g. diving, surfing or fisheries enhancement, and so in general, the biodiversity benefits have often not been adequately assessed. Also there is a tendency to undervalue the intertidal soft sediment areas (Copley 2006), which tend to be the main areas where habitat is being lost. Nevertheless, artificial substrata are widely considered to both increase/enhance local biodiversity and productivity, and thus they may have the potential to mitigate against negative impacts in the context of individual OWF development projects, where an assessment of impacts leads to net benefit overall as a result of their introduction.

In evaluating the potential for mitigation of habitat loss using artificial reefs, consideration has to be given to the communities that artificial substrata host, as these can be quite different from their natural counterparts (Santos and Monteiro 1998; Aseltine-Neilson et al. 1999). This requires an objective assessment of the relative merits of a general increase in biodiversity *per se* over an increase in species that naturally and locally colonise local hard substrata. This issue is complicated where there is a lack of hard-substrata and, therefore, baseline community for comparative purposes, and emphasises the need to specify and justify the outcome of any benefits considered to accrue directly as a consequence of OWF development (Pratt 1994).

There are several well documented instances of artificial reefs being used to mitigate against losses in benthic productivity. For example, in Delaware Bay, US, artificial reefs have been shown to increase productivity by between about 150 and 900 times compared with the natural substratum at the site (Burton et al. 2002; Steimle et al. 2002). In this example, the loss of benthic productivity occurred as a consequence of the dumping of dredged material and was still not fully compensated by the introduction of artificial reefs. In any event, the justification of major changes in seabed use by making-up for productivity losses in other areas, represents a gross simplification of the value of more expansive, albeit less productive, areas of seabed.

In another instance where an artificial reef was constructed to mitigate losses of rocky habitat resulting from a shoreline development project, significant increases in economically important fish species were reported (Hueckel et al. 1989). These increases also proved to surpass those of natural rocky bottom investigated adjacent to the development site. This strongly suggests that artificial reefs have potential not only to mitigate against habitat loss, but to enhance productivity generally, and can be designed and manipulated specifically to yield the required biological and socio-economic outcomes, to develop the commercial potential of a sea area (Jensen, 2002). However, the effects of artificial reefs are sometimes ambiguous – Ambrose and Anderson (1990) observed that some species of infauna were enhanced whilst others were depressed around an artificial reef, and so assumptions about the consequences for mitigating habitat loss or productivity cannot be made without reference to local species and ambient environmental conditions. Given the current state of knowledge about interactions between environmental factors and biological community development, research involving a number of different pilot experimental structures may well provide the best approach to ascertaining the exact reef design that will have the desired mitigation effect.

The significant biomass associated with some artificial reefs has resulted in artificial reefs being proposed as a mechanism for improving water quality (Hughes et al. 2005). Of primary interest in this capacity is the mussel which, en masse, filters large volumes of water and is effective in removing particulates including those of organic origin. This approach has been proposed as a method to clean up the degraded marine ecosystem of Neva Bay, Gulf of Finland by promoting the growth of zebra mussels (*Dreissena polymorpha*) (Antsulevich 1994), in the Pomeranian Bay (Southern Baltic) by promoting growth and subsequent removal of blue mussel (*Mytilus edulis*) (Chojnacki, 2000)and to utilise the elevated concentrations of dissolved nutrients and particulate matter derived from fish farming operations (Angel et al. 2002; Angel and Spanier 2002).

Perhaps the best example of purpose-built artificial structures in a mitigative role comes from the US, where an extensive pilot reef system has been constructed to mitigate against kelp biotope loss, following the construction of the San Onofre Nuclear Generating Station (SONG) in California (Ambrose 1994;

Deysher et al. 2002). In this instance surveys of natural reefs were conducted prior to the deployment of the artificial reefs, to establish which design configuration would be most likely to facilitate recruitment and long-term survival of kelp. Low-relief, solid rock reefs with moderate coverage of sand were considered optimal (Deysher et al. 2002) and results from surveys on the newly constructed 56 – module experimental reef has shown encouraging results. This work emphasizes the need a *priori* to consider design aspects of artificial substrata to facilitate functioning of specific ecosystems. This concept is already appreciated in the design of offshore coastal protection structures that aim to maximize ecosystem benefits, whilst simultaneously protecting the coastline (Martin et al. 2005).

Habitat loss mitigation can be directed to restoring a generic habitat and/or aimed at specific species. Single species restoration activities are often directed towards fisheries, individual coral species or algae (as in the SONG example above). Where fisheries are concerned, care must be taken in restocking to ensure that local genotypic adaptations are preserved. The extent of genotypic adaptation is likely to be a function of the relative isolation of the stock in question (Ward, in press) and failure to consider this can result in genetic dilution and the deterioration of local stocks.

9 Habitat Requirements and Potential Fishery Augmentation of Major Commercial Crustacea

The UK hosts several commercially important crustacean fisheries. These include species such as prawns (*Nephrops*), lobsters and various crab species. Of primary interest to the current review are the reef-occupying species which include the brown crab and, in particular, the European lobster.

9.1 Edible crab (*Cancer pagurus*)

The edible crab (brown crab) is a widely distributed, carnivorous/omnivorous and commercially important decapod (Lawton and Hughes 1985; Addison and Bennett 1992). The edible crab exploits a broad-range of environments, ranging from soft muds into which it can hide or dig for food (Hall et al. 1991; Hall et al. 1993), to hard, rocky substrata where it exploits, and seeks shelter, in crevices. Alongside the broad range of habitats adopted by brown crabs is a tolerance of current speeds ranging between 0 and 3 knots, varying exposure and a depth range of 0 to 100 m (Neal and Wilson 2007). Adult brown crabs are sensitive to reduced salinities (<17), a sensitivity not shared by juveniles (Wanson et al. 1983).

Given the catholic nature of habitat selection by the brown crab, with the exception of brackish environments, it is probable that they will, if previously present, be largely unaffected by the presence of offshore wind farms; Todd and Bently (1992) have demonstrated such a finding on the Torness artificial reef. Unlike lobsters, it is apparent that not all crabs are obligate reef-dwellers and there is, therefore, probably limited potential to increase local stocks through reef-provision. The main evidence for relationships between crabs and artificial reefs comes from the detailed studies of Page et al (1999), who demonstrated the relationships of crabs to artificial structures can be extremely complex and species specific (see also http://www.hornsrev.dk/Miljoeforhold/annualreport2004).

They were able to show that four species of commercially important crab exhibited different relationships to an offshore oil platform, with platforms providing recruitment habitat for *C. antennarius*, with individuals staying as residents in the vicinity, whereas *C. anthonyi* (which were recruited elsewhere), were attracted to the platform and aggregated as adults around the platform. On the other hand *C. productus* and *Loxorhynchus grandis* were also recruited elsewhere, but occurred temporarily at the platform without aggregating. Page et al therefore concluded that these inter specific differences in abundance, recruitment behaviour and distribution, demonstrated a clear need to consider the responses of individual species to artificial reefs before making assumptions about their effects on crab populations. Although there is some evidence to suggest that crab populations increase over time in association with OWFs, (the number of adults and juveniles increased markedly between 2003 and 2004 at Horns Rev http://www.hornsrev.dk), this effect could apparently be explained by natural succession predation and recruitment phenomena. Consequently the evidence so far suggests that it is very unwise to make assumptions about the additional production associated with the reef structure, and its enhancement of the local crab production. Where the presence of wind farms in existing brown crabs areas precludes fishing, then the fishery can be expected to be commensurately smaller.

9.2 The European lobster (*Homarus gammarus L.*)

The European lobster is an aggressive, highly prized fishery species. Over the last 20 years considerable research effort has been focussed on enhancing lobster stocks through the release of juveniles, both in the UK and abroad, particularly the US, where the focus has been on the closely related species *H. americanus* (Kline-Milne). Evidence from both species will be used in the prediction for the purposes of this review.

Lobsters have a dispersive larval phase, of approximately one month, after which the larvae settle onto the benthos and enter the early benthic phase (EBP) (Bannister et al. 1994). Competent larvae target habitats where they can find shelter, and such habitats include cobbles and rocks, under which they can hide, to a cohesive mud, into which they can burrow (Bannister et al. 1994). Lobster larvae will reject motile, non-consolidated sands and gravels (Cobb and Wahle 1994). The EBP lasts two to three years (5 to 35 mm carapace length), during which time the lobster adopts a cryptic lifestyle in order to reduce its vulnerability to predation (Wickins et al. 1996).

Lobsters are omnivorous and exploit various food sources dependent on their particular habitat. Burrow-based EBP individuals will take anything manageable that they come across, through burrowing, or which subsequently falls into the burrow in addition to suitable epibenthic organisms growing in the tunnel (Wickins et al. 1996). Food includes bivalves, polychaetes, echinoderms and macroalgae (Elner and Campbell 1987). Lobsters eat until satiated hiding any left-over food for consumption at a later time (Wickins et al. 1996). The growth and survival of juvenile lobsters is greater where there is a consistent and plentiful food supply, the latter occurring as it precludes the need for risky excursions in pursuit of food (Wickins et al. 1996).

As juvenile lobster grow they become decreasingly liable to predation and, concomitantly, increasingly vagile. Burrowing lobsters are forced from their enlarged tunnel systems by collapse and under such circumstances, the lobsters leave the burrowable habitat and move into a more suitable rocky habitat. Shelter-seeking behaviour occurs during ecdysis, when the lobster is particularly vulnerable to predation (and during which time mating occurs) and, more routinely, to escape strong currents. Whilst lobsters are considered to show a degree of site fidelity there are records of them moving significant distances, for example, Jensen et al (1994a) recorded an individual *H. gammarus* moving 16 km from an artificial reef on the South coast of the UK while Cobb and Wahle (1994) report that *H. americanus* may wander hundreds of kilometers per year, probably as part of a autumn/winter migration between shallow coastal water and off shore canyons.

The depth distribution of lobsters is determined by depth-associated physical factors such as exposure to wind and tidal currents, salinity and temperature. Shallow water offers less of a buffer to such physical forcing, particularly wave action which can be expected to be severe at many of the proposed offshore wind farm locations. When a given habitat necessitates either excessive sheltering from currents, or provides an insufficient supply of food or oxygen through insufficient current, the result will be the same – a reduced growth rate and survival. Whilst *H. americanus* can survive salinities as low as 10 ppt, for extended periods (days to weeks), it suffers increased metabolic costs and reduced growth rates as a consequence (Jury et al. 1994). Even if *H. gammarus* tolerates similar salinity reductions in estuarine environments, particularly those associated with periodic reductions in temperature, these conditions are stressful and likely to be predominantly unsuitable environments.

Pre-adult and adult lobsters are reef-obligate and select sites that supply sufficient food and oxygen (Howard and Bennett 1979) and shelter from currents and predation (Stottrup et al. 1998; Linnane et al. 2000). A number of criteria, including den length, entrance size, presence of multi-openings (escape routes), internal aspect ratio (manoeuvring space) are all aspects that may influence the suitability of cracks and crevices for lobsters. As lobsters grow (in steps following ecdysis) they need to move to increasingly larger crevices. As a given cohort of lobsters grows, it suffers mortality that is dependent on a number of factors. These include predation, competition and disease. In attempting to provide a lobster-bespoke habitat (‘designer-reef’) the goal is to provide a spectrum of habitat-sizes that maximizes the survival of the cohort.

9.2.1 POTENTIAL IMPACT OF OWFS ON LOBSTER FISHERIES

There is potential for augmenting local lobster fisheries, through habitat provision, in habitat-limited circumstances. However, to offer any significant potential the additional habitat created by the offshore structures must be located in areas that are otherwise suitable for lobsters. Lobsters are ubiquitous around the UK and, therefore, one of the best indicators of the suitability of a habitat is the presence of existing populations. This need not include adults, particularly in circumstances where juveniles are prevented from growing sufficiently large to enter the local fishery as a consequence of a lack of habitat. It is worth mentioning that where populations are effectively habitat limited, there is some evidence to suggest that artificial habitats can augment the fishery. Briones-Fouyrzan and

Lozano-Alvarez (2001) investigated the potential of artificial shelters to enhance populations of lobsters, and were able to show that by mimicking the large crevice–like shelters sought by juvenile spiny lobsters, density increased significantly in experimental sites in comparison with control sites.

The environmental conditions preferred and tolerated by lobsters are summarized in Table 7 below. Lobsters will not be successful in areas characterised by motile sands and gravels and/or frequent and strong wave induced currents. This effectively means that shallow, exposed areas are unlikely to be suitable. However, some areas, for example, around Cromer are characterised by sand, yet sustain lobster fisheries. These may be associated with the polychaete *Sabellaria spinulosa*. This is a tube building worm that can stabilise otherwise mobile sediments through the construction of tubes that can aggregate to form reefs. These reefs offer complexity at a scale relevant to lobsters (all sizes) and a hard substratum facilitating diverse, productive epibenthic communities. However, at the present time, it is unclear whether these communities have potential to enhance the growth and survival of lobsters.

Table 7: Summarising the environmental preferences and tolerances of *H. gammarus* with respect to temperature, salinity, oxygen, pH and ammonia. (from Kristiansen et al. 2004)

Parameter	Optimal condition	Natural range	Lethal condition
Temperature (C)	18 – 22	1 – 25	<0, > 31
Salinity	28 – 35	28 – 35	<8, >45
O_2 (mg l^{-1})	6.4	4.0 – 8.2	<1, >saturation
pH	8	7.8 – 8.2	<5, >9
Ammonia (mg l^{-1})	<0.14	0 – 0.3	>1.4

However, to evaluate the potential for OWFs to augment local fisheries at a given site, a systematic assessment of the extent to which the habitat is currently limiting the population size (and size-structure) is required.

Table 8: Summary of conditions in Round 2 areas and their suitability for lobsters with respect to substratum and food, temperature/salinity and shelter. [See http://www.offshore-sea.org.uk/consultations/Wind_R2/index.php and Milligan (2005)]

Key to conditions: 1 = poor; 2 = fair; 3 = good; 4 = excellent.

R2 area	Shelter/ Substrate/food	Temp/ Salinity	Notes on conditions in Round 2 area lobster fisheries
North-West (Solway to N Wales coast)	1/1/1	1/3	Taken throughout the year in pots and as by-catch in bottom trawls/fixed nets; population may be limited by availability of suitable substrate – artificial reefs and turbine foundations may be beneficial.
The Greater Wash	2/2/3	2/3	Major lobster fishery throughout the year peaks May to November – second most valuable species for potting fleet; population may be limited by suitable substrate – artificial reefs and turbines may be beneficial.
The Thames estuary	1/2/1	2/3	Taken in pots throughout the year peaks May/June; important species for fishing fleet; population limited by availability of suitable substrate artificial reefs and turbines may be beneficial.

Table 8 summarises the conditions in Round 2 areas relevant to lobster growth and survival, and although all the Round 2 areas host lobster fisheries, Milligan (2005) suggests that in all areas lobster populations are limited by availability of suitable substrates. The introduction of artificial structures may therefore provide additional habitat which could be exploited. Although lobsters survive in all three areas, the conditions in the Greater Wash area appear to be generally more suitable for lobster growth than in the other two Round 2 areas (see also Appendix i). The Thames estuary may have more potential than is apparent at present, and the deeper water sites would probably merit further investigation.

10 Aquaculture Potential of Offshore Wind Farm Sites

This section considers the potential for aquaculture within OWF footprints, as opposed to the enhancement of the populations of naturally occurring species for commercial exploitation. We assume that development of aquaculture in association with OWFs would apply the principles of sustainability, and although 'sustainable aquaculture' is generally accepted to mean that fish and shellfish are cultivated under environmentally friendly conditions – for the purposes of this review, sustainable aquaculture is defined as *'the development, culture and management of fisheries/shellfisheries resources in a manner which ensures that the activity is environmentally non-degrading, technically appropriate, economically viable and socially acceptable, thus contributing to the satisfaction of human needs for present and future generations'*. (adapted from FAO 1997).

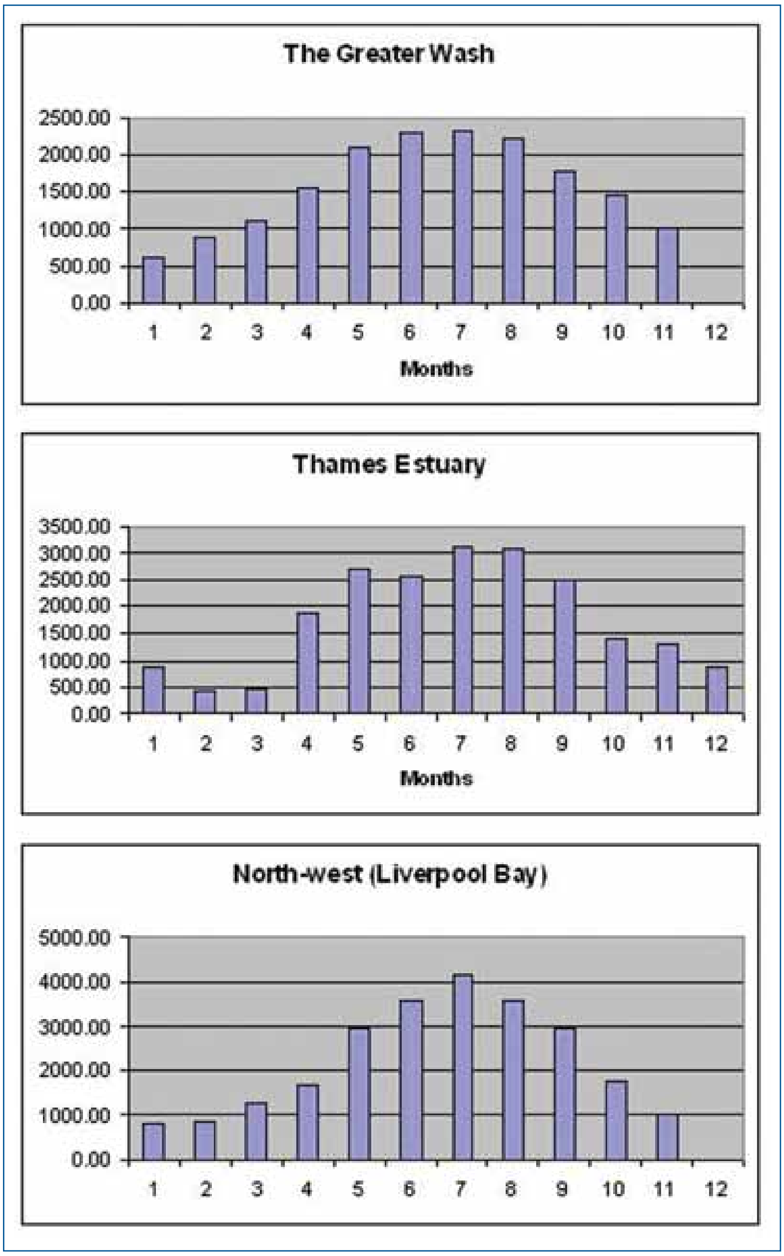
10.1 Commercial species of bivalves

Mussels (*Mytilus edulis*) are common in the intertidal/inshore areas of all the Round 2 areas and are dredged and/or hand picked mainly through the winter months in all areas, although in the Eastern Irish Sea area (North-west) this activity continues through to July/August (Milligan 2005). Mussels have also been recorded on sarns off the west Wales coast (Hiscock 1986) and at the Montrose Alpha platform in the North Sea (Forteath et al 1982), the Tern Alpha and Eider B platforms in the northern sector, as well as Gannet Alpha and Kittiwake Alpha in the central sector (Whomersley and Picken 2003). At these locations they remained present throughout the 11 year time series of observations, demonstrating the potential for mussel larvae to remain viable in the plankton whilst being transported long distances. Consequently it was not surprising to see that mussels were amongst the first organisms to settle on turbine towers at North Hoyle (see Figure 12) and for the potential within the OWF footprint for culture of shellfish to be recognized (Dr. Stephen Lockwood, Independent consultant, Sept 2005, pers. comm.). However there is a significant amount of work to be done to test the feasibility of this development option, now briefly reviewed below.

