Complementary Benefits of Alternative Energy: Suitability of Offshore Wind Farms as Aquaculture Sites

Inshore Fisheries and Aquaculture Technology Innovation and Development

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Summary

The large scale growth in salmon production in the UK has resulted in most available near shore finfish sites being used up for finfish farming. The development of offshore sites or technology improvements alone hold the key for the sustained growth of the UK aquaculture industry. The offshore wind industry has been rapidly expanding in the UK and will occupy major amount of coastal offshore space when zoning plans are developed. The prospects for using the offshore wind farm areas for aquaculture production (finfish and other species) has the potential to open up new sites for finfish farming in the UK. This work examined the suitability of aquaculture in offshore wind farms from the point of view of all the stakeholders involved.

The outcome indicates that offshore wind farms are not open to the idea of aquaculture but are receptive to study habitat enhancement as a means to mitigate the impact of offshore wind farms on fisheries. The seabed owner (Crown Estate) does not allow any other profit making activity within the offshore wind farms. This is bound to create conflicts with other profitable users of the sea which in turn would affect the offshore wind farm industry. This can be solved only by the implementation of marine spatial planning for which aquaculture in offshore wind farms would be an example. The development pattern of new species for aquaculture in the UK has not made available any new species with a commercial potential in present day offshore wind farm locations. The technology for aquaculture equipment in offshore locations exists but has not been tried out. Less than 3 % of the total area leased for an offshore wind farm is actually occupied by the offshore windfarm piles and foundations. There is ample space between the piles to start aquaculture operations without disturbing the main activity of electricity generation. Marine spatial planning steps by the The Crown Estate and semi commercial trials alone can take the concept forward for the ultimate benefit of the UK seas.

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1. Introduction

Maximisation of value from unit area of land or sea is in the best interest of any nation in the world. Maximisation of value from the sea has seldom been realised elsewhere as it has been realised here in the United Kingdom (UK) with a multitude of sea based economic activities. A major step towards maximising the value of UK seas is the on-going large scale development of offshore wind farms (OWFs). This is in addition to all the other profitable utilisation of the seas which was estimated to be UKP 69 Billion in 1999-2000 (Pugh and Skinner, 2002).

OWF development has reached its present level due to the inexhaustibility of wind when compared to oil and the absence of emissions when compared to green house gas emission from oil. Both these reasons have ensured the fast paced progress in the UK OWF sector which has resulted in wind farms beginning to take up significant space in the UK seas.

OWFs in the UK have often run into troubled waters due to conflict with other profitable users of the sea like fishing and shipping and due to impact on the environment. While the mitigation for impact on the environment would be to construct wind farms in less damaging areas, the mitigation for conflict with other users of the sea could be coexistence with as many economic activities as possible. This is also meaningful from the point of maximising returns from the total water spread area leased for a farm.

Unlike in the case of shipping and fishing aquaculture is a static activity which will not interfere with the wind farm operation. Conflict with fishermen can be minimised as aquaculture can offer employment or income earning opportunities to the fishermen. OWFs might also have the potential for becoming marine protected areas as the unutilised waters between the wind farm piles would be taken up by aquaculture cages, rafts or long lines.

With a multitude of activities taking place in the seas around UK, the government of the UK is at present working on developing a system of marine spatial planning to ensure the coexistence of all activities. (Defra, 2002) The present work is an ideal

example of what can be made possible by marine spatial planning. The pile of the wind turbines in an OWF occupies much less space when compared to the total water spread area leased for the farm. If properly planned, these unutilised waters around the wind farm piles can be put to good use (aquaculture) without affecting the safe and continuous operation of the wind farm.

The suitability of aquaculture in OWFs has been explored in this work in order to contribute to commitments towards marine spatial planning drawn up by the UK Government in its marine stewardship report (Defra, 2002), the EU in its European Marine Strategy (European Commission, 2002) and by OSPAR (Bergen Declaration, 2002).

2. Background

2.1 Offshore Wind Farms in the UK

The first round of OWF development in the UK began in 2000 leading to fifteen leases of which four have been built as of now. The success of the first round prompted the UK Government to announce a second round (fifteen leases) in order to fulfil commitments to the renewables obligation of providing 10% of energy from renewable sources by 2010 (DTI, 2003). The success of the first round prompted the electricity companies to tap into the emerging technology in offshore wind energy. The target was to build around 3000 new turbines supplying enough power for 3.5 million UK households, totaling between 3.5% and 5.5% of the UK's electricity requirements. (Hollister, 2003) As of December 2004, 1100 to 1200 wind turbines are in place producing 750-800MW (Macaskill, 2004).

The OWF developments in the UK are mainly located around North Wales and North West England, East England, East Anglia and South East England. The UK is presently identified as the best market for wind in the world (Ernst and Young, 2004), due to its favourable combination of wind resource, strong offshore regime and the recent extension of the relevant legislation, the Renewables Obligation, to 15% by 2015. This would ultimately result in OWFs in Scotland as can be seen from the Beatrice deep water wind farm development off the east coast of Scotland.

OWF development in the UK is often hampered by conflicting reports about the wind resource available and its stability (Sinden, 2005). Yet there is a favourable policy for OWF development as the Government perceives it as one of the key sources to meet the Renewables Obligation. The full extend of impacts on the environment and other profitable user of the sea is still being discussed without conclusions as evident from COWRIE seminar at the BWEA Conference 2005 in Cardiff. On the whole however benefits from offshore wind energy can be expected to compensate for any negative effects on the environment as it is a carbon free source of energy. (SDC, 2005)

At present the UK has commissioned 124