10.1.1 GENERAL ENVIRONMENTAL CONSIDERATIONS

Within all three Round 2 areas (North-west, the Greater Wash and the Thames Estuary), seasonal variations in temperature, salinity, suspended particulate matter range from 5 to 18°C, 31 to 36 ppt and 2 to 250 mg l^{-1} respectively (See Appendix ii summarising data provided by BODC and Figure 11 below). These variations lie well within the environmental conditions tolerated by mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas*), which demonstrate remarkable physiological plasticities (Hawkins and Bayne 1992; Gosling 2003). Both *M. edulis* and *C. gigas* continue to grow unchecked at temperatures of up to at least 20°C (Widdows 1978; Shpigel 1992), fully compensating through osmotic regulation for reductions in salinity down to at least 20 ppt (Almada-Villela 1984; Brown and Hartwick 1988), and with responsive feeding behaviours that maintain organic absorption rates over ranges of turbidity which may exceed 400 mg of suspended particulate matter l^{-1} (Hawkins et al. 2006).

Figure 11: Monthly average primary production (mgC/m2/day) based on remote sensing data 1998 to 2003 corrected using Morel (1991). (Data supplied by Tim Smyth, Plymouth Marine Laboratory)



Notwithstanding the physiological and physical limitations, recent studies by Buck et al. (2005) have also demonstrated that offshore culture of mussels may benefit from a number of advantages in comparison with inshore sites. These include beneficial effects on growth performance, increase in product quality, reduced levels of parasitic infection and so on. These would be important considerations with respect to the profitability of a shellfish culture operation, but would need to be set against the increases in time and resource in steaming to sites and difficulties in maintaining rafts etc. during sub-optimal weather conditions. Buck et al (2005) also commented that these outcomes are likely to be very site specific depending on the levels of contamination etc. of adjacent waters and should not be assumed until pilot scale trials have been undertaken. There may be more interest in pursuing offshore shellfish culture in future as many estuarine sites become less viable (and downgraded) as a result of persistent water quality problems

10.1.2 CONSTRAINTS TO OPTIMUM PRODUCTIVITY

Within the general ranges of temperature, salinity and suspended particulate matter, net energy balance and growth in *M. edulis* and *C. gigas*, (and other mussel and oyster species such as *M. galloprovincialis* or *Ostrea edulis*), can be compromised by food availability, becoming negative in waters where phytoplankton concentrations as indicated by chlorophyll fall below thresholds of about 0.8 µg chlorophyll l^{-1}, whilst normally showing good positive growth at about 2 µg chlorophyll l^{-1}, and even faster growth during transients blooms when concentrations may exceed 20 µg chlorophyll l^{-1} (Hawkins et al. 1999; 2006).

In both the North west and the Greater Wash, chlorophyll concentrations typically fall below 0.8 µg l^{-1} during winter months between about November and March (as Figure 11above, and see also Appendix ii). At all other times of year, chlorophyll concentrations in the North west and the Greater Wash exceed that minimum threshold of 0.8 µg chlorophyll l^{-1} for growth, where concentrations have been recorded in excess of 5 µg l^{-1}. However, an annual survey undertaken by Dr. Mark Trimmer (Queen Mary College, University of London, Sept 2006, pers. comm.) indicates that concentrations of chlorophyll in the outer Thames estuary may remain below 0.8 µg l^{-1} throughout the year. (see also Appendix ii).

Therefore, on the basis of data indicating typical ranges of temperature, salinity, suspended solids and chlorophyll, it seems likely that both *M. edulis* and *C. gigas* will survive and grow in the North west and the Greater Wash areas, but that there may be insufficient food, at least in terms of living phytoplankton, to sustain profitable annual growth within the outer Thames Estuary. Although in terms of shellfish diet this may be supplemented by non-living organic detritus, the availability and concentration year round needs further evaluation. Other issues, such as potential levels of mussel predation by eider duck, may also influence the practicality of bivalve aquaculture at OWFs, but these need further assessment at specific sites.

10.1.3 DEVELOPMENT OF SUSTAINABLE BIVALVE CULTURE OPTIONS AT OWF SITES

Existing baseline data from Round 2 areas, some of which is site specific to OWFs (see Appendix ii), currently allows us to predict with reasonable confidence that mussels could grow well given literature values of minimal requirements (see also Figure 12 below). However, much better quality information will be required to estimate sustainable ecological capacities for shellfish growth at individual OWF sites and to ensure investor confidence in a commercial development plan for shellfish culture at a given OWF site. Miller (2002) discussed the application of experimental ecological approaches to establishing ecological processes and yielding specific improvements in the application of artificial reefs to achieve management goals. However, it became apparent in the course of Miller's research that the outcomes were strongly site dependent, whether increased fisheries production, improvements in water quality or habitat restoration were under consideration.

The logical extension of Miller's work is the fully integrated approach to modelling sustainable shellfish production capacity currently being developed at PML, and applied for e.g. in China (see SPEAR: Sustainable options for People, catchment and Aquatic Resources (www.biaoqiang.org) and in northern Irish sea loughs (see www.ecowin.org/smile). This approach would establish the optimum mix of species and carrying capacity in response to local environmental conditions at a given OWF site. In effect, site specific models describing the hydrodynamics, land-based inputs, primary production and seston availability are linked with those describing the feeding, metabolism, growth and population dynamics of each shellfish species, taking into account interrelations with other organisms that already exist within each given OWF environment. Only by modelling the complex set of feedbacks, both positive and negative, whereby suspension-feeding shellfish interact with ecosystem processes, can we realistically assess the sustainable environmental capacities for enhancement and/or culture within an OWF, prior to recommending development and investment in a particular aquaculture development facility (Dowd 1997; Prins et al. 1998; Bacher et al. 2003; Duarte et al. 2003, 2005; Nunes et al. 2003).

Figure 12: Photographs showing North Hoyle turbine towers and associated young whiting (left) and dense settlement of mussels (right) observed during 2004 monitoring surveys. (Photos reproduced courtesy of Francis Bunker, MarineSeen, Pembroke, SA71 5RN).

Currently none of the OWF sites which are progressing leases have adequate environmental baseline data to allow predictions of shellfish production using this type of model at the present time. However, once set up for a specific site, and calibrated for local environmental conditions, the shellfish models have the potential to predict sustainable production capacities of shellfish, which will be important in linking production with market capacity. Also the models can predict the consequences of ecosystem perturbations for shellfish production – for example, changes in food supply, temperature changes and knock on effects for growth and productivity of shellfish. These studies would need to be linked to others focusing on the optimal production technology for deployment within a specified OWF footprint. We would see a pilot study at a given OWF site, indicative of the likely potential within each Round 2 area, as the next step, and further details of taking this forward research are provided later in sections.

Also, as there is evidence to suggest that the presence of artificial structures alters the components of the benthic infaunal community, with potentially important implications for nutrient regeneration around artificial reefs (Danovaro et al, 2002), it would theoretically be possible to test the potentially enhancing effects of an artificial reef in close proximity to mussel rafts using this modelling approach. This type of effect might develop in intensity (if only locally) as the artificial reef and associated aquaculture operation becomes established within an OWF footprint. Some of the designs proposed by Buck et al (2004) appear to have potential to exploit this type of enhancing effect. Fabi et al (2002) were also able to demonstrate that the composition and abundance of the infaunal community is driven more by physical factors than biological – and suggested that the artificial structures altered the surrounding seabed, favouring siltation and accumulation of organic matter inside the reef, as a result of changes in current flow and wave action. Again the knock-on effects of proximity to artificial structures, including reefs deployed for scour protection, need to be considered as part of a fully integrated approach to modelling sustainable shellfish culture systems in association with OWFs.

10.1.4 LEGAL AND POLICY CONSIDERATIONS

Although the legal and policy implications of aquaculture development in OWFs have been acknowledged (Mee 2006), research studies undertaken by Buck and colleagues as early as 2002 (but see Buck et al. 2004), have set the scene for acting on observations of mussel settlement at existing OWF sites and in fact, pilot scale facilities are now already being developed in Liverpool Bay (Dr. David Fletcher, Mon Aqua Tech. Ltd., March 2007, pers. comm.).

Partly because of the pressure on sea space in some areas, and the conflicts amongst different interest groups, it has widely been recognized that there is a need to use sea space as efficiently as possible, effectively doubling up on compatible activities to optimize sea space use (Mee 2006). Despite the current licensing barriers to developing aquaculture within OWFs, it is expected that these will ultimately be overcome, if there is sufficient support from the aquaculture sector, especially in situations where fishermen have been displaced from the OWF footprint. (Discussions at Stakeholder workshop, reported in Mee 2006) Certain types of fishing activity or fishing gears may have to be excluded to ensure operational security at some OWF sites, and offering alternative employment or economic options to fishermen, has been viewed as a potentially attractive means of mitigating the impacts of exclusion for affected communities. Where conservation benefits can be identified as a potential further benefit these should also be progressed with local stakeholders – for example, it has been suggested that there may be an opportunity to use OWF footprints to progress aspects of the recovery programme for native oyster (Clive Askew, Shellfish Association of GB, April 2007, pers. comm.). This type of initiative is obviously preferable to encouraging the spread of non native species such as *Crassostrea gigas* – which ultimately has the potential to go wild and to displace native species.

10.2 Farming fish in conjunction with offshore wind farms

The use of offshore wind farm sites for the development of fin fish aquaculture is intuitively attractive and has received recent attention Buck et al (2004) and Mee (2006). In addition, a separate study on the future potential of offshore fin-fish farming has recently been completed (James and Slaski 2006). In this section, we summarise and comment on existing information on the issues relating to the potential development of fin fish aquaculture ventures adjacent to or integrated with OWFs in Round 2 areas.

10.2.1 SPECIES AND THEIR REQUIREMENTS

Salmon are near-ideal aquaculture species from the husbandry perspective – they are very fast growing, tolerant of domestication and, above all, have very large eggs that hatch to give juveniles with a substantial yolk sac, which can be weaned directly onto an artificial diet. As salmon are the globally-dominant cultured carnivorous species, much effort has been expended on their immunology and many major disease challenges can now be controlled through a combination of vaccines and medicines. Salmon also have a wide salinity tolerance, and their temperature tolerance range makes them near ideal for Scottish waters with an upper limit of around 20°C.

Cod are currently being cultivated at a relatively small scale in Scotland and elsewhere. Cod are a more demanding fish to culture than salmon, producing many small eggs and larvae that require live feed from the earliest stage. Much progress has been made, but there is still much more to be learnt to optimise cod culture. However, the economics of cod production are currently unfavourable and the product is sold to a niche rather than a commodity market. Thus, in comparison with salmon, there is less incentive for commercial investment in research and development, for example, in vaccines. However, a large proportion of the engineering and processing infrastructure that has been developed over many years for salmon is appropriate for cod culture.

In terms of currently farmed fin-fish species, salmon and cod are the only species that can be considered for culture alongside OWFs at the present time. However, future opportunities to farm halibut and turbot should not be discounted altogether. These are high value fish that have several advantages over salmon in terms of their potential for aquaculture. This includes high food-conversion efficiencies and high product yield (filleting yields about 49%) (Arthur, 1999).

Turbot is currently exclusively farmed using land-based (pump-ashore) systems (Jim Treasurer, Ardtoe, Feb 2007, pers. comm.) but it is difficult to assess whether there is potential for transfer of any elements of this technology to exposed offshore locations such as the Round 2 areas at the present time. More is known, however, with regard to halibut which is currently sea-farmed around the UK (Scotland and Wales). There is considerable cross-over between halibut and salmon farming and salmon infrastructure could, to a large extent, also be used to farm halibut. The main difference between the species is the need, by halibut, for a solid substratum on which to rest and a preference for a lower energy site (Arthur, 1999). The requirement for a lower energy situation indicates that halibut would not be suited to a majority of offshore wind-farm sites.

Sea bass are a major culture species in the Mediterranean, and are increasing their range northward as a consequence of changing oceanographic conditions, and could have some potential for farming in southern UK waters. However, in our view, it is highly unlikely that a UK based offshore sea bass industry could compete with the Mediterranean industry in the foreseeable future, as infrastructure costs would likely be higher but growth slower owing to lower temperatures. Nevertheless, if the worst predictions of mean sea water temperature change are realised in future, sea bass are likely to suffer temperature stress with climate change even in culture facilities in the Mediterranean, thus pushing the production of this species further north. Consequently, the opportunity presented by OWF sites for culture of sea bass may well be reconsidered in future, especially if the technology challenges can be overcome. Modified versions of open ocean cages (which are 500 times larger than conventional cages), combined with the identification of suitable temperature and current climate for sea bass should not be discounted altogether as a way forward for development of fin-fish aquaculture at OWF sites (Laurie Ayling, Maris Fish Ranches Ltd, Jan 2007, pers. comm.).

10.2.2 ENGINEERING AND BIOLOGICAL CONSIDERATIONS

With regards to operating farms in highly dynamic offshore areas there are two main issues: the robustness of the structural engineering of the cage array and the tolerance of the cultured fish to the hydrodynamic conditions in terms of growth and survival.

The engineering issues are complex and are dealt with only briefly here. The main stresses are from wind, their associated waves and from currents generated by both wind and tides. Submerging cages beneath the waves significantly reduces the stresses on structures due to wave energy and such an approach will probably be necessary in offshore areas where significant wave height is regularly greater than 2m. However, in such locations depth will be a constraining factor and there will need to be sufficient depth such that a submerged structure will have adequate clearance from both the surface and the sea bed. Given that offshore culture will necessarily have to be large to benefit from economies of scale and to offset increased infrastructure and logistical costs, it is difficult to envisage operations in less than about 40 m of water. These depths increase significantly (to 80-100m) where open ocean systems such as those being promoted by Maris Fish Ranches Ltd. are concerned, because of the need not only to avoid higher current speeds in shallow water, but also the requirement to submerge cages whilst ensuring adequate ground clearance (Laurie Ayling, Maris Fish Ranches Ltd. Jan 2007, pers.comm). Consequently, although there is considerable interest in the design and operation of submerged cages, further work is required before such systems become fully demonstrated and operational.

Fish in culture require a constant replacement of water to remove metabolic wastes but excessive current speeds can exhaust or damage fish and lead to poor growth and mortality. Fish farms are currently located in areas with relatively modest mean currents of less than 0.1 ms^{-1} but with occasional peaks of up to 1 ms^{-1} where wind and tide act together. The most extreme environments where salmon are cultured in the UK are probably in the voes and channels around Shetland. Waves generate short period orbital currents that can damage and stress fish but, as their energy diminishes with depth, submersible cages offer protection from these. Wind driven currents also diminish with depth, but tidal currents are maintained throughout the water column except for near the bed where frictional forces operate. Thus, in areas where submerged cages are feasible, tidally induced currents are the limiting factor, whereas in areas where submerged cages are infeasible due to depth or other constraint, wind and wave induced currents must be added to the tide to determine whether a site has the potential to meet the biological requirements of the cultured fish.

10.2.3 ECONOMIC AND POLICY CONSIDERATIONS

A detailed analysis of the economics of offshore aquaculture has recently been completed by James and Slaski (2006). This report concludes that while offshore fin fish aquaculture is fundamentally appealing, several economic, legal and technical challenges must be overcome before investor confidence will be sufficiently high for this to proceed. Economic viability is highly dependent on external market forces that will likely drive the price of fish up in the long term – decreased supply from wild stocks, increased demand from consumers – thus potentially increasing the viability over time, but is also strongly dependent on the capital investment required for the new technologies that must be developed. For offshore aquaculture to proceed within the footprint of OWFs, substantial legislative changes are required, some of which are already anticipated in the Marine Bill Consultation. Mee (2006) identified issues relating to multiple uses of Crown Estate leased areas and suggested that legislative or regulatory change would be required. The notes on development of land based facilities below, obviously avoid the problems inherent in trying to bring about changes in policy to allow commercial development within OWF footprints (see discussion in below in next section).

10.2.4 INTERACTIONS WITH CHANGING CLIMATE

Climate is changing and with it oceanic circulation patterns, heat fluxes and chemistry. Several scenarios have been proposed including: extreme and rapid cooling of the NE Atlantic related to a reduction in Thermo Haline Circulation, for which there is some tentative evidence (Curry et al 2003); increased water temperatures from increased greenhouse gas concentrations; increased storminess owing to increased energy storage in the upper ocean; and decreases in seawater pH owing to the increased oceanic concentrations of carbon dioxide in the ocean.

Each of these scenarios will likely affect OWFs and their integration with aquaculture in different ways:

- extreme cooling: may reduce fish growth
- increased temperature: may exclude salmon and cod but may benefit sea bass culture
- increased storminess: may increase risks of catastrophic damage to installations and increase their cost
- decreased pH: may reduce growth and survival of shellfish (but probably not fish)

Notwithstanding these observations, there appear to be two emerging strategies which will allow the sector as a whole to respond to the likely effects of climate change, both with potential linkages to OWFs. The first, involving a move to land based, fully controlled closed systems for fin fish culture, using state of the art recirculation technology. This option is developing fast, with culture of turbot and sea bass entering the third year of production at facilities in Anglesey. There may be more interest in future in siting onshore facilities close to power infrastructure to take advantage of cheaper power (Dr. Simon Davies, University of Plymouth, Sept 2006, pers. comm.). But it is clear that land-based systems already avoid many of the pitfalls now endemic to the cage production industry such as disease transmission to wild species, repeated disease outbreaks due to exposure to environmental variables and the negative impacts resulting from escapees and organic waste. The benefits of incorporating elements such as broad species diversity, ability to target specific market demand, full traceability, quality assurance and high standards of environmental management are extremely attractive to the UK market, and the highly successful levels of production achieved in the first few years of operation at the Anglesey facilities indicate that there is a land based future for a broad range of fin fish species in the UK. (Dr. David Fletcher, Mon Aqua Tech, Ltd. Feb 2007, pers.comm).

The main second option appears to be development support for offshore culture of species such as sea bass which are already moving north (www.ukbass.com) and which are likely to become stressed in Mediterranean waters in the longer term. It appears that bass could benefit from warmer water in the southern UK to achieve faster growth rates than at present, if the technical considerations associated with offshore cage design could be overcome.

10.2.5 SPECIFIC RECOMMENDATIONS REGARDING OWF SITES

From the discussion above, the following simple criteria can be set up to screen proposed OWF sites for fin fish culture potential:

The site must:

1. be reasonably deep – 30m but deeper if Hs> 2 on a regular basis to allow for submerged cages
2. should have maximum tidal current speeds of less than 1m/sec-1

It is evident that if depth is considered, all the OWF sites so far identified would be excluded as suitable for fin fish culture, except Gwynt y Mor. However, given that only one end of this site is >30m and that the significant wave height is high, this site would also be discounted if these simple criteria are applied. However, this assessment is based on technology currently in use for salmon culture, and does not take account of developments of potential new technology for exploitation at sites offshore in association with wind farms.

In conclusion then, there does not appear currently to be a consensus regarding the future of fin fish aquaculture within OWF footprints at present, but doubts have been expressed as to whether there is realistically much potential in the foreseeable future. And so in the meantime, it is evident that the development of land based culture is expanding fast, apparently with many advantages over the salmon industry. However, this does not exclude the option of developing offshore fin fish culture with appropriate species suited to climatic conditions, nor its association with OWFs – all these different options need to be progressed on an experimental basis to ensure that the whole sector has a sustainable future in UK waters.

10.3 Harvesting and aquaculture of commercial species of seaweeds

Commercial production of seaweed has been growing rapidly in the last decade (6.1 mmt in 1995) and is now 86 % of total seaweed supplies worldwide, with a significant proportion supplied by Japan, where seaweed culture is the most productive and economically profitable form of aquaculture. A major review commissioned by the Irish government to contribute to development and exploitation of seaweeds is expected soon (National STI Strategy: 'Sea Change: A Marine Knowledge, Research & Innovation Strategy for Ireland' (2007-2013). The stated target of doubling the value of the seaweed sector from €10 million to €20 million focussing on high value export markets, will provide important insights into the issues and challenges involved in developing this sector, including an evaluation of the biotech/high value compounds potential of indigenous algal species.

The following section briefly reviews the current main uses of seaweeds, focussing on species which grow in UK waters and then poses the question as to whether either harvesting seaweeds directly from structures associated with OWFs (e.g. scour protection materials), or seaweed culture in association with OWF sites is a viable option to explore. Much of the information presented is extracted from David Mc Hugh's excellent FAO technical paper (441) and supported by Guiry and Blunden's earlier review (1991) and the references therein.

10.3.1 SEAWEED CULTIVATION IN EUROPE

Seaweed production in NW Europe at present amounts to approximately 332,477 tonnes, with Norway (192,426t), France (70,336t) and Ireland (36,000t) the main countries involved, and smaller amounts (< 35000t in total) produced jointly by Estonia, Spain, Scotland and Iceland. A further 3000+ tonnes is produced by Italy mainly using aquaculture methods. These figures from FAO 2002, are both not up to date, but probably not very accurate because of informal uses of hand harvested biomass in agriculture. For example in Jersey where traditional exploitation of wracks for agriculture is ongoing. Table 9 below summarises the main commercial uses of seaweeds present in NW Europe.

Table 9: Summary of seaweed species present in NW Europe and their current principal known commercial uses. Taken from Guiry and Blunden, (1991) and updated with reference to Mc Hugh (2003). (See also http://www.seaweed.ie/uses_ireland/default.html)

Brown seaweeds	Current known commercial uses
Laminaria digitata *L. hyperborea* *L. saccharina*	Food ingredient, Nutraceuticals (food supplements) Growth enhancer, Fungicides, Bactericides Surface protecting substances, Biomedicine (surgery, transplantation, encapsulation)
Undaria pinnatifida (wakame)	Uses as per Laminariales (but introduced)
Alaria esculenta	Sea vegetables, Food additive (animal feed), Nutraceuticals (food supplements)
Fucus spp. (e.g. F. serratus, F. vesiculosus)	Soil conditioner (e.g. Jersey), Fertilisers/liquid extracts, Stimulants for plant defence systems ('plant vaccines'), Fungicides, Bactericides, Enzymes, Biomedicine (surgery, transplantation, encapsulation)
Ascophyllum nodosum	Fertiliser/liquid extracts e.g. Maxicrop; Stimulants for plant defence systems Fungicides, Bactericides, Biomedicine (surgery, transplantation, encapsulation)
Himanthalia elongata	Soil conditioner
Red seaweeds	
Chondrus crispus	Food ingredient (carrageen moss), Para-pharmaceuticals, Cosmetics
Gelidium Gracilaria, Pterocladia	Manufacture of agar, Also Gracilaria spp.-Anti-coagulant
Asparagopsis armata	Bioactive compounds with proven effects (e.g. Anti wrinkle, anti dandruff, anti acne)
Palmaria palmata	Food ingredient ('dulse'), Food additive (animal feed – protein for shellfish, fish, cattle and poultry), Antibiotic, Para-pharmaceuticals, Cosmetics, Food engineering
Porphyra spp.	Food ingredient (Nori/laverbread), antibiotic, pharmaceuticals, Food engineering
Laurencia spp.	Anti-inflammatory
Kappaphycus/ Betaphycus pp.	Carrageenan
Phymatolithon/ Lithothamnium	Maerl – used as soil additive
Ceramium spp.	Anti-tumour
Green seaweeds	
Ulva spp./ Enteromorpha spp.	Food ingredient (including condiments) Food additive (animal feed)*
Delesseria sanguinea	Anti-viral
Dumontia contorta	Anti-bacterial

10.3.2 UK SPECIES AND THEIR DISTRIBUTION

It appears that most of the species currently exploited for commercial purposes worldwide are present on rocky shores around the UK, and despite geological and morphological diversity of UK shores, algae tend to settle where surfaces are available and also generally within five hours of the release of spores. This latter fact combined with tidal dynamics and wave action may in some circumstances restrict the potential colonization of novel surfaces which are beyond dispersal limits of spores. Evidence from offshore rigs and wind farm analogues suggests however that there is often good growth of kelps on these structures, and in the absence of specific propagule dispersal studies, it appears that kelp sporelings at least, may be robust enough to survive substantial longer periods between release and settlement than some other species Hiscock et al. 2002). In general however, algae do not grow and flourish on vertical surfaces, although slopes which are in excess of 20° from the vertical are suitable for colonization, some species (for e.g. the kelps) are more likely to be found in abundance on horizontal surfaces.

Although algae are generally the first species to colonise surfaces (after initial microbial succession) and initially dominate the species assemblage on novel surfaces, they can be rapidly succeeded by barnacles, mussels and other encrusting fauna thereafter (Bunker 2004). Evidence from the Poole Bay reef indicates however that a variety of rhodophytes continue to flourish seasonally even after some of the encrusting fauna have become established.

Table 10: Summarizing presence of species with known commercial potential in Round 2 areas. Distribution checked on National Biodiversity Network database and ground truthed with reference to post construction surveys from Blyth and North Hoyle OWFs (Mercer (2001), and Bunker (2004) respectively)

Brown algae	UK Distribution	Post construction surveys/and/or wind farm analogues
Laminaria digitata *L. hyperborea* *L. saccharina*	Recorded from coastal locations adjacent to all round 2 areas	Kelp sporelings recorded at all R2 monitoring sites Sarns (Hiscock (1986) Offshore rigs (Forteath et al 1982)
Fucus spp.	*F. vesiculosus* – all areas	*F. serratus* recorded on sarns (Hiscock 1986)
Ascophyllum nodosum	All coastal round 2 areas	No data
Red seaweeds		
Chondrus crispus	All areas except The Greater Wash	Recorded on sarns (Hiscock 1986)
Palmaria palmata	Recorded Liverpool Bay – but not The Greater Wash to N. Kent coast	Recorded on sarns (Hiscock 1986)
P. purpurea *P. dioica*	All coastal areas but not Humber to Wash Recorded Thames estuary only	*Porphyra* spp recorded at North Hoyle (Bunker 2004)
Phymatolithon spp./ Lithothamnium spp.	Phymatolithon – mainly S coast; No records coastal round 2 areas	Sporelings of crustose coralline algae recorded at all sites
Green seaweeds		
Ulva spp. *Enteromorpha spp.*	Ubiquitous	Both species recorded at North Hoyle Bunker 2004) and at Montrose Alpha platform (Forteath et al 1982); *Enteromorpha* only on sarns (Hiscock 1986)
Delesseria sanguinea	No records Wash to N. Kent or North-west	Recorded at Blyth OWF and sarns (Hiscock 1986)
Dumontia contorta	All coastal round 2 except Greater Wash	No data

10.3.3 PRACTICAL AND ENGINEERING CONSIDERATIONS

As is apparent from the brief literature review and data collated above, there are two possible routes to exploiting algal biomass in association with OWFs:

(i) Harvesting by hand collection

Firstly, algae can be hand collected; this mode of harvesting algae is the principal means of harvesting algae at present in north-west Europe. Although various mechanical methods, such as those used to harvest *Macrocystis* mechanically in California, have been evaluated for the Irish context, these have yet to be proven as a cost effective and acceptable way to harvest algae grown at scales of current European operations. Consequently, the economic potential of algal harvesting has to be scaled to the biomass which can reasonably be harvested and the species involved (Kelly et al 2001). Most of the harvesting operations are currently manual by part-timers in Ireland, Brittany and off shore Scotland, and are mainly geared to relatively small scale commercial production of alginates, or traditional/artisanal uses of seaweeds for food (e.g. dulse), health care products (e.g. seaweed baths, decorative soaps etc) or horticultural products (e.g. seaweed extract fertilizer) and crafts (e.g. cards, lampshades etc). The quantities of algae required to support these applications can probably mostly be supplied by coastal resources with out resorting to offshore sites (see also Werner and Kraan 2004).

The question for the task in hand is whether the increased opportunity presented by rock armouring around the bases of wind turbines, would amount to a useful opportunity to expand harvesting of algae, which could be developed into a commercial operation. In the first place, rock armouring will only be deployed in situations where, by definition, there is already a problem with scouring. There is some evidence to suggest that older artificial reef structures which are closer to natural rock substrata are more successfully colonised by macroalgae (Boaventura et al. 2006). However, if a commercial operation dependent on natural recruitment were to contemplated, much more work needs to be done to compare colonisation at different reefs, depths etc. in a systematic way to enable natural colonisation processes by macroalgae to be better understood. Also even if rock armouring represented a significant increase in habitat opportunities in a high energy environment, it is questionable whether successful colonization and growth by algal species would occur in quantities which would make them viable to exploit commercially. Also, although some species are adapted to high energy conditions, where high scour is an issue, the thalli tend to be stunted and often fragmented as result of the constant vigorous wave action, and this may compromise their success as commercial products.

It also seems very unlikely that unless local (mainland) sources of algae have been exhausted or a particular sought after species is only otherwise present in a protected area adjacent to an OWF, farmers would be willing to incur the costs of fuel and labour in travelling to OWFs and between turbines to exploit algae associated with rock armouring around turbine structures. It also seems unlikely that it would be worthwhile to adapt mechanical harvesting to exploit reef areas, given the relatively dispersed nature of the surfaces. As a general rule, though, it would be prudent to consider each OWF footprint for potential on its own merits, linked to the site specific opportunities identified and interest generated amongst local stakeholders.

(ii) Seaweed aquaculture

It is worth noting that development of seaweed culture within OWF footprints will invariably necessitate access to suitable onshore services and infrastructure. In some areas these may turn out to be prohibitively costly with pressure on coastal land uses. For e.g. some types of seaweed aquaculture need back up laboratories for seeding of ropes (*Laminaria spp.*), and in general, to exploit value-added there is a need for onshore facilities for processing/transport to markets. On the other hand, systems which depend on natural settlement of spores (as opposed to laboratory development and seeding of sporelings) will be restricted by factors such natural dispersal distances, size of the spore source and habitat availability of the species of interest. In studies carried out by Reed et al (2004) the density of recruits of *Macrocystis pyrifera* was found to be correlated to the bottom cover of artificial substrate, and that after an initial supply, the density of recruits rapidly declines with distance from the nearest population source. Although this study covered *Macrocystis* only, it is probably fair to assume that spatial availability of spore supply and bottom cover of hard substrate explain much of the variation observed in recruitment of common algal species to offshore coastal structures (Dr. Keith Hiscock, MBA, Sept 2006, pers. comm.)

In addition to spore supply, there may be issues related to hydrographic/wave climate and sea conditions generally within the OWF site which need to be considered. Recently, Buck et al (2004) have investigated several possible designs for rafts in association with wind farms, and these have potential for algal culture as well as shellfish. They have also investigated a new offshore-ring system for open ocean culture of macroalgae which can sustain rough weather conditions. They tested different construction methods and mooring systems, and refined the design considerably (Buck and Buchholz, 2004). However concerns have been expressed at the potential conflicts with wind-farm operation and maintenance (Mee 2006) and how the system itself could be maintained and seaweed harvested. Further investigations into the efficacy of this system for culture of *Laminaria saccharina* were tested using a modelling approach, with frond sizes, and drag coefficients taken into account for the simulations (Buck and Buchholz 2005). Results showed that culture of *L. saccharina* does appear to be feasible in high energy environments, providing basic requirements with respect to substrate, hydrography and weather conditions are met.

Although there are currently numerous culture methods in use worldwide, it is also worth mentioning that there is an extremely dynamic technology development programme in relation to seaweed culture in Japan, and only recently a new culture method has been developed and endorsed by the Bureau of Fisheries and Aquatic Resources (BFAR), which is apparently able to withstand strong winds, big waves and other negative conditions. The *'Modified triangular method'* is the most efficient known seaweed aquaculture system, in terms of net profit, compared for example, with traditional mono-line culture methods, which only realize half of the net profit gained by the new methods.

The potential of algal culture to enhance fisheries productivity reported by Bergman et al (2001) at two different lagoon sites, suggests that synergies between algal culture and fisheries could be developed and applied within the context of OWFs. In this instance, algal farming affected the associated fish fauna in terms of abundance, species richness, trophic identity and fish community composition, mainly it was concluded, as a result of habitat structure rather than utilisation of macroalgae as a direct food resource. These observations obviously have significant implications which should be investigated further, and we are already aware that there is much to learn from the Japanese – both with regard to technology development and husbandry – however much of the information is difficult to access and remains in the grey literature and so we are unable to benefit from the experience and innovation of others.

11 Commercial Fisheries Management Considerations

It has often been suggested that the footprint of OWFs might offer an opportunity to enhance the fisheries associated with an OWF as a result of reef effects or to mitigate the impacts of excluding some types of fishing activity/gears from operating within the OWF footprint, by contributing other fisheries management benefits to local fisheries. This section explores some of this potential by focussing on species which are commercially significant in UK waters, and by considering the habitat changes induced by introducing turbines together with scour protection into the Round 2 areas.

11.1 Current fishing activity in Round 2 areas

The table below which collates data taken from Milligan (2005), summarises the important commercial fish species taken by fisheries in each Round 2 area, based on weight landed. (Species marked with Y are present whilst '+' indicates that they may be an important part of the by-catch in the area).

Table 11: Summarising the main commercial fishery species present in the Round 2 areas. (extracted from Milligan 2005).

Species	Greater Wash (GW)	Thames Estuary (TE)	North–west* (NW)	Main metier used (where species specific information available)
Elasmobranchs				
Spurdog	Y	Y	Y	
Lesser spotted dogfish		+	+	**Longlines**
Tope	Y	Y		
Smoothhound		Y		
Skates and rays	Y	Y	Y	**Tangle and trammel nets, longlines**
Gadoids				
Cod	Y	Y	Y	**Gill/trammel nets, longlines**
Haddock			Y	
Pollock			+	
Whiting	Y	Y	Y	**Gill and trammel nets**
Hake			+	
Flatfish				
Turbot	Y	Y	Y	**Tangle and trammel nets**
Brill	Y	Y	Y	**Tangle and trammel nets**
Dabs	+	+	Y	
Lemon sole	Y	Y	Y	**Tangle and trammel nets**
Flounder			+	
Plaice	Y	Y	Y	**Tangle and trammel nets**
Sole	Y	Y	Y	**Tangle and trammel nets**

*Eastern Irish Sea

Species	Greater Wash (GW)	Thames Estuary (TE)	North–west* (NW)	Main metier used (where species specific information available)
Other fish				
Angler		+	Y	
Bass		Y	Y	**Fixed and drift nets (all), Longlines/ handlines (TE only)**
Gurnards		+	+	
Herring		Y		**Drift nets (GW and TE)**
Sprat	Y	Y	Y	

*Eastern Irish Sea

Taken together with the summaries of fishing activity provided in Appendix iv, it is apparent that the main commercial species present in all Round 2 areas are cod, whiting, turbot, brill, sole, plaice, and sprats. Haddock, pollack and flounder are apparently absent from the Greater Wash and Thames estuary areas, whereas herring and smooth hound are absent from the Greater Wash and North-west areas. Bass is evidently absent from the Greater Wash area.

Appendix iii summarises the key characteristics of the life cycles of the main commercial species identified, and it appears that there are several species which may utilise rocky substrates at some stages in their life cycle, notably cod, whiting and bass.

Despite a very thorough recent study commissioned by BERR, which in consultation with fishermen suggested that as a precautionary measure, commercial fishing should be excluded from OWFs, the report has not been endorsed by the FLOWW (Fisheries Liaison with Offshore Wind and Wet renewables group), and some operational OWF sites have decided not to exclude fishing (e.g. Kentish Flats, Scroby Sands). BERR report also concluded that recreational fishing should be permitted but subject to a code of practice relating to specific risks.

11.2 Interactions between commercial fishery species and artificial reefs

Monitoring and assessment of habitats created by artificial reefs to determine their characteristics and effectiveness for promotion of fisheries management functions, has been of prime interest to scientists in the last two decades, and in a recent review Baine (2001) identified more than 90 published articles on artificial reefs worldwide to enhance fisheries management objectives. Although artificial reefs have been used to replace lost physical structure or compensate for destroyed habitat from an acute event, as in south east Florida Shelf, for instance, they can provide an opportunity to test the functioning of artificial reefs. Eklund's results (1997) provide some of the first towards better understanding of the ecological processes limiting fish production in association with an artificial reef, and thus, can be used to enhance design and management toward the goal of increased fisheries production. This study also showed that it is possible to design and manage artificial reefs with the aim of promoting benthic communities as a forage base for the target fish species, thus providing marine areas with greater availability and heterogeneity of refuge space which in turn supports more fish.

Several studies have compared fish assemblages at reef sites with those from areas without reefs. Sanchez-Jerez et al (2002) for example, examined the effect of artificial reefs on the dietary requirements and the structure of resident fish assemblages. They used a visual census to study four fish species (*Diplodus annularis, D. vulgaris, Chromis chromis* and *Apogon imberbis*) at artificial reef blocks placed in *Posidonia oceanica* meadows. They report differences in fish assemblages between the reef and non reef sites that were attributed to the abundance of prey items, with higher fish abundance observed at the artificial reef site attributed to increases in food, increased feeding efficiency and the presence of shelter to reduce predation, enhanced recruitment and other indirect effects. Similarly, Santos et al (2002) studied the daily variation in the density of fish species at an artificial reef in the Algarve (southern Portugal). They recorded a total of 18 species, and found that about 61% of the species were considered resident, while 33% used the reefs mainly for foraging and or shelter.

Relini et al (2002a) studied the feeding habits of four commercial fish species on an artificial reef in Loano in the Ligurian Sea to assess the role played by the reef in the fish diet. They used spear fishing and trammel nets to catch a total of 612 individuals from the surrounding reef to examine their stomach contents. Using suction sampling and grabs, they also sampled the abundance of the prey items on the reef and surrounding bottom and their results showed that three species *Serranus cabrilla*, *D. annularis* and *S. notata* fed primarily on reef associated decapods while *Scorpaena porcus* did not, indicating that the major part of the diet of the fish assemblages on the artificial reef belonged to the artificial reef community.

Habitat requirements and site fidelity to artificial reefs was studied by Workman et al (2002) for juvenile red snapper, using visual surveys and tagging experiments. They found that habitat requirements of the smallest settlers were met by the presence of small structures, including shells and burrows, but as they grew bigger they preferred larger and more complex structures. Recruitment to the larger structures was however, limited by the presence of larger fishes. They concluded that the proximity of large artificial reefs to smaller structures influences recruitment patterns, and that juvenile red snapper are not only faithful to structures but also have homing capabilities. Wilhelmsson et al (2006) investigated another aspect of fish habitat requirements, and by introducing vertical structures into a reef, they found after only one year significant increases in fish abundance (though not diversity), which they attributed to expansion of habitat.

In longer term studies, Stephens and Pondella (2002) were considering whether artificial reefs act as sources or sinks for fish using data collecting over a 24-year period. They compared annual densities of fish larvae from artificial reefs with those from control areas in Southern California Bight, and showed high densities of larvae at the artificial reefs compared to the non-reef areas. Using larvae of the 12 commonest genera of reef fish species they found that five were significantly more abundant in the samples from the artificial reef. Their results indicate that mature artificial reef contributes a significant resource to the reef fish larval pool, and thereby acting as a source and not a sink.

The literature relevant to understanding the potential enhancing effects of artificial reefs for fish productivity is in fact, substantial – however, the most important general principles to emerge from our review and which apply to the present analysis are as follows:

1. Artificial reefs increase the habitat complexity of marine areas thereby increasing fish density and species richness (Charbonnel et al. 2002 and others cited above). There is also evidence to demonstrate that there is a gradual increase in species richness and diversity and the appearance of new species over time at artificial reefs (Relini et al 2002b) although there appears to be a lack of credible long term data sets to illustrate this fact at North European sites. Evidence from monitoring surveys at all the existing OWFs suggests increased association of some commercial species with turbine towers e.g. North Hoyle, Whiting and Cod; (and see also http://www.hornsrev.dk/Engelsk/default_ie.htm).
2. The carrying capacity of artificial reefs is higher than in neighbouring areas and catch per unit effort (CPUE) in number and weights, density and biomass of fish species is higher in artificial reefs than control areas (Pondella et al. 2002 and Zalmon et al. 2002 respectively).

Consequently it appears that the evidence in favour of enhancing effects for fisheries production from artificial reefs is overwhelmingly positive – however, it is Baine's work (2001) which questions the efficacy of reefs in meeting their original objectives, with 50% of 30 case studies investigated not achieving their intended objectives, thus casting doubt on simplistic assumptions about universal outcomes. The proportion of these case studies analysed which were fisheries related was not unfortunately specified, however, this analysis strongly suggests that there is still considerable potential to improve the design of artificial reefs for enhancement of fisheries production. If these outcomes are to be considered for OWFs, then greater effort needs to be targeted at development and application of tight design criteria, including with regard to the deployment of scour protection etc. if fisheries enhancement objectives are to be fulfilled.

11.3 Habitat requirements of principal commercial species

The principal commercial species of fish recorded in OWF areas to data, from sources of data which include Cefas monitoring surveys, baseline characterisation of OWF sites for EIAs etc, include the following: cod, plaice, herring, dover sole, lemon sole, flounder, whiting, bass, turbot, sprat, thornback, spotted and cuckoo rays and dogfish. The precise nature and extent of benefits which might accrue from closure of individual offshore wind farm sites to some forms of commercial fishing, will need to be determined on a site specific basis and through consultation between the OWF operators, the local fishermen and their representatives. However, it is worth noting that there may be particular benefits which flow from the presence of turbine structures and their scour protection for individual species, which could beneficially be exploited in some contexts. There are a number of species specific studies of behaviour associated with artificial reefs e.g. Jorgensen et al 2002, working on cod, showed that cod reside to a moderate degree around decommissioned oil platforms, but that the reason for this could not be conclusively established – (whether there was reduced risk of predation, shelter from currents, good feeding conditions). This leads us to conclude that the potential benefits for individual species will need to be considered on a case by case basis.

Appendix iii summarises the habitat requirements and main food preferences of the most important commercial species in UK waters, and it is apparent that on the basis of this information alone, there are a few species which may benefit directly from the introduction of rocky reef areas into otherwise gravely/sandy/silt coastal environments in which OWFs are located. For example, Whiting adults (*Merlangius merlangus*) tend to be found at a depth range of 10-200 m, but are mainly found between 25-100 m above sand and mud. However, juvenile fish of approximately 3 cm often shelter in the tentacles of large jellyfish and younger fish generally seek out and inhabit inshore reefs and wrecks. We have already noted elsewhere in this report the large numbers of young whiting associated with turbine towers at North Hoyle (Bunker 2004, see also Figure 12). On the other hand Bass (*Dicentrarchus labrax*) as a schooling species, moves and feeds in open water, but Bass are frequently closely associated with rocky reefs (Hiscock et al. 2002). Although they are found mainly in coastal and estuarine waters during the summer (10 to 30m) they migrate to deeper water (up to 100m) in the winter. It is clear therefore that for Whiting and Bass, the presence of OWF structures together with their scour protection and associated colonising communities, might offer new habitat opportunities which play a role in expanding/developing or maintaining stocks. This may be applicable generally, or in some specific areas where stocks are either under stress from loss of habitat or from excessive fishing activity.

Studies ongoing in North America in relation to decommissioning of oil and gas platforms (Hervey 2002), illustrate the complexity of achieving the right balance between the potentially desirable impacts of enhancing a fishery, and avoiding the non-sustainable commercial and recreational fishing pressure on nearby natural reefs. Hervey advocated a holistic approach to considering whether structures are necessary to support a sustainable fishery or contribute to a healthy ecosystem, otherwise the potentially enhancing effects of reefs, may surprisingly exacerbate the risk of further stock collapses.

11.4 Evidence from monitoring studies at existing OWFs

Although there are only limited monitoring studies within existing OWFs to provide direct evidence of the interaction between artificial reefs and fisheries, these provide important data to indicate that at the sites investigated at least, there is evidence both for and against an enhancement effect at the present time. For example, at Horns Rev the average density of sand eels (all species) increased 300% within the wind farm array with a corresponding decrease in the reference area allowing the conclusion that sand eels were not negatively affected by the construction and presence of the wind farm within the OWF footprint, but that displacement of fishing effort to the outside of the footprint probably adversely affected local populations (Jensen and Spanier 2004). However, it is not always straightforward to distinguish between FAD effects and artificial reef enhancing effects – again at Horns Rev, an 8-fold increase in biomass available as food resource for fish was observed around the foundations and scour protection, when compared with the original soft sediment habitat (http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/AnnualReport-2004 and Bioconsult A/S, 2003a). On the other hand, at Kentish Flats in the Outer Thames estuary, although some species (bass, sole, flounder and roker) showed an immediate increase on the basis of CPUE immediately after construction of the OWF, this effect did not persist and corresponding increases were found in the reference areas. Specifically, no difference was found between the OWF and the reference area for population structure of bass and differences recorded were attributed to natural variability of the populations investigated (EMU Ltd. 2006).

11.5 Bass restoration and OWFs

The continuing collapse of many fish stocks through commercial overfishing in the late 1990s, and the worrying development of the winter offshore bass fishery, resulted in 1998 in the development of a conservation programme by BASS to campaign for more and bigger bass (*Dicentrarchus labrax*) to be available for recreational anglers (Leballeur and Rowe 2003). As a result of an extensive bass tagging programme, BASS was able to demonstrate that the bulk of fishing mortality of bass stocks, takes place within the inshore fishery. Proper management controls were obviously needed for the inshore bass fishery, and with this in mind, a bass management plan has been developed which details a number of measures, including implementation of closed areas and the 'golden mile' around the UK to assist the restoration of bass (see www.ukbass.com/restorationproject/index.html)

Given current efforts to support bass driven by the sea angling community, the opportunity presented by OWFs for implementing closed areas as part of the bass management plan is a potentially attractive prospect for sea anglers. A key aspect of progressing restoration in a closed area for bass, is the requirement for use of hook and line only. That is, to be clear, exclusion of all other gears, such as long lining, nets and trawling from the area. To a large extent these gear restrictions map quite neatly onto the requirements of OWF operators themselves to protect access to turbines and to ensure operational security. However, it is worth pointing out that there remains an opportunity even in this scenario, for the commercial fishing sector to diversify into charter boat operation, and thus mitigate some of the impacts of a closed area for the commercial fishers.

As part of the initiatives underway at present, there will be a review of the bass nursery areas for the UK, and these are expected to be extended in some areas, notably in the Thames estuary (www.ukbass.com/bassmanagementplan/bmp/index.html). Given the relative economic potential of the sea angling sector (£100m approx) in comparison with the commercial fisheries returns from bass (£3.5m approx) (Drew 2003), there is considerable interest in promoting any measure which could support further restoration of bass to assist in development and improved sustainability in the sea angling sector. The footprints of OWFs, offer an excellent opportunity to run a pilot study to test the effect of closure to commercial fishing in parallel with revised measures for nursery closure for bass, possibly focusing on the Thames estuary as a priority (John Leballeur, BASS, Jan 2007, pers.comm.). It is possible that there is potentially far greater return from the resource as a result of restoring the species and managing for the sea angling community than in promoting cage culture at the present time.

11.6 OWFs as marine protected areas (MPAs)

Areas closed to fishing such as no-take MPAs present a viable option to protect many commercial species and their habitats. No-take MPAs are designed to concentrate and protect both fish and habitats from destructive fishing techniques such as trawling, and thus allow the fishery to recovery sufficiently to sustainable levels of fishing effort. Where artificial reefs have been included in the OWF footprint for scour protection or other functions, the areas will not be easy to trawl (even where trawling is not prohibited)(Jensen 2002) and so they have the potential to be set up as MPAs. Many studies indicate that enhancing MPAs with artificial reefs can help to ensure increased recruitment of juvenile fish to adults, and eventually result in an enhancement of fisheries production (Wilson et al., 2002, Bohnsack and Sutherland, 1985).

Artificial reef blocks are generally regarded as relatively inexpensive and effective way to protect most of the habitats present including those in an MPA (Bayle-Sempere et al, 1994). Turpin and Bortone (2002) conducted an assessment of artificial reef pre and post-hurricane to look for evidence for their potential use as fish refugia. Their study found that lighter materials were moved for distances of around 1000m, while materials of higher densities were unaffected by the wave surge. Because some reefs were displaced, fishing pressure was greatly reduced for at least one year and their results suggest that artificial reefs may serve as refugia from fishery harvest following severe storms, and thus have the potential to mitigate against negative effects on some species. This refugia function has potential utility in the design of marine reserves, as well as offering an alternative strategy in the development of fisheries management plans.

Wilson et al (2002) discussed the advantages of linking artificial reef deployment with the creation of a network of no-take zones. The authors noted that a variety of different arrangements will manipulate the fishery towards increased fish production, including deployment of an artificial reef in offshore open waters, away from inshore natural rocky shores. On the other hand, Pitcher et al. (2002) using 'ECOSPACE' a spatial model which simulates biomass fluxes in response to the fishing using different fisheries and gear types, found that small protected areas with man – made reefs achieve little to avert the collapse of fisheries – but that larger protected areas can potentially do more to restore valuable fisheries.

Rodwell et al. (2003) have also experimented with predictive models based on habitat requirements of individual species, which high-lighted the specific contribution of habitat improvements to a fishery. Most economic studies have failed to consider habitat quality improvement as an economic benefit of marine reserves, but Rodwell et al have developed and tested a deterministic and discrete-time model which describes the dynamics of a fish stock subdivided between a fully protected marine reserve and adjacent fishing grounds. They developed an explicit habitat-quality function to enable them to run the model, and were able to show that habitat-quality improvements can augment fish biomass and catch levels, with the greatest benefits to fishery catch, resulting from locating the reserve where habitat can recover quickly once protected and where the area is not subject to other stresses such as pollution or sedimentation.

If transferred to the context of OWFs as closed areas, it would theoretically be possible to model the consequences of closure using the same approach, but based on hypothetical habitat improvements for target species resulting from introduction of scour protection or other artificial reef material. At present the information available from existing OWFs sites is not sufficiently detailed to allow application of this model to predictive questions. Further information is required on exactly the area of scour protection introduced into the OWF footprint and the impact on habitat quality for target species. This is potentially an area to explore in the forward research programme.

It is becoming apparent that because many fishers are unable to utilize areas occupied by offshore wind turbines or because certain gears have to be excluded for operational reasons, they may be more willing to support the creation and management of no-take zones to coincide with an OWF footprint, especially where there are likely to be benefits for fisheries in adjacent waters

(Mee, 2006). Where restoration of fisheries or development of no-take areas is being considered in association with an OWF, the outcomes from predictive models as described above, may well facilitate consultation with fishers, and could be used to engage them in the first place with consideration of alternative options. It is also important to be aware that fishers displaced from areas closed to fishing, if not controlled, may have an increased impact on fish populations and the environment outside the closed OWF area (Dinmore et al. 2003).

12 Data Gaps and Recommendations for Future Research

12.1 General observations

The interaction between OWFs and their receiving environment, including the biotic interactions, are complex and involve understanding across every aspect of marine ecology and hydrography. Our understanding of the marine environment is not complete and there are, therefore, aspects of the wind farm-environment interaction which require further research to assist in the prediction of the likely reef-effects of OWFs for the benefit of fisheries or development of commercial aquaculture.

It is also notable that artificial reef technology lacks a complete history and there is no global database to provide global consistency to include data on location, research, design evaluation statistics and training (Seaman 2002). With the unprecedented increase in opportunities for evaluating the success of artificial reefs in different geographical/spatial contexts – the offshore renewable sector could perhaps take the initiative and start one such a database, building on the excellent work initiated under the EARRN (European Artificial Reef Resource Network) based at NOC. (www.noc.ac.uk/soes/research/groups/**EARRN**). There is little doubt that a need has arisen to collate experience worldwide from different artificial reef projects, at present the infrastructure to ensure that the knowledge and experience is applied as efficiently as possible appears to be lacking.

It is also relevant to highlight the difficulties inherent in progressing applications requiring integration of multiple disciplines, when a significant body of the literature is not peer reviewed and not available because of commercial confidentiality issues. Although this has been corrected with respect to the Round 2 OWF applications, there is a considerable body of information which could beneficially be brought into the public domain. This would avoid a great deal of research/investigative activity being lost to future benefit – and better still, ensure that OWF operators themselves collectively benefit from generic research activity.

12.2 Specific data gaps identified

We have had to make some important assumptions about the data gaps we have identified, because of the dynamic nature of the debate in OWF circles and stakeholder groups around the feasibility (or otherwise) of different development options. Clearly there are some trends evolving which depend on the experience of individual developers, their assessment of technology options and associated costs, invariably at specific sites, but as the sector moves forward and develops, it will become apparent that some of the suggestions below are either more (– or less) important depending on other criteria.

The following summarises therefore, the specific data gaps (including issues which do not yet appear to be resolved) which have been identified in this study in relation to optimising the benefits from reef effects within OWFs.:

Wind farm design/operation

- How is future erosion control to be managed (mattresses, stone ballast or other)?
- Will there be (is there?) a move to deeper-water tripod designs?
- How will fouling be controlled (methods and degree of subsequent disturbance)?
- Is it possible to consider design optimisation for fisheries enhancement at the earliest possible development stage?

Socio–economic

- To what extent are safe fishing and wind farms operationally mutually exclusive?
- How can wind farm-based fisheries be optimally managed (to include ownership issues)?

Impacts of wind farm operations

- What are the effects of EMFs on reef communities?
- What are the impacts of operational (chronic) noise on vertebrates (particularly fish)?
- How will pile cleaning be undertaken? and how often?
- Are OWFs potentially significant in promoting invasion of alien species?
- How does the turbine layout/presence of scour protection influence behaviour and distribution of motile fauna?

Reef-associated behaviour

- What triggers lobster (*H. gammarus*) movement? Is such behaviour likely to significantly reduce wind farm associated lobster fisheries.
- What is the role of surface texture on colonization (rock-ballast specific)?
- How does the orientation of a reef in relationship to the prevailing current affect colonisation?
- What is the role of habitat complexity in population structure? Can we design rocky-scree to provide optimal habitat for commercially important species, e.g. lobster?

- How useful are synthetic fronds, mats and mattresses as artificial reefs? In particular do these sediment-catching devices offer anything for juvenile lobsters?

Development of bivalve culture

- What is the carrying capacity of existing OWF sites? Are food resources adequate at all R2 sites to sustain profitable shellfisheries?
- Are the new designs proposed for offshore culture of shellfish suitable for deployment and maintenance in conditions of exposure at most OWF sites?,

Development of seaweed culture

- What added benefit (over onshore/near coast or estuarine culture) may be obtained from culturing species further offshore?
- To what extent could culture operations depend on natural levels of spore dispersal of key species?
- How feasible are some of the new technologies for culture offshore in UK waters?

Enhancement of fisheries:

- Are any individual commercial species sufficiently valued to consider modifying habitat within an OWF to benefit single species?
- What potential is there to modify OWF design to optimise the reef effect?
- Is there an OWF site where we could test the model for predicting habitat improvement needed for fishery enhancement?
- Is there a site where we could test the efficacy of implementing a bass restoration management plan to enhance the local sea angling opportunities?
- Is there an OWF site where we could test whether general benefits accrue to local fisheries as a result of creating a no-take area? or partial no-take (exclusion of some gears and not others)?

Some of the data gaps noted above need to be addressed before the potential reef effects of OWFs can be properly evaluated and provision made to maximize their potential benefit. However, in the meantime, the forward research programme needs to be formulated with some specific goals in mind as outlined below.

12.3 Main areas of research to be addressed

The following therefore summarises the main areas of research which need to addressed as a priority, then suggests possible ways of progressing each topic.

12.3.1 NATURE OF SCOUR PROTECTION MATERIAL

The first and major consideration is to determine the nature of the ballast material (if any) that will be used around wind farms. Stone ballast has obvious reef potential but this is not necessarily the best (cheapest) option available to the operators of OWFs, although it has proved successful at Horns Rev. If the industry is moving towards the broad-scale adoption of buoyant-frond-lines (mattresses and mats) to control scour, then these materials must be investigated in terms of their reef potential, particularly in relationship to their general enhancing effects for fisheries and suitability for lobster juveniles in particular. There are also new and as yet unproven methods of scour protection being tested (www.BWEA.com. and Jo Toland, Rubicon, Feb 2007, pers. comm.) and these should not be excluded from any evaluation. None of these scour protection materials can be considered for their reef enhancing effects, independently from the question of decommissioning of OWFs, and in fact if we are to consider the question of scour mitigation holistically, the ideal scenario is that design optimisation for both scour protection and biodiversity/fisheries enhancement are fully integrated and undertaken at the earliest stage possible in the project.

12.3.2 HABITAT COMPLEXITY, AND ITS ROLE IN DETERMINING BENTHIC COMMUNITY STRUCTURE

To properly evaluate the potential economic benefit of alternative ballast options (rock v. mats v. nothing) a significant research effort is required to target specifically the potential benefits that bespoke habitats can have on the survival and growth of both decapods and fish. The rock (or similar material) scour protection that has been used to date has, intuitively, the greatest potential for creating a mosaic of niches that would be expected to provide decapod-friendly habitat.

Shelter selection by lobsters (within the scour protection) and crabs (on the outer surfaces of scour protection) is not properly understood or quantified. Research is required to assess the needs of *Homarus gammarus* (European lobster) at a variety of life stages and sizes, especially the early benthic phase lobsters which are considered to be burrow dwellers but which have never been consistently collected from the wild. There are fundamental questions to be answered about; (a) how lobster shelter selection varies with the size and life cycle stage of each animal (unpublished work suggests that lobsters are quite individual in their selection); (b) the number of shelters that are occupied by individuals within a given time frame (work on the Poole Bay reef showed that lobsters would move between shelters frequently (daily in some cases); (c) the foraging distances of lobster with regard to size, sex and moult state; (d) the 'site loyalty' of sexually mature lobsters (the majority of which will be above the MLS (minimum landing size)), most previous work has studied animals below the MLS, the majority of which would have been immature (e) establish the nearest neighbour distances for these 'aggressive' animals and (f) establish an artificial habitat type that would be acceptable to the early benthic phase lobsters, so allowing population of wind farms from hatchery reared animals if colonization by adults and or naturally occurring larvae appears to be unlikely or would occur within an unacceptably long time frame. In parallel with these recognized research needs, it would be helpful to evaluate some of the recent programmes in Cornwall and NE UK coast which have applied existing knowledge and very practical approaches to expand local lobster fisheries.

Given the outcome of recent monitoring data from Horns Rev, which records substantial increases in crab populations over the previous year, it would be prudent to consider how this knowledge could be utilized to benefit crab fishermen working areas within or adjacent to OWFs – both existing, built and proposed. Crabs appear to utilize hard substrata differently from lobsters, sheltering within crevices on the outside of the scour protection. Crabs are considered to be more mobile than lobsters, work by Edwards in the 1960s and 1970s (Edwards 1979) demonstrated that tagged mature female crabs could move 20+ miles over a 12 month period. Studies to quantify daily and/or foraging movements, nearest neighbour distances and site loyalty would allow an evaluation of the value of OWFs to crab populations and so their potential to contribute to sustainable fisheries.

Field work and laboratory studies using both lobsters and crabs taken both from the wild and hatcheries and utilizing electromagnetic (developed at the NOC), acoustic and conventional tagging expertise and combined with complexity modelling and measuring methodologies that have been developed at SAMS would provide many of the answers to these questions. Once the biological parameters are known then habitat creation by using a variety of rock sizes could be modelled using techniques pioneered by Wickens and Barker (1997) and field tested.

In a similar fashion, commercial fish species could be assessed for site loyalty using acoustic telemetry and feeding behaviour by comparing stomach contents with reef epifauna/prey items (or using lipid analysis or isotope techniques). How scour protection is utilized by very mobile species will allow an evaluation of the importance of such a habitat to the individual fish and so too the enhancement effect for the population as a whole.

12.3.3 MOVEMENT AND BEHAVIOUR OF LOBSTERS

The goals of assisting fisheries through habitat provision needs to be established, particularly with respect to whether the revenue needs to be internalized (i.e. kept within a restricted area). This necessitates an understanding of the movement and behaviour of lobsters which is currently poorly understood. The approach here would be to firstly fully evaluate existing data then, if necessary mark, release and recapture lobsters. This is a costly exercise but could be done in conjunction with fishermen's organizations/associations.

12.3.4 FEASIBILITY OF MUSSEL CULTURE WITHIN AN OWF

The potential offered by rapid and prolific mussel settlement on OWF structures and associated scour protection needs to be further investigated. Our predictions from models ground truthed in a variety of locations, indicate that in the case of the North-west R2 area at least, (and probably to some extent in the other Round 2 areas) primary production is more than adequate to support good growth year round. Although it may be impractical to harvest mussels directly, an enhanced supply of mussel larvae originating from turbine structures to adjacent rafts for mussel culture, could contribute to security of larval supply for aquaculture operations. These considerations and the importance in identifying suitable market opportunities in driving aquaculture development, should be carried out in tandem with further pilot scale field studies. It is clear for e.g. that despite the progress of colleagues at Alfred Wegener Institute in developing and evaluating different novel structures for mussel culture associated with OWFs (Buck et al, 2004), assessing the performance and adequacy of these structures in the context of the North-west R2 area may prove to be more challenging than at the current test location off the German coast. We recommend that pilot studies to test the feasibility of using other structures recently developed in France and Australia should be undertaken as a priority in the North-west.

Current OWFs are designed for the exclusion of all non-OWF focussed activities. If OWFs are to play a role in a commercial fishery such as mussel culture, then there needs to be research undertaken into the best way to design an OWF to allow access by fishing boats, whilst maintaining access to the turbines for maintenance, ensuring that cable runs are not damaged and that all authorized users of the OWF site can work in safety. This should be a desk top study undertaken in collaboration with the OWF developers.

In addition, the models to allow prediction of shellfish growth are already available (Hawkins et al, 2006) but need to be configured using data specific to OWF sites where bivalve aquaculture has been identified as a viable option. Again sites in the North-west R2 area currently appear to show the most promise.

12.3.5 COMMERCIAL EXPLOITATION OF SEAWEEDS

Although the development of seaweed resources for commercial exploitation may seem only a very a distant prospect for the UK, the ambitions of the Irish government for developing the potential of seaweeds point to an important opportunity. The mostly likely target species are predominantly dependent on laboratory culture of sporelings, and until the potential enhancing effects of OWF reefs, or structures specifically deployed for commercial operations located offshore can be further assessed, there will be a need for onshore facilities. It has been suggested that culture offshore using systems suitable to withstand exposed conditions, would help meet the demand for single species and clean macroalgae grown under well controlled conditions for pharmaceutical and cosmetic use (Buck and Buchholz 2005), but realistically this option needs further evaluation and will probably still be limited to the OWFs with relatively lower wave energy environments. However, if competition for sea space intensifies significantly, and transportation costs continue to escalate, it may become cost effective to lease space within OWF footprints for commercial producers with specialized requirements (for e.g., such as better water quality) which cannot be reliably found in estuaries or the more accessible coastal fringe. An assessment of the current economic development potential of seaweeds for the UK, similar to that recently completed by the Irish government (National STI strategy 2007 – 2013), would provide much needed strategic direction in this sector. At present, anecdotal evidence suggests that there are important niche markets which could be exploited as a result of the added value obtained from offshore culture of seaweeds, and this opportunity is particularly relevant to the OWF context.

12.3.6 THE EFFECT OF CHRONIC NOISE AND EMFS

The effect of noise produced by wind turbines and other anthropogenic sources, on the benthos, cetaceans and some species of fish is largely unknown. Further research should be conducted to assess to extent to which noise influences the physiology and behaviour of fish and cetaceans particularly (Wahlberg and Westerberg 2005) although initially field observations could be undertaken to assess the extent of the need for further research in this area. Subsequently, in the case of fish, it would be appropriate to undertake tank based observations concentrating on a commercially relevant, easily maintained species (such as cod). Cod frequently vocalize, particularly during mate selection and so the influence of extraneous noise on this behaviour could be assessed in tank-based experiments. Chronic noise is also a potential problem for cetaceans, potentially drawn to an OWF by the presence of prey species. Specialist T-POD detectors, developed and used by researchers within the Danish wind farm experiments would allow evaluation of the frequency of cetacean presence which could be linked to turbine noise levels.

The influence of electromagnetic fields on benthic communities also remains largely unknown, and although studies have been initiated by the Danish wind farm programme at Nysted, the results were inconclusive. The recent COWRIE (Gill et al. 2005) identified that current knowledge gaps include a proper assessment of which species are sensitive to EMFs and how the effects are manifested. This issue is currently further being assessed with additional COWRIE funding and results are expected mid 2008 (Dr. A. Gill, University of Cranfield, Sept 2006, pers. comm.).

12.3.7 DEVELOPMENT OF EPIBIOTIC COMMUNITIES

The development of epibiotic communities on structures that mimic OWF scour protection needs to be evaluated, in order to establish the potential for such structures to act as habitats for rare and unusual biota, as well as to provide data on productivity and nutrient generation potential that can feed into future OWF proposals. Whilst being aware that there will always be site/season of deployment variation in community development, some generalisations have been drawn about the most likely communities that would develop on OWF scour protection. Routine monitoring of such sites should provide data on the movement of epibiotic species along the North-South gradient of water temperature, as well as revealing the likelihood that OWFs will provide substrata suitable for colonization by 'invasive' 'alien' species, an important aspect to evaluate if OWFs are to be considered as a management tool for conservation. A related question which could be addressed at the same time as routine monitoring of the epibiotic community relates to the presence of mobile predators on and around the OWF scour protection, and their impact on the seabed, in the form of predation of existing epifauna and infauna. The possible existence of a 'feeding halo' extending from the scour protection needs to be evaluated, as should such an effect be seen then the potential benefits of OWFs as a protected area with conservation value need to be re-evaluated in light of this information

12.3.8 OWFS AS 'NO-TAKE' AREAS FOR MANAGEMENT OF FISHERIES

The beneficial effect of implementing a 'no-take' MPA to coincide with an OWF footprint could potentially be assessed at any of the existing OWF sites in collaboration with local fishermen. Anecdotal reports of the effects of OWF closure are currently yielding confusing signals regarding the benefits to fisheries. However, to test the closure and potential reef enhancing effects in a systematic way, monitoring over longer time scales (5 to 10 years) and predictive tools such as those developed by Rodwell et al. (2005) need to be applied. Nevertheless, as this initial reef effect study has shown, it is difficult to assess the beneficial effect of introducing the reef effect as a fisheries enhancement measure over time, without adequate baseline data for an individual site. Thus more detail is required for a target OWF site before the Rodwell et al. type of modelling exercise is feasible. This is because the reef enhancing effect depends on the extent and nature of the colonising community associated with scour protection in an individual OWF, and the habitat opportunities this offers to the target fish species. Nevertheless, by selective and carefully targeting of data collection at a pilot OWF site pre-construction, we would be able to simulate the effect of introducing different artificial reef structures into an individual OWF site, then ground truth the model after construction. Theoretically this exercise could be undertaken for an existing OWF site such as North Hoyle or Kentish Flats, however, the necessary management measures to support the modelling need to be considered in consultation with the OWF operator at an early stage, to ensure effectiveness of this approach.

12.3.9 LONG TERM IMPACTS OF ARTIFICIAL REEF STRUCTURES

The long term impact of artificial reef structures in terms of community development and impact on sediment structure will also need to be considered. In addition to the biological community development on a single turbine tower, there are the research questions posed by the existence of several towers over a given sea area. The question arises as to whether tower/scour protection fouling communities and associated mobile fauna become a self sustaining entity once the habitat volume exceeds a certain limit (the Japanese have a minimum size for artificial reef developments, because they consider that a reef 'won't work' if the habitat provision doesn't exceed 150,000 m^3). If rock scour protection is the dominant material used and if (ideally) the make up of the scour protection is influenced by the site, independent research findings for example, lobster habitat requirement, then the creation of multiple wind farms may well be the largest artificial reef experiment in Northern Europe. Assessment of the impacts of habitat creation at this scale needs to be understood in terms of biological and physical changes, and notably for sediment transport and water current movements.

This work should also be considered in the context of decommissioning, since currently the expectation is that scour protection will be removed with pylons after a 25 year generating life. Whilst currently one viewpoint of scour protection is that of a habitat pollutant, affecting the 'pristine' sandy/muddy seabed biota, and that removal of scour protection will be a positive conservation measure. On the other hand, if monitoring shows development of a community that supports species of conservation importance, then removal (when the time comes) may not be such a clear cut decision. Equally, if scour protection is providing sufficient habitat to support a fishery (a fishery production rate of 0.005 – 0.02 kg m^{-3} has been used by Polovina (1989)) then the expected requirement to balance conservation value of an area with the socio-economic aspects of scour protection removal, may not produce the result expected under current legislation. Such a discussion needs to be underplayed with data, not speculation.

12.3.10 GROUND TRUTHING ARTIFICIAL REEF DESIGN MODELS USING EUROPEAN OWF DATA

Finally, the only attempt to evaluate the success of artificial reefs in achieving their original design objectives (Baine, 2001) indicates that up to 50% show no beneficial effect or inconclusive results (sample size 30). This indicates strongly that there is a need to improve the artificial reef design process to meet fisheries enhancement objectives, which as we have noted elsewhere in this report, need to respond to specific local drivers applicable to a given OWF site and socio-economic context. Recent attempts using a mathematical model (DARC) – (Deployment of Artificial Reef Communities) to simulate economically and biologically effective artificial reef ecosystems with finite budgets (Lan and Hsui, 2006 a and b) may well have significant potential, but are as yet unproven.

Models could be tested and developed further by effectively ground truthing at existing artificial reef test sites (such as Poole Reef or Loch Linnhe), and then they may have some application in the context of OWFs in the UK, particularly to assess the ecosystem benefits of different sizes of reef, which will have knock-on effects for enhancement of fisheries and crustacean aquaculture.

12.4 Main elements of the forward research programme

12.4.1 OWF SITE DEPENDENT QUESTIONS

Because OWFs are being built now, they present observational and experimental opportunities, which should be exploited optimally if possible, and moreover, in parallel with monitoring already underway in relation to licensing requirements for individual OWFs. The strong site dependent nature of the outcomes emerging from research on artificial reefs worldwide, makes the opportunity presented by existing OWFs particularly valuable, as we have access to a natural laboratory (all the R2 areas) covering a significant area of sea space. It has been suggested that an OWF monitoring strategy should be developed for the UK – as at Horns Rev – however, although it is sensible to provide generic guidance on the aspects which are likely to require monitoring at all sites, and to attempt to establish common methods for monitoring across the sector, the monitoring requirements at each site will be different because of the unique nature of each site and the stakeholder perspectives associated with that site. Consequently we do not think it is helpful to be prescriptive in terms of the sector – wide monitoring strategy, but rather to indicate priorities which have emerged as a result of the current review.

The elements of the forward programme which we would recommend are progressed with support of OWF developers at operational facilities sites are:

- Continue monitoring the development of epibiotic communities – this will allow further detailed analysis of enhancement potential for commercially important species (All)
- Continue monitoring to allow assessment of OWFs as ‘no-take’ areas for management of fisheries (including possible Bass restoration areas)(e.g. at Kentish Flats)
- Identify at least one OWF site where monitoring is undertaken to allow assessment of ecosystem restoration potential which can result from closure,
- Identify one OWF site where adequate baseline characterisation can be undertaken in the course of routine monitoring to support predictive modelling approach in Rodwell et al (2005) (see below)
- Test feasibility of shellfish culture within an OWF footprint focussing on the operational issues of both OWF operators and shellfish farmers to build confidence on both sides (North Hoyle?)

- Identify an OWF site to collect additional appropriate field data to assist in the application of sustainability principles and to showcase the bio-economic models for shellfish culture and therefore too the potential for long term success of co-location of OWF and shellfish culture,
- Preliminary testing of new technologies for exploitation of bivalves and seaweeds (North Hoyle?)
- Long term impacts of artificial reef structures (All)

All these elements could be progressed as part of ongoing monitoring programmes with the agreement of the OWF operators and local stakeholders (if agreement can be reached) and with little interference to operations at OWFs.

12.4.2 ARTIFICIAL REEF BASED RESEARCH

In addition to research questions which can be progressed at individual OWF sites in tandem with routine monitoring studies, the artificial reefs in Poole Bay and Loch Linnhe present significant opportunities to progress some elements of the forward research programme, supported by regular ongoing monitoring and research studies activities at each site. For example:

- movement and behaviour of lobsters,
- lobster shelter selection depending on size, life cycle stage and the physical environment (habitat complexity and exposure to water flow),
- the number of shelters that are occupied by individuals within a given time frame
- the foraging distances of lobster with regard to size, sex and moult state;
- ‘site loyalty’ of sexually mature lobsters
- parameters determining nearest neighbour distances
- identify an artificial habitat type that would be acceptable to the early benthic phase lobsters

The focus on lobsters (above), is not accidental, given the current status of scour protection in operational wind farms to undertake the necessary studies.

12.4.3 DESK-BASED AND LABORATORY SCALE STUDIES

Some of the questions raised will need to be considered at the laboratory scale or by means of a desk based study before transferring to a pilot scale investigation or site based enquiry, for e.g.

- The effect of chronic noise and EMFs on benthos (possibly supported by field observations)

- Ground truthing artificial reef design models using local (European) OWF data – further interrogation of existing datasets focusing on fisheries enhancement reefs would be beneficial,
- Undertake predictive modelling of sustainable yields of shellfish at named OWF sites with additional field data, to demonstrate yields which are theoretically possible from an OWF area with adequate resource,
- Adapt OWF site characterisation data to allow predictive modelling of the impact of no-take combined with reef enhancing effect (i.e. test Rodwell et al.2005 approach).

13 Discussion and Conclusions

13.1 Colonisation of OWFs by marine biota

When introduced into the marine environment, turbine towers together with their associated scour protection in effect, constitute an artificial reef, and the surfaces are readily colonised by a typical and broadly predictable assemblage of organisms, reflecting zonation patterns observed in adjacent rocky shore communities. Site dependent factors such as proximity to rocky shores and hydrographic conditions including degree of scour influence the presence of some species and the absence of others at specific OWF sites. The structures may also extend the distributions of some mobile species such as crabs, lobsters and fin fish, as a result of new habitat opportunities.

13.2 Predictions of anticipated finfish shellfish and other marine biota associated with structures

Although the precise predictions of the commercial species which may be anticipated at a given OWF site are not generally possible, predictions of the likely presence or absence of target commercial species have been made for the purposes of this report on the basis of:

(a) presence of the target species in existing R2 areas,

(b) extrapolation from OWF analogues in adjacent or similar geographical areas;

(c) presence of target species on structures of built OWFs and

(d) literature sources focussing on habitat requirements and distribution of target species.

Although the scientific literature is broadly in agreement that there IS likely to be an enhancement effect for finfish and Crustacea, the extent and nature of the effect, it appears, is heavily dependent on the nature of the reef created, and the characteristics of the indigenous populations at the time of introducing the artificial reef. Many artificial reefs have failed to achieve their objectives, including those for fisheries/lobster enhancement, because of the ad hoc approach taken to introducing artificial reef into the environment. i.e. little consideration of target species involved, their habitat requirements or the scale of reef which would be needed to ensure an enhancement effect. Consequently it is not straightforward to extract general principles which could apply to the current analysis, and so we have therefore highlighted the research which could be undertaken to introduce some scientific rigour into this process.

Nevertheless, our analysis shows there may be some potential to enhance existing crab fisheries through introduction of scour protection at some sites, and the increases in yield will provide a boost to the income of local crab potters. Exclusion of mobile fishing gears appears to represent the most compatible compromise between the operational requirements of an OWF and fishing activity, and at present it appears that the development of a partial 'no-take' need not exclude deployment of fixed gears such as lobster and crab pots, nor developing and expanding the recreational opportunities around sea angling, especially for seabass, which may be supported at some OWF sites.

Although there may ultimately be important opportunities for lobster fishers in association with OWFs, we think it will be essential to undertake further research to clarify key questions to understand better the relationships between lobsters and the nature and extent of scour protection, before developing options for a lobster fishery.

13.3 OWFs and aquaculture

At the present time there appears to be very little potential for fin fish culture within OWFs. Because of shallow water depths and current speeds, the conditions at existing R2 OWF sites are not ideal for cage culture of salmon or cod, and although there is some indication that climate change may prevent sea bass from growing successfully in the Mediterranean in the much longer term, their successful transfer to UK waters would depend on similar criteria. The current moves to culture turbot and halibut on shore suggest that if systems which are fully closed and based on recirculation technology can be profitable, it is unlikely that offshore finfish culture facilities will develop, except in deeper water further offshore than the existing OWFs.

Exploration of the potential for mussel culture appears to be one of the most straightforward economic opportunities within existing OWFs – although, development of appropriate technology for culture in water depths at OWFs will require some further investigation. It is doubtful whether enhancing effects of scour protection will be particularly relevant in the case of mussels, except where facilities are sufficiently close to reefs to benefit from local effects, as there is ample food resource to support growth, at all sites except possibly in the Thames estuary, where further assessment of the resource is advisable.

The opportunities presented by seaweed culture in the UK have yet to be recognised and an appropriate strategic direction provided for the sector. It appears that there may be significant niche opportunities afforded for seaweed culture by OWFs, because of the avoidance of near coast pollution in some areas, but the feasibility and operability of appropriate technologies for culture needs to be tested within an OWF footprint.

13.4 Data gaps and work programme

We have identified a substantial inventory of data gaps, many of which could be addressed in the course of routine monitoring at existing sites as a result of judicious and intelligent use of resources and personnel. The recommendations for the programme of research have been made without consultation with OWF operators, and we are acutely aware that they are generally very preoccupied with technical and operational issues at the present time. However, as the sector develops and experience increases, there may be greater flexibility to find compromise between the OWF design per se and the enhancement/mitigation opportunities for local fisheries in particular. The predictive models are already in existence to inform the design optimisation process to support specifically fisheries enhancement, and this would ensure that a much more scientific approach to designing reefs is applied to individual OWF sites, to ensure better outcomes than is apparent in the artificial reef sector as a whole at present.

One of the enhancement effects associated with OWFs which should be investigated as a priority is the opportunity to develop ‘no-take’ MPAs based on the footprint of the OWF; the potentially enhancing effects of scour protection within a ‘no-take’ area can be assessed initially by using an existing predictive model, and then ground truthed over time as data becomes available from the no-take area. Eventually it should be possible to test the enhancement potential of different types/sizes/extents of scour protection in association with turbines and to consider the optimal artificial reef configuration at an OWF site for its enhancement potential. Also the potential benefits of demonstrating that ‘no-take’ yields to fishers may have a knock-on effect for the fisheries sector as a whole, and help to generate support for enhancement/environmental restoration actions elsewhere. Ideally the target species selected for the enhancement effect at an individual OWF site should be identified in collaboration with local fishermen, and in the course of discussions which would anyway be necessary to bring about exclusion of mobile gears to ensure operational security at an OWF site.

Finally, it has also been suggested that whilst commercial benefits from fisheries and aquaculture are desirable, there is a case for closing an OWF footprint simply to allow restoration of indigenous biological communities, thereby improving ecosystem health and resilience with knock on benefits for wider ecosystems. At the present time it would be difficult to identify UK coastal waters which are subject to no anthropogenic impacts at all, and some areas are degraded as a result of historical exploitation and unsustainable activities. Because normal OWF operational requirements are believed to have relatively low impacts on either the benthos or water column communities, a better understanding of the potential benefits of allowing areas of sea-bed to effectively to lie ‘fallow’, could be obtained from long term closure and monitoring of ecosystem health and function at selected OWF sites. This could enable us to develop a novel understanding of the natural resilience and recovery potential of coastal ecosystems.

14 References

Abelson A, Weihs D, Loya Y (1994) Hydrodynamic impediments to settlement of marine propagules, and adhesive-filament solutions. Limnology and Oceanography 39: 164-169

Addison JT, Bennett DB (1992) Assessment of Minimum Landing Sizes of the Edible Crab, Cancer-Pagurus L, on the East-Coast of England. Fisheries Research 13: 67-88

Ambrose RF (1994) Mitigating the effects of a coastal power-plant on a kelp forest community – rationale and requirements for an artificial reef. Bulletin of Marine Science 55: 694-708

Angel DL, Eden N, Breitstein S, Yurman A, Katz T, Spanier E (2002) *In situ* biofiltration: a means to limit the dispersal of effluents from marine finfish cage aquaculture. Hydrobiologia 469: 1-10

Angel DL, Spanier E (2002) An application of artificial reefs to reduce organic enrichment caused by net-cage fish farming: preliminary results. ICES Journal of Marine Science 59: S324-S329

Anon (1998) Aspects recommended by the workshop to be taken into account for a proposal of draft OSPAR guidelines on artificial reefs. AR 98/5/1, Annex 4 (Ref 3.7), Sea, 9 pages.

Antsulevich AE (1994) Artificial reefs project for improvement of water quality and environmental enhancement of Neva Bay (St-Petersburg county region). Bulletin of Marine Science 55: 1189-1192

Arce AM, Aguilar-Davila W, Sosa-Cordero E, Caddy JF (1997) Artificial shelters (casitas) as habitats for juvenile spiny lobsters *Panulirus argus* in the Mexican Caribbean. Marine Ecology-Progress Series 158: 217-224

Aseltine-Neilson DA, Bernstein BB, Palmer-Zwahlen ML, Riege LE, Smith RW (1999) Comparisons of turf communities from Pendleton Artificial Reef, Torrey Pines Artificial Reef, and a natural reef using multivariate techniques. Bulletin of Marine Science 65: 37-57

Aston Z (2006) Modelling and Measuring Water Motion on the Loch Linnhe Artificial Reef – (i) Potential Biological Effects and (ii) Implications for Coastal Hydrodynamics. MRes thesis, 109 pp. School of Marine Science and Technology, University of Newcastle.

Baine M (2002) The North Sea rigs-to-reefs debate. ICES Journal of Marine Science 59: S277-S280

Bannister RCA, Addison JT (1998) Enhancing lobster stocks: a review of recent European methods, results, and future prospects. Bulletin of Marine Science 62: 369-387

Bannister RCA, Addison JT, Lovewell SRJ (1994) Growth, movement, recapture rate and survival of hatchery-reared lobsters (*Homarus gammarus* (Linnaeus, 1758)) released into the wild on the English east coast. Crustaceana 67: 156-172

Barry J, Wickins JF (1992) A model for the number and sizes of crevices that can be seen on the exposed surface of submerged rock reefs. Environmetrics 3: 55-69

Baynes TW, Szmant AM (1989) Effect of current on the sessile benthic community structure of an artificial reef. Bulletin of Marine Science 44: 545-566

Beck MW (1995) Size-specific shelter limitations in stone crabs – a test of the demographic bottleneck hypothesis. Ecology 76: 968-980

Bentley MG, Todd CD (1999) A study of fish and macrocrustaceans around the Torness artificial in the Firth of Forth (North Sea). In: Relini G, Ferrara G, Massaro E (eds) Seventh International Conference on Artificial Reef and Related Aquatic Habitats, San Remo, Italy, pp 113

Blaxter JHS (2000) The enhancement of marine fish stocks. Advances in Marine Biology 38: 1-54

Boaventura D, Moura A, Leitao F, Carvalho S, Curdia J, Pereira P, de Fonseca LC, dos Santos MN, Monteiro CC (2006) Macrobenthic colonisation of artificial reefs on the southern coast of Portugal (Ancao, Algarve). Hydrobiologia 555: 335-343

Bohnsack JA, Ecklund A-M, Szmant AM (1997) Artificial reef research: is there more than the attraction-production issue. Fisheries 22: 14-16

Bohnsack JA, Sutherland DL (1985) Artificial Reef Research – a review with recommendations for future priorities. Bulletin of Marine Science 37: 11-39

Bortone SA (1998) Resolving the attraction-production dilemma in artificial reef research: some yeas and nays. Fisheries 23: 6-10

Bradbury RH, Reichelt RE (1983) Fractal Dimension of a Coral-Reef at Ecological Scales. Marine Ecology-Progress Series 10: 169-171

Breitburg DL, Palmer MA, Loher T (1995) Larval distributions and the spatial patterns of settlement of an oyster reef fish – responses to flow and structure. Marine Ecology-Progress Series 125: 45-60

Brock RE, Kam AKH (1994) Focusing the recruitment of juvenile fishes on coral-reefs. Bulletin of Marine Science 55: 623-630

Brown CJ (2005) Epifaunal colonization of the Loch Linnhe artificial reef: Influence of substratum on epifaunal assemblage structure. Biofouling 21: 73-85

Bryan GW, Langston WJ (1992) Bioavailability, Accumulation and Effects of Heavy-Metals in Sediments With Special Reference to United-Kingdom Estuaries – a Review. Environmental Pollution 76: 89-131

Bulleri F, Abbiati M, Airoldi L (2006) The colonisation of human-made structures by the invasive alga Codium fragile ssp tomentosoides in the north Adriatic Sea (NE Mediterranean). Hydrobiologia 555: 263-269

Bulleri F, Airoldi L (2005) Artificial marine structures facilitate the spread of a non-indigenous green alga, Codium fragile ssp tomentosoides, in the north Adriatic Sea. Journal of Applied Ecology 42: 1063-1072

Bunker F.St.P.D (2004) Biology and video surveys of North Hoyle wind turbines 11-13th August 2004. A report to CMACS Ltd by Marine Seen, Estuary Cottage, Bentlass, Hundleton, Pembs. SA71 5RN

Burton WH, Farrar JS, Steimle F, Conlin B (2002) Assessment of out-of-kind mitigation success of an artificial reef deployed in Delaware Bay, USA. ICES Journal of Marine Science 59: S106-S110

Byrne BW, Houlsby GT (2003) Foundations for offshore wind turbines. Philosophical Transactions of the Royal Society of London Series a-Mathematical Physical and Engineering Sciences 361: 2909-2930

Caddy JF (1999) Fisheries management in the twenty-first century: will new paradigms apply? Reviews in Fish Biology and Fisheries 9: 1-43

Caley MJ, Carr MH, Hixon MA, Hughes TP, Jones GP, Menge BA (1996) Recruitment and the local dynamics of open marine populations. Annual Review of Ecology and Systematics 27: 477-500

Castro KM, Cobb JS, Wahle RA, Catena J (2001) Habitat addition and stock enhancement for American lobsters, *Homarus americanus*. Marine and Freshwater Research 52: 1253-1261

CMACS (2003) A baseline assessment of electromagnetic fields generated by offshore wind farm cables. COWRIE EMF 01-2002, 65 pp.

Cobb JS, Wahle RA (1994) Early-Life History and Recruitment Processes of Clawed Lobsters. Crustaceana 67: 1-25

Collins KJ, Jensen AC, Lockwood APM (1990) Fishery enhancement reef building exercise. Chemistry and Ecology 4: 179-187

Copley (2006) Briefing note on artificial reefs for Chairman of Stakeholder workshop 'Suitability of offshore wind farms as aquaculture sites', at RINA, London, March 1st, 2006.

Deysher LE, Dean TA, Grove RS, Jahn A (2002) Design considerations for an artificial reef to grow giant kelp (*Macrocystis pyrifera*) in Southern California. ICES Journal of Marine Science 59: S201-S207

Eggleston DB, Lipcius RN, Miller DL (1992) Artificial shelters and survival of juvenile Caribbean spiny lobster *Panulirus argus* – spatial, habitat, and lobster size effects. Fishery Bulletin 90: 691-702

Elner RW, Campbell A (1987) Natural diets of lobster *Homarus americanus* from barren ground and macroalgal habitats off southwestern Nova Scotia, Canada. Marine Ecology-Progress Series 37: 131-140

Energi-E2 (2005) The Danish Offshore Wind Farm demonstration project: Horns Rev and Nysted Offshore Wind Farms – Environmental impact assessment and monitoring, Review Report 2004. Teglholmen, A. C. Meyers Vaenge 9, DK-2450 Kobenhaven SVpages.

FAO. (1997) Fisheries management. FAO Technical Guidelines for Responsible Fisheries. No. 4. Rome,. 82p.

Feld T (2004) Site Specific Certification of Offshore Wind Farms – cost effective designs will make the offshore projects economically viable North American Wind power

Forteath, G.N.R., Picken, G.B., Ralph, R. & Williams, J., 1982. Marine Growth Studies on the North Sea Oil Platform Montrose Alpha. Marine Ecology Progress Series, 8, 61-68.

Fowler AJ, Jensen AC, Collins KJ, Smith IP (1999) Age structure and diet activity of pouting on the Poole Bay artificial reef. Journal of Fish Biology 54: 944-954

Garnick E (1989) Lobster (*Homarus americanus*) Population Declines, Sea-Urchins, and Barren Grounds – a Space-Mediated Competition Hypothesis. Marine Ecology-Progress Series 58: 23-28

Gee JM, Warwick RM (1994) Metazoan Community Structure in Relation to the Fractal Dimensions of Marine Macroalgae. Marine Ecology-Progress Series 103: 141-150

Gee JM, Warwick RM (1996) A study of global biodiversity patterns in the marine motile fauna of hard substrata. Journal of the Marine Biological Association of the United Kingdom 76: 177-184

GHP (Garrad Hassan and Partners Ltd) (2005). Description of the UK Round 2 offshore wind farm projects. Report no. 11153/BR/01. Report to Seafish, 67pp.

Gill AB (2005) Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology 42: 605-615

Gill AB, Gloyne-Phillips I, Neal K, Kimber J (2005) The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms – a review. COWRIE-EM FIELD 2-06-2004, 57 pages.

Goldson AJ, Hughes RN, Gliddon CJ (2001) Population genetic consequences of larval dispersal mode and hydrography: a case study with bryozoans. Marine Biology 138: 1037-1042

Grosholz E (2002) Ecological and evolutionary consequences of coastal invasions. Trends in Ecology & Evolution 17: 22-27

Guichard F, Bourget E (1998) Topographic heterogeneity, hydrodynamics, and benthic community structure: a scale-dependent cascade. Marine Ecology-Progress Series 171: 59-70

Guillen JE, Ramos AA, Martinez L, Lizaso JLS (1994) Antitrawling reefs and the protection of *Posidonia oceanica* (L) Delile meadows in the western Mediterranean Sea – demand and aims. Bulletin of Marine Science 55: 645-650

Hall SJ, Basford DJ, Robertson MR, Raffaelli DG, Tuck I (1991) Patterns of Recolonization and the Importance of Pit-Digging by the Crab Cancer-Pagurus in a Subtidal Sand Habitat. Marine Ecology-Progress Series 72: 93-102

Hall SJ, Robertson MR, Basford DJ, Fryer R (1993) Pit-Digging by the Crab Cancer-Pagurus – a Test for Long-Term, Large-Scale Effects on Infaunal Community Structure. Journal of Animal Ecology 62: 59-66

Hamer B, Hayman SJ, Elsdon PA, Fleming CA (1998) Happisburgh to Winterton Sea Defences: Stage Two. In: Allsop NWH (ed) Coastlines, structures and breakwaters. Thomas Telford Publishing, London, pp.

Henderson AR, Morgan C, Smith B, Sorensen HC, Berthelmie R, Boesmans B (2002) Offshore wind power a major new source of energy for Europe Renewable Realities – Offshore Wind Technologies Orkney

Hiscock S (1986) Sublittoral survey of the mid-Wales Sarns (reefs): Sarn Badrig, Sarn-y-bwch and Cynfelin patches. July 2nd-9th, 1986. Nature Conservancy Council CSD Report No. 696, Peterborough, 71 pp.

Hiscock K, Tyler-Walters H, Jones H (2002). High level environmental screening study for offshore wind farm developments – marine habitats and species project. Report no. W/35/00632/00/00. Report to The Department of Trade and Industry. Marine Biological Association, Plymouth, 34pp.

Howard AE, Bennett DB (1979) The substrate preference and burrowing behaviour of juvenile lobsters (*Hommarus gammarus*). Journal of Natural History 13: 433-438

HR Wallingford (2005). Wind farm impacts on seabed processes. Report no. EX 5207. Report to Seafish, 18pp plus appendices.

Hughes DJ, Cook EJ, Sayer MDJ (2005) Biofiltration and biofouling on artificial structures in Europe: The potential for mitigating organic impacts Oceanography and Marine Biology – an Annual Review, Vol. 43, pp.

Hunter W (2006) Quantifying the environmental benefits of Artificial Reefs: an investigation into the ecological effects of habitat complexity and fisheries exclusion. Work Placement Report for the MSc ‘Aquatic Bioscience’. Division of Environmental and Evolutionary Biology, University of Glasgow, 62 pp.

James MA, Slaski R (2006) Appraisal of the opportunity for offshore aquaculture in UK waters. Report of Project FC0934, commissioned by Defra and Seafish from FRM Ltd., 119 pp.

Jensen AC, Spanier E (2004) Artificial reefs: life from the scrap heap. In, Stow, D. (ed.) *Encyclopedia of the oceans*. Oxford, UK, Oxford University Press, p.220

Jensen AC, Collins KJ, Free EK, Bannister RCA (1994a) Lobster (*Homarus gammarus*) movement on an artificial reef – the potential use of artificial reefs for stock enhancement. Crustaceana 67: 198-211

Jensen AC, Collins KJ, Lockwood APM, Mallinson JJ, Turnpenny WH (1994b) Colonization and fishery potential of a coal-ash artificial reef, Poole-Bay, United-Kingdom. Bulletin of Marine Science 55: 1263-1276

Jensen AC, Collins KJ, Smith IP (1998) Artificial reefs in lobster enhancement programmes. Canadian Industry Report of Fisheries and Aquatic Science 244: 79-84

Jury SH, Kinnison MT, Howell WH, Watson WH (1994) The Effects of Reduced Salinity On Lobster (*Homarus americanus* Milne-Edwards) Metabolism – Implications For Estuarine Populations. Journal of Experimental Marine Biology and Ecology 176: 167-185

Kaiser MJ (2006) The Louisiana artificial reef program. Marine Policy 30: 605-623

Keough MJ (1983) Patterns of Recruitment of Sessile Invertebrates in 2 Subtidal Habitats. Journal of Experimental Marine Biology and Ecology 66: 213-245

Konar B (2000) Seasonal inhibitory effects of marine plants on sea urchins: structuring communities the algal way. Oecologia 125: 208-217

Kristiansen TS, Drengstig T, Nostvold E (2004) Development of methods for intensive farming of European lobster in recirculated water. 6-2004, Institute of Marine Research, Bergen, Sweden, 52 pages.

Lan CH, Chen CC, Hsui CY (2004) An approach to design spatial configuration of artificial reef ecosystem. Ecological Engineering 22: 217-226

Lawton P, Hughes RN (1985) Foraging Behavior of the Crab Cancer-Pagurus Feeding on the Gastropods Nucella-Lapillus and Littorina-Littorea – Comparisons with Optimal Foraging Theory. Marine Ecology-Progress Series 27: 143-154

Lindquist N, Hay ME, Fenical W (1992) Defense of ascidians and their conspicuous larvae – adult vs. larval chemical defense. Ecological Monographs 62: 547-568

Linnane A, Ball B, Mercer JP, Browne R, van der Meeren G, Ringvold H, Bannister C, Mazzoni D, Munday B (2001) Searching for the early benthic phase (EBP) of the European lobster: a trans-European study of cobble fauna. Hydrobiologia 465: 63-72

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

Love MS, Caselle J, Snook L (1999) Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin. Bulletin of Marine Science 65: 497-513

Luckhurst BE, Luckhurst K (1978) Analysis of Influence of Substrate Variables on Coral-Reef Fish Communities. Marine Biology 49: 317-323

Madsen PT, Wahlberg M, Tougaard J, Lucke K, Tyack P (2006) Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology-Progress Series 309: 279-295

Mandelbrot BB (1982) Chapter 34 Texture: Gaps and lacunarity; cirri and succolarity Fractal Geometry of Nature. W H Freeman and Company, pp

Martin D, Bertasi F, Colangelo MA, de Vries M, Frost M, Hawkins SJ, Macpherson E, Moschella PS, Satta MP, Thompson RC, Ceccherelli VU (2005) Ecological impact of coastal defence structures on sediment and mobile fauna: Evaluating and forecasting consequences of unavoidable modifications of native habitats. Coastal Engineering 52: 1027-1051

Matthiopoulos J, McConnell B, Duck C, Fedak M (2004) Using satellite telemetry and aerial counts to estimate space use by grey seals around the British Isles. Journal of Applied Ecology 41: 476-491

McConnell BJ, Fedak MA, Lovell P, Hammond PS (1999) Movements and foraging areas of grey seals in the North Sea. Journal of Applied Ecology 39: 573-590

Mee L (2006) Complementary benefits of alternative energy: suitability of offshore wind farms as aquaculture sites. Report to Seafish Project ref No: 10517. 36pp.

Menge BA (2000) Recruitment vs. postrecruitment processes as determinants of barnacle population abundance. Ecological Monographs 70: 265-288

Mercer T (2001) Blyth Offshore Wind Farm: Post-Construction Sublittoral Biological Survey., Aquatic Environments, 28 pages.

Milligan S (2005). Study on fishing activities that may be carried out in and around offshore wind farms. Report no. C2337/01. Report to Seafish. Centre for Environment, Fisheries and Aquaculture Science, 41pp plus appendices.

Miron G, Bourget E, Archambault P (1996) Scale of observation and distribution of adult conspecifics: Their influence in assessing passive and active settlement mechanisms in the barnacle Balanus crenatus (Brugiere). Journal of Experimental Marine Biology and Ecology 201: 137-158.

Morel, A. (1991). Light and marine photosynthesis: A spectral model with geochemical and climatological implications, Progress in Oceanography, 26, 263-306.

Morikawa T (1996) Status and prospects on the development and improvement of coastal fishing ground International Symposium on Marine Ranching in Ishikawa, Kanazawa, Ishikawa Prefecture, Japan

Neal KJ, Wilson E (2007) Cancer pagurus. Edible crab. Marine Life Information Network: Biology and sensitivity key information sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Date accessed: 20/02/2007. Available from: http://www.marlin.ac.uk/species/Cancerpagurus.htm.

Nowell ARM, Jumars PA (1984) Flow environments of aquatic benthos. Annual Review of Ecology and Systematics 15: 303-328

Pelc R, Fujita RM (2002) Renewable energy from the ocean. Marine Policy 26: 471-479

Pickering H, Whitmarsh D (1997) Artificial reefs and fisheries exploitation: A review of the ‘attraction versus production’ debate, the influence of design and its significance for policy. Fisheries Research 31: 39-59

Pickering H, Whitmarsh D, Jensen A (1998) Artificial reefs as a tool to aid rehabilitation of coastal ecosystems: investigating the potential. Marine Pollution Bulletin 37: 505-514

Pitcher TJ, Watson R, Haggan N, Guenette S, Kennish R, Sumaila UR, Cook D, Wilson K, Leung A (2000) Marine reserves and the restoration of fisheries and marine ecosystems in the South China Sea. Bulletin of Marine Science 66: 543-566

Pratt JR (1994) Artificial habitats and ecosystem restoration – managing for the future. Bulletin of Marine Science 55: 268-275

Qiu JW, Thiyagarajan V, Leung AWY, Qian PY (2003) Development of a marine subtidal epibiotic community in Hong Kong: implications for deployment of artificial reefs. Biofouling 19: 37-46

Rees EIS, Walker AJM (1984) Macrobenthos community and population monitoring studies around the dumping ground Sewage sludge disposal in Liverpool Bay. Research into effects 1975 to 1977. Part 2. Appendices. Department of the Environment (Water Technical Division), London, pp

Reid JB, Evans PGH, Northridge SP (2003) Atlas of cetacean distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough, 82 pages.

Relini G, Zamboni N, Tixi F, Torchia G (1994) Patterns Of Sessile Macrobenthos Community-Development On an Artificial Reef In the Gulf Of Genoa (Northwestern Mediterranean). Bulletin of Marine Science 55: 745-771

Richmond M, Seed R (1991) A review of marine macrofouling communities with special reference to animal fouling. Biofouling 3: 151-168

Rilov G, Benayahu Y (1998) Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. Marine Environmental Research 45: 431-451

Rose C (2005) Modeling and measuring the habitat complexity of artificial reefs. PhD.203 pp. University of Newcastle, School of Marine Science and Technology, University of Newcastle

Sanchez-Jerez P, Ramos-Espla A (2000) Changes in fish assemblages associated with the deployment of an antitrawling reef in seagrass meadows. Transactions of the American Fisheries Society 129: 1150-1159

Santos MN, Monteiro CC (1998) Comparison of the catch and fishing yield from an artificial reef system and neighbouring areas off Faro (Algarve, south Portugal). Fisheries Research 39: 55-65

Sayer MDJ (2001) Fisheries: artificial fishery manipulation through stock enhancement or restoration. In: Steele J, Thorpe S, Turekian K (eds) Encyclopedia of Ocean Sciences. Academic Press, London, pp

Simard F (1996) Socio-economic aspects of artificial reefs in Japan. In: Jensen AC (ed) First European Artificial Reef Research Network Conference. Southampton Oceanography Centre, Ancona, Italy, pp 233-240

Smith IP, Collins KJ, Jensen AC (1999) Seasonal changes in the level and diet pattern of activity in the European lobster *Homarus gammarus*. Marine Ecology-Progress Series 186: 255-264

Smith IP, Jensen AC, Collins KJ, Mattey EL (2001) Movement of wild European lobsters *Homarus gammarus* in natural habitat. Marine Ecology-Progress Series 222: 177-186

Snelgrove PVR, Butman CA (1994) Animal-sediment relationships revisited – cause versus effect. Oceanography and Marine Biology 32: 111-177

Spanier E (1994) What are the characteristics of a good artificial reef for lobsters. Crustaceana 67: 173-186

Steimle F, Foster K, Kropp R, Conlin B (2002) Benthic macrofauna productivity enhancement by an artificial reef in Delaware Bay, USA. ICES Journal of Marine Science 59: S100-S105

Stottrup JG, Helmig S, Petersen JK, Krog C, Zorn R, Madsen HT, Olsen J (1998) Is there a case for artificial reefs in Denmark? ICES 1998/V:5

Sumer BM, Whitehouse RJS, Torum A (2001) Scour around coastal structures: a summary of recent research. Coastal Engineering 44: 153-190

Svane I, Petersen JK (2001) On the problems of epibioses, fouling and artificial reefs, a review. Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I 22: 169-188

Talisman P (2006) Beatrice wind farm demonstration project – frequently asked questions

Todd CD, Bentley MG, Kinnear J (1992) Torness Artificial Reef Project. In: Baine M (ed) Artificial Reefs and Restocking Conference. Unpublished, Stromness, Orkney Islands, Scotland, pp 15-21

Wahlberg M, Westerberg H (2005) Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology-Progress Series 288: 295-309

Wanson S, Pequeux A, Gilles R (1983) Osmoregulation in the Stone Crab Cancer-Pagurus. Marine Biology Letters 4: 321-330

Ward RD (In press) The importance of identifying spatial population structure in restocking and stock enhancement programmes. Fisheries Research In Press, Corrected Proof

Whitmarsh D, Pickering H, Sarch MT (1995) Economic appraisal of artificial reef structures for lobster production – final report. Centre for Coastal Zone Management, University of Portsmouth, 130 pages.

Whomesley and Picken (2003) Long term dynamics of fouling communities found on offshore installations in the North Sea JMBA 83, 897-901

Wickins JF, Roberts JC, Heasman MS (1996) Within-burrow behaviour of juvenile European lobsters *Homarus gammarus* (L). Marine and Freshwater Behaviour and Physiology 28: 229-253

Wilding TA (2006) The benthic impacts of the Loch Linnhe artificial reef. Hydrobiologia 555: 345-353

Wilhelmsson D, Malm T, Ohman MC (2006) The influence of offshore wind power on demersal fish. ICES Journal of Marine Science 63: 775-784

Wilson KDP, Cook DC (1998) Artificial reef development: a marine protected area approach. In: Morton B (ed) 3rd International Conference on the Marine Biology of the South China Sea, Hong Kong, pp 529-539

APPENDIX I

Summary of Background Environmental Information Extracted from Environmental Statements and SEAs 2, 3 and 6

(www.offshore-sea.org) (also see inventory Appendix v)

Summary Table	North-west (S. Irish Sea/Liverpool Bay) Sites
Substrata	Varies from sandy gravel to medium and coarse sands fine sands clay mud, areas of tillate course glacial deposit – featureless sands;
General hydrographic conditions	S to N water movement overall; complex intermediate water movements; tidal range increases E to W – strong semi diurnal tides 7.8m range; 100 yr storm surge + 1.7 to –1.3m
Temperature and salinity range	Winter temp 5 to 7.5C summer 13 to 16C salinity 31 to 33ppt (max 22C min 1C – sea bed max 18 min 1C)
Stratification/fronts	Liverpool Bay front results in some thermal stratification in summer
Current speeds/direction	Mainly E to W: 0.5 to 1.0 m/sec springs max 1.7m/sec neaps approx 50% of springs; complex direction and variable in shallower water;
Residence time/flushing	1 year flushing time with residual flow of 2 to 8 kms per day
Water quality	Hydrocarbons below Ospar levels isotopes below known effects levels offshore waters Pb, Cd and Hg concentrations above background (1997) marine litter (plastics) common;
Winds	Westerly winds predominant 5 to 10 m/sec Beaufort 3 to 5; extreme winds from west; 5.6m/sec.
Wave climate	Exposed to remote and locally generated waves most exposed to NW. 5.3m wave ht (13.6m max) for design. 11.2 secs wave period; Dominant waves from SW 0.6m mean to 5.1m max wave ht.
Effects of climate change	Sea level predicted 4mm/year; winter winds stronger summer weaker storm surges more frequent
Sediment transport	Bed load transport dominant in the W controlled by peak currents Estuaries dominant in the east; E and W divided by Irish sea mud belt; some fines in suspension; tidal currents only mobilize up to medium sand – are a significant transport during storm events; scour limited by depth of sand fines sands and silt in suspension on every tide
Turbidity/suspended seds/	8 to 139mg/l with mean of 55mg/l;
Phytoplankton – main species, chlorophyll	Mostly coastal and mixed spp – regular seasonal blooms Phaeocystis, Chaetoceros and Gyrodiniun annual production 200gC/m2/day
Zooplankton	Dominated by copepods – most spp in planktonic stages; typical shallow water spp for coastal areas higher productivity in region of Liverpool Bay front
Benthos	***Venus*** communities dominant in E Irish Sea; no known rare or protected spp. ***Amphuira*** communities typical further N – epibenthos dominated by decapods, brittle and starfish;
Fish and shellfish	See Appendix iv

Summary Table	The Greater Wash
Substrate	Muddy sandy gravel and sandy gravel; both types are gravel lag thin veneer with little mobile material depth <0.5m – glacial till below – generally featureless (no rocky outcrops) typical of swept seabed from which fines winnowed out; C – dominated by coarse sandy gravel or gravelly sands, occasional cobbles and shell – very low silt; sediments 0 to 0.5m thick seabed mainly free of bedforms occasionally arsenic unusually high but below PEL
General hydrographic info	Max spring tidal range is 6m
Water depth	6 – 8m below chart datum shallowest in the west deepest in the east
Temperature and salinity range	34 psu may rise to 34.25 in summer Mean temps 5°C to 15C winter and summer resp
Stratification/fronts	Fronts important to development of plankton – disruption by towers could alter location of fronts
Current speeds/direction	Peak spring and neap 1m/sec and 0.5 m/sec resp; flood tide flows S and ebb flows N out of the Wash; Spring and ebb tide velocities up to 1.3m/sec predicted currents insufficient to mobilise sediments flood tides N to NW direction: ebb tides currents flow in ESE direction
Residence time/flushing	High dispersion potential – tidal excursions 6 and 14kms neaps and springs resp
Water quality	Excellent water quality based on Bathing waters monitoring though east coast threatened by eutrophication especially from the Humber/Ouse systems which are a major source of nutrients for the N sea; release of contaminants from seds – all below probable effects levels;
Winds	Ave wind speed 9m/sec
Wave climate	Locally generated waves mainly from the N and mainly <2m in ht; significant wave hts up to 2.7m (1 in 1 month) 4.41m (1 in 1yr)
Sediment transport	Longshore sediment transport along the Norfolk coast; Peak tidal currents could potentially mobilise some of material
Turbidity/suspended seds/light penetration	Nearshore areas of N Sea generally have high concentrations of suspended sediment SS loads range from 2mg/l to as much as 100 – 200 mg/l in storm conditions; EA coastal monitoring data 5 to 525mg/l with an average of 129mg/l
Phytoplankton	Mainly neritic spp – southern mixed water species present – spring bloom march spreading inshore during April. Standing stock peaks in April/May and remains until October – i.e. no mid summer decline
Zooplankton	Dominated by copepods peaks between May and September – imp food source for adult herring – abundance has increased since 1981 despite generally low primary production (PP) – may be due to periodic/localised above ave PP which occurs near the Humber
Benthos	Infaunal benthic community homogenous across much of the area – dominated by *Sabellaria*; Juvenile Mytilus occur in grab samples with remaining spp mainly polychaetes no rare or scarce spp – high abundance of mussels but adults occurring in much reduced abundance; Poor sand (disturbed by currents) Ascidian gravel – primarily epifauna; bryozoan/hydrozoan turf; distributions of spp conforms to established relationships with physical environments;
Fish and shellfish	See Appendix iii and Appendix iv

Summary Table	Thames Estuary
Substrate	Ranges from sands and gravels extensive bedforms ripples mega ripples up to 5m high banks and channels composed of muds sands and gravels to very shelly silty fine to very fine sand overlying London clay – seds 1m to 5m thick; all seds show maxima which are below levels of concern for contaminants
General hydrographic information	Tidal range –springs – 4.7m range neap range 2.9m – highest tide 5.6m; GS – spring range 4.1m – max tidal range – 4.9m; storm surge 50 yrs = 2.5m
Water depth	1.0 to 29m water depth; spring range 4.3 neap 1.5 storm surge 2.5m above predicted tide;
Temperature and salinity range	Fully saline 34 – 35.5ppt; 17 to 18C max dissolved 90 to 98 % sats –
Stratification/fronts	Water column well mixed for most of the year;
Current speeds/direction	Flood/ebb is SW to NE max current is 1 to 1.2m/sec though direction modified by major sandbanks and channels; flood 0.45 to 0.7m/sec; Net clockwise rotation around the banks – max flow > 1m/sec reducing in shallow areas
Residence time/flushing	Full tidal excursion is approx 13kms on both flood and ebb
Water quality	High compliance for list 1 and 11 in Thames estuary outer estuary high quality shellfish production area; no abnormal levels of contaminants; HCs/:PCBs below lts of detection – nutrients levels relatively high exceeded EQS for ammonia.
Winds	Predominantly SWW to W – hourly mean speeds 5.6 to 7.7m/sec; SW predominate 30%; 8.5m/sec annual mean over 50% of wind from S to NW direction; ave wind speed – 7.5m/sec;
Wave climate	Exposed to combination offshore swells and local wind waves – most exposed to E – local structures cause reflection/refraction and shoaling; largest waves occur from SW with max 5.5m
Effects of climate change	6mm per year ex Defra (up to 2030)
Sediment transport	Dominated by large sandbanks – offshore sources but no clear patterns and no net transport into the estuary – clockwise sediment transport pathway with transport from S to N flanks – evidence of migration and reshaping of banks; clockwise transport driven by tidal asymmetry;
Turbidity/suspended seds/light penetration	Relatively constant 30 to 75mg/l with peak of 200mg/l – U/W vis poor;
Phytoplankton	Mean spring chlorophyll a – 5.8 to 31 ug/l; summer 2 to 6.5 ug/l max may 80.7 ug/l; subject to eutrophication at some times but PP low due to turbid conditions – 79gC/m2/yr (less than central N sea); Phaeocystis blooms – (retentive nature of estuary?)
Zooplankton	Typical coastal locations – density of copepods low
Benthos	Annelids dominate 63% crustacean molluscs < 5% richness and diversity generally low – broadly typical of wider Thames estuary – no rare or scarce benthic spp in development area; infaunal benthos dominated by polychaetes (60%); sessile epifauna-bryozoans, sponges and hydroids some echinoderms.
Fish and shellfish	SeeAppendix iii and Appendix iv

APPENDIX II

Summarising Primary Production, Salinity and Temperature in Round 2 Areas from Diverse Data Sources

Liverpool Bay	Ex Environmental statements (see Appendix v)
Temperature	5-7.5°C Feb/Mar; 13-16°C Aug/Sep Seabed temps 7 to 12 (max 18°C and min 1°C)
Salinity	31-32 g/kg winter 31-33 g/kg summer
SPM	21.6 to 250.4mg/L; Mean + 121mg/L

Liverpool Bay: ex *Kennington et al. (2005)*		
Seasonal data	**Chlorophyll (ug/L)**	
	Inshore (max)	***Offshore (max)***
Jan	–	–
Feb	3.5	<0.5
March	5.0	<2.0
April	20	<10
May	–	–
June	<10	<10
July	<13	<2.0
August	<12	<3.0
Sept	<15.4	<4.0
Oct	<6.0	
Nov	–	–
Dec	<3.0	

The Greater Wash	Ex Environmental statements (see Appendix v)
Temperature	15.5°C summer 5°C winter
Salinity	34 to 34.25 psu
SPM	2-200 mg/l offshore storms (HR Wallingford) 5mg/l to 525mg/l inshore (EA monitoring) ***Mean 129mg/l***

Outer Wash	**Chlorophyll (mg L^{-1})**		**Total suspended seds (mg L^{-1})**	
(BODC data)	**Monthly averages 1988 to 1995**		**Monthly averages 1988 to 1995**	
	Jan	0.332	Jan	81.99
	Feb	0.729	Feb	no data
	Mar	0.992	Mar	no data
	Apr	1.248	Apr	82.38
	May	5.306	May	8.79
	Jun	2.438	Jun	6.32
	Jul	1.536	Jul	17.13
	Aug	1.699	Aug	3.72
	Sep	2.571	Sep	10.92
	Oct	0.693	Oct	21.17
	Nov	0.463	Nov	63.23
	Dec	0.461	Dec	33.29
	Salinity (PSU) Mean = 33.6 ***Min = 20.4 Max = 34.9***		**SW temp** Mean = 10.6 ***Min = 4.2 max = 18.8***	

Thames estuary and outer Thames	**Ex environmental statements**
Temp	17-18C max
Salinity	Kentish Flats – Fully saline 34 – 35.5ppt
SPM	35-200 mg/L (peak with 2.5m waves) ***Mean 70mg/L***

Outer Thames **(BODC data)** **0612032b**	**Monthly mean values 1906 to 2006** ***(N.B. not all data for all years e.g. earliest cphl is 1978)***								
TEMP	**SAL**	**DO2**	**P**	**SI**	**NO3**	**NO2**	**NH3**	**CPHL**	
Month	C	PSU	umol/L	umol/L	umol/L	umol/L	umol/L	umol/L	ug/L
Jan	7.21	34.32	294.8	1.177	8.870	21.822	0.271	0.699	0.745
Feb	6.74	33.51	306.7	1.303	9.671	21.106	0.267	2.657	0.118
Mar	6.36	34.16	317.8	1.622	5.912	48.848	0.231	0.725	0.688
Apr	8.70	34.67	309.8	0.438	1.666	10.484	0.162	0.489	0.434
May	10.36	34.56	312.9	0.234	0.954	5.200	0.121	0.575	0.412
Jun	13.84	34.74	280.1	0.255	0.818	1.569	0.098		0.387
Jul	16.23	34.66	279.8	0.335	1.834	1.191	0.144		0.121
Aug	17.31	34.65	273.6	0.372	1.802	1.286	0.200	1.919	0.236
Sep	16.80	34.83	255.5	0.488	2.771	5.766	0.635	4.624	0.121
Oct	14.82	34.73	266.2	0.757	3.886	3.293	0.558		0.166
Nov	11.75	34.72	273.2	3.015	8.039	24.091	0.559	1.021	0.143
Dec	9.82	34.73	278.8	0.802	4.031	10.808	0.707	1.467	0.108

APPENDIX III

Habitat Requirements of UK Commercially Significant Species of Fish

Cod: *Gadus morhua*

HABITAT

Extensive depth range from below the shore to continental shelf (1-600 m). Occupies a wide variety of habitats – open water, rocky areas, sandy areas. Generally found near seabed. Younger, smaller fish live close inshore.

BIOLOGY

Schooling fish. Migrates to breed on specific spawning grounds e.g. central North Sea in February-April. Spawns once a year. Larvae drift to nursery areas e.g. southern North Sea or east coast of Scotland. At 20 mm after 2-2.5 months, young fish become demersal. Mature at 68-78 cm, 4-5 years (North Sea).

Omnivorous – young feed on copepods, older fish consume crabs, shellfish, other fish.

Plaice: *Pleuronectes platessa*

HABITAT

Demersal. Bury into sand, gravel, muddy bottoms between depths of 0-200 m. Also found in estuaries. Young fish inhabit intertidal pools and the shallows.

BIOLOGY

Migrate to breed on specific spawning grounds – breeds December-March in southern North Sea in a depth of 20-50 m and February-March in Irish Sea. Planktonic eggs and larvae drift inshore. Slow-growing, living up to 30 years. Active mainly at night.

Feed on a variety of benthic invertebrates – molluscs, polychaete worms, small fish.

Herring: *Clupea harengus harengus*

HABITAT

Schooling fish found in open water. Maximum depth approximately 250 m. Spend the day in deeper water near the seabed and rise to the surface at night. Schools of young fish found close inshore and in estuaries.

BIOLOGY

There are distinct breeding stocks or races. Times and places of spawning vary according to the race. Spring spawners tend to use spawning grounds close inshore, whilst autumn and winder spawners migrate offshore. Eggs stick to gravel, shells and stones on the seabed. Larval fish are pelagic and drift with the currents. When approximately 5 cm long, they form shoals and move into shallow water and estuaries for 6 months-1 year. Migrate long distances between spawning and feeding grounds.

The young feed on phytoplankton. Adults consume zooplankton e.g. copepods euphausians, sand eel larvae.

Dover sole: *Solea solea*

HABITAT

Tend to lie buried in sandy and muddy seabeds during the day. Depth range 0-200 m. Young found in estuaries and shallow waters.

BIOLOGY

Breed February-June in the south-western parts of Britain, April-August in North Sea in depths of 40-60 m, in specific areas. Larval fish drift into shallower water and estuaries. Adults can breed when 3-5 years old. Migrate into deeper, warmer water in the winter.

Feed on small benthic invertebrates such as polychaete worms, crustaceans and molluscs.

Lemon sole: *Microstomus kitt*

HABITAT

Prefers firm sand or gravel. Also found in stony and rocky areas. Depth range 2-400 m. Only young are found in shallow water.

BIOLOGY

Does not have specific spawning grounds. Spawns in deep water (100 m) in April-July in western British Isles and May-August in the Faeroes. Eggs and larvae drift with the currents. Young fish settle on the bottom when about 3 cm long. Males breed when 3-4 years old and females when 4-6 years old. They can live for up to 20 years.

Fed on soft bodied invertebrates such as polychaete worms, the siphons of bivalve molluscs. They will eat barnacles and chitons in rocky areas. Feeding is seasonal, mainly April-August and ceases in December.

Flounder: *Platichthys flesus*

HABITAT

Found on sandy and muddy seabeds. Able to tolerate wide variations in salinity and is often found in lagoons and estuaries. Depth range 1-100 m.

BIOLOGY

Migrates into deeper, warmer water during the winter. Breeds in the sea January-April. Eggs float near the surface. The young live in shallow coastal areas and estuaries, feeding on plankton and insects. They reach sexual maturity by 3-4 years old.

Adults prey on small fish and benthic invertebrates during the night.

Whiting: *Merlangius merlangus*

HABITAT

Adults tend to be found above sand and mud. Younger fish may inhabit inshore reefs and wrecks. Depth range 10-200 m, but mainly found between 25-100 m. Juvenile fish of approximately 3 cm shelter in the tentacles of large jellyfish.

BIOLOGY

Spawn in open water between January-July. The young fish drift with the plankton for up to a year. The young then move down to inhabit area closer to the seabed.

Young fish consume shrimps and other crustaceans, whilst adults prey on sand-eels, sprat and crustaceans. The proportion of fish in the diet increases with age.

Sprat: *Sprattus sprattus*

HABITAT

Depth range 10-150 m. Open water schooling fish. Juveniles sometimes found in estuaries.

BIOLOGY

Migrates between winter feeding and summer spawning grounds. Some spawn throughout the year. Spawn at a depth of 10-20 m. Produce pelagic eggs. Adults come to the surface at night to feed.

Feed on planktonic copepods.

Bass: *Dicentrarchus labrax*

HABITAT

Schooling fish. Move and feed in open water, but are closely associated with rocky reefs. Depth range 10-100 m. Found mainly in coastal and estuarine waters during the summer and migrate to deeper water in the winter.

BIOLOGY

Spawning occurs in spring, eggs are pelagic and larvae remain within sheltered areas such as estuaries. Growth is slow and fish can live for up to 20 years. Tolerant of salinity changes.

Adults feed on small schooling fish whilst the young consume small shrimps and crabs.

Turbot: *Psetta maxima*

HABITAT

Found on sand, gravel and muddy seabeds. Depth range 20-70 m. Common in brackish waters. Young usually found in shallow water.

BIOLOGY

Spawn between April-August between 10-40 m depth. Forms pelagic eggs. Larval fish float in the plankton before settling on the bottom as young fish (4-6 months old).

Feed on sand-eels, sprats, herring, gobies, crustaceans and molluscs.

Thornback ray: *Raja clavata*

HABITAT

Found on muddy, sandy and gravely bottoms. Lie on the bottom covered in sand during the day. Depth 2-300 m.

BIOLOGY

Internal fertilisation. Female comes inshore to lay eggs in capsules on sandy/muddy flats. Individuals produce between 52-170 eggs per year. Embryo takes 4-5 months to hatch.

Feed on benthic invertebrates such as molluscs, crabs, shrimps and echinoderms.

Spotted ray: *Raja montagui*

HABITAT

Bottom dweller found between 20-345 m.

BIOLOGY

During the summer females lay 24-60 egg capsules per individual per year on sandy/muddy flats.

Feed mainly on crustaceans.

Cuckoo ray: *Leucoraja naevus*

HABITAT

Demersal. Depth range 20-500 m.

BIOLOGY

Breeds all year. Individuals lay 50-170 eggs on sandy or muddy bottoms.

Feed on crustaceans and other benthic organisms.

Lesser spotted dogfish: *Scyliorhinus caniculus*

HABITAT

Mainly demersal. Depth range 10-780 m. Usually found on sandy, coralline, gravel or muddy bottoms.

BIOLOGY

Internal fertilisation. Female lays egg in a case which is attached to the seabed e.g. seaweeds, pink seafans between November-July. Young hatch after 5-11 months. Nocturnal. Rest on the bottom during the day.

Feed on a wide variety of organisms e.g. crabs, shrimps, worms, gobies, sand eels.

Greater spotted dogfish, Bull Huss: *Scyliorhinus stellaris*

HABITAT

Found on rough, rocky seabed areas. Depth range 1-400 m.

BIOLOGY

Internal fertilisation. Female lays egg in a case which is attached to the seabed between April-September. Nocturnal. Rest on the bottom during the day.

APPENDIX IV

Fishing and Shellfishing in the Round 2 Areas Short Summaries of the Main Activities

(1) Fisheries and Shellfish in the Greater Wash Area

(COLLATED FROM SEA 2/3 (WWW.OFFSHORE-SEA.ORG.UK) AND EASTERN SEA FISHERIES JOINT COMMITTEE ANNUAL REPORT, 2005)

The North Sea is one of the world's most important fishing grounds. This particularly includes the mixed demersal fishery that targets cod, haddock and whiting, caught using otter trawls and seine net vessels, in the central and northern parts of the region. An important bycatch species in this fishery is monkfish. Cod and other gadoids off the NE coast of England were surveyed in 2006. Cod and Whiting were most abundant on the hard ground whilst Haddock were predominantly found on the softer offshore sediments. (http://www.cefas.co.uk/FSP/publications/FSP200607Prog1NEcodfinalreport.pdf)

Plaice and sole are taken in a mixed flatfish fishery by beam trawlers in the south/southeastern North Sea. Cod are often caught as bycatch using beam trawlers targeting plaice and cod. Plaice are also caught using seine and gill nets. Herring is one of the most important species landed by the UK pelagic fleet using purse seines, offshore trawls and fixed nets. Coastal waters of Eastern England is an area (among others), that lands the greatest amount of herring, particularly during the third quarter of the year. Another major pelagic year round fishery is for mackerel. By weight it is the most abundant pelagic species landed. Peak landings occur in July to September. Sand eels are taken using trawlers using fine meshed gears with the majority of landing coming from the central North Sea.

Economically valuable fish that are found in the North Sea therefore include whiting, cod, haddock, plaice, sole, lemon sole, monk fish, herring, sand eel, mackerel, and sprat.

Crustacean fisheries such as shrimp and edible crab, are generally of high value and target specific grounds at different times of the year. A range of gears, such as bottom trawls, prawn trawls, seines, pots and dredges are used in these fisheries. The pink shrimp fishery is also concentrated in the deep muddy areas of the Flaxen Ground.

Fisheries for lobster and brown shrimp are valuable for coastal communities in both Scotland and England, however, exploitation is largely restricted to inshore waters outside the area of interest, and is not discussed in the SEA2 fisheries report. However, the recent ESFJC annual report (2005) suggests that the lobster and particularly the brown shrimp fishery provided the greatest income for Wash fisherman. Also mussel stocks are reported to be at their highest level since the 1980's. The cockle fishery has however declined significantly being the lowest since 1998. Another important fishery within the Wash is the Razor shell fishery.

The edible crab fishery is an important source of income to UK shellfishers. Crabs are captured in traps, (pots or creels), which are baited with fresh fish. Larger vessels will work up to 1000 traps. Crab fisheries occur on coarse grounds in coastal UK waters.

(2) Fisheries and shellfish in North-west (Liverpool Bay/Irish Sea) Round 2 area

COLLATED FROM SEA 6 (SEE WWW.OFFSHORE-SEA.ORG.UK) AND NORTH WEST AND NORTH WALES SEA FISHERIES COMMITTEE (NWNWSFC) ANNUAL REPORTS

Throughout much of the region otter trawlers land plaice, sole, and rays from spring to autumn, and cod and whiting during winter. Whilst the cod fishery off Whitehaven has declined, the haddock fishery has increased dramatically. Some shrimp beamers periodically switch to flatfish when shrimp are less available. Gill, tangle and trammel nets are used to catch a variety of demersal species throughout the district, and in more recent times a growing number of trawlers have switched to netting. Flatfish continue to provide the mainstay of inshore grounds, along with rays during the warmer months and especially within the Solway Firth. The main target species for the netting fleets are sole, plaice, flounder, rays, turbot and brill. Longlines are used in a few areas to catch cod, rays and spurdog. Skate and ray are also caught in this area on lines by anglers.

Bass are taken in gill nets and on handlines from spring through to autumn. Bass is a very important angling fish and there are several bass nursery areas in the district to protect juvenile stocks. Some drift netting for herring occurs in autumn and winter although effort is generally low as only small, local markets are supplied. Mackerel and herring are taken by nets in small quantities, whilst mackerel caught on handlines provide an important resource for the charter angling sector.

Fisheries for diadromous species are concentrated in rivers and estuaries, so outside of the SEA 6 region.

Mussels are gathered by hand in the largest UK mussel fishery in the Menai Strait. Small 'seed' mussels are brought to the Strait from eroding mussel beds elsewhere in the District, and laid on the seabed by specialist dredgers. The Strait provides superb growing conditions, produces over 15,000 tonnes of mussels per year, and exported to Europe. The Conwy Mussel Fishery is smaller and managed by a group of 20 fishermen who collect the mussels in a more traditional way with long handled rakes from open boats. This fishery produces approximately 300 tonnes of mussels each year, exclusively for the home market.

Potting vessels operate from a variety of locations all around the Welsh part of the NWNWSFC District, and also from the Barrow/Walney Island area. Although a few hardened operators fish all year round, the main season begins in spring around April after the prawn season has finished, and peters out slowly between autumn and winter. Brown crabs provide an important resource off the Lleyn Peninsula where under 10 m boats set pots out to 6 nm from the coast. Many fishing ports along the Welsh coast support a small number of beach boats potting for crab and lobsters out to 6 nm. A shrimp fishery pursued between the Dee and Duddon estuaries runs from April through to December.

Prawns are caught with lightweight polypots that are weighted to move lightly just over the seabed. There is a short autumn season just after the lobster and crab fishery begins to slow down, and another longer and more productive season in spring between March and April. The prawn fishery is another relatively young industry with little background research.

Relatively few trawling boats operate in the NWNWSFC District and much of the fishing concerned with inshore waters is carried out by angling boats

(3) Fisheries and Shellfishing in the Thames Estuary Round 2 areas.

COLLATED FROM SEA 2/3 (WWW.OFFSHORE-SEA.ORG.UK) AND KENT AND ESSEX SEA FISHERIES COMMITTEE REPORTS

The Thames Estuary supports important commercial fisheries, as well as freshwater and marine recreational angling. Commercial fishing boats operate within the estuary, fishing for species including sole, cod, bass, ray, sprats, plaice, herring and eels. The most important commercially fished species in the Thames is the Dover sole, although the Greater Thames, including Medway and Blackwater estuaries, supports a herring fishery that is recognised as distinct to the region.

There is also a well-established cockle industry, believed to be the largest in the UK. An average of 8230 tonnes per year (live weight) of cockle was landed at Leigh-on-Sea between 1991 and 2001. Dredging for cockles and trawling for fin fish are both practices restricted to the lower estuary and it is an offence to carryout such activities past a line extending from Coalhouse Fort on the Essex coast to Cliffe Fort on the Kent coast.

Jellied eels are a local infamous delicacy and the Thames supports an eel fishery regulated by the Environment Agency with fyke nets licensed for use as far upstream as Tower Bridge. http://www.thamesweb.com/page.php?page_id=48&topic_id=8

Most of the commercially important species in this area spawn in the spring, although sand eel and herring are exceptions. Shrimp, edible crab and lobster tend to be winter spawners.

One of the most important fisheries in the North Sea is the mixed demersal fishery that targets cod, whiting and haddock. In central and southern areas of the SEA2 regions otter trawls are less common. Most effort is confined to the Northeast coast of the UK and Scotland. Dogger Bank and the southern North Sea is an important area for spawning of cod.

Whiting is also landed off Dogger Bank. In the North Sea, whiting is one of the main predators of other commercial important fish species. Haddock has a predominantly northerly distribution, however they can be occasionally be caught south of the Dogger Bank during the summer. Plaice are typically a coastal species, and be found at highest abundance in the southern part of the North Sea. Fishing for herring is mainly uses purse seines and trawls offshore and to a lesser extent by fixed nets in coastal waters. Landings of herring are greatest in the third quarter of the year from five predominant areas around the UK including northwest of the Dogger Bank and in coastal waters of eastern England. Sole is a southern species in the North Sea. The Thames estuary is of particular importance as a spawning ground for this species.

Crustacean fisheries are generally of high value and target specific area using different gear types throughout the year. Bottom trawls, prawn trawls, seines pots and dredges are used in crustacean fisheries. Norway lobsters are landed from the north and west of the Dogger Bank among other areas around the UK and Scotland. Other economically important species include the edible crab caught in pots or creels occurring on coarse ground in coastal waters. Larger vessels will work up to 1000 traps.

There is concern about the stocks of herring, cod, whiting, saithe, plaice and sole which are close to or outside Safe Biological Limits. Catch levels for many fish stocks are almost certainly not sustainable.

APPENDIX V

Strategic Environmental Assessments (SEAs) and Environmental Statements Utilised for Summarising Generic Data Presented in Appendix i for R2 Areas

http://www.offshore-sea.org.uk/consultations/Wind_R2/index.php

http://www.berr.gov.uk/energy/sources/renewables/renewables-explained/wind-energy/page27403.html

http://www.offshore-sea.org.uk/consultations/SEA_2/index.php

http://www.offshore-sea.org.uk/consultations/SEA_3/index.php

http://www.offshore-sea.org.uk/consultations/SEA_6/index.php

Barrow Offshore Wind Farm Environmental Statement, 2002. Prepared by RSK Environment Limited for Warwick Energy Limited.

Burbo Offshore Wind Farm, Vol 2: Environmental Statement. 2002. SeaScape Energy Ltd.

Gunfleet Sands Offshore Wind Farm Environmental Statement Non Technical Summary, 2002, GE Gunfleet Ltd. (277 pages)

Gwynt y Môr Offshore Wind Farm Environmental Statement, 2005. Npower Renewables Ltd.

Greater Gabbard Offshore Wind Farm Environmental Statement, 2005. Prepared by Project Management Support Services Ltd on behalf of Greater Gabbard Offshore Winds Ltd. (672 pp).

Kentish Flats Environmental Statement, 2002, Prepared on behalf of GREP by Emu Ltd, Durley, Hampshire. (10 Chapters).

London Array Limited, 2005. Environmental Statement – Volume 1: Offshore Works. Prepared by the RPS Group Plc on behalf of London Array Limited

London Array Limited 2005. Environmental Statement – Volume 2: Onshore Works. Prepared by the RPS Group Plc on behalf of London Array Limited.

Lynn Offshore Wind Farm Environmental Statement, 2002. AMEC Offshore Wind Power Limited.

North Hoyle Offshore Wind Farm, Environmental Statement, 2002. NWP Offshore Ltd.

Robin Rigg Offshore Wind Farm EPC Contract Pre-Tender Health and Safety Plan, 2002. Garrad Hassan and Partners Ltd.

Rhyl Flats Environmental Statement, 2002. Prepared by ERM for Celtic Offshore Wind Ltd.

Sheringham Shoal Wind Farm, Environmental Statement, 2006. Scira Offshore Energy Ltd.

Thanet Offshore Wind Farm Environmental Statement, November 2005, Volume 1 and 2: Appendices. Prepared by Royal Haskoning for Thanet Offshore Wind Limited.

Thanet Offshore Wind Farm Environmental Statement, November 2005, Volume 3: Environmental Statement Parts III, IV and V. Prepared by Royal Haskoning for Thanet Offshore Wind Limited.

Thanet Offshore Wind Farm Environmental Statement, November 2005, Volume 4: Appendices. Prepared by Royal Haskoning for Thanet Offshore Wind Limited.

Printed in UK on recycled paper.
Department for Business, Enterprise and Regulatory Reform. www.berr.gov.uk
First published January 2008. URN 07/1681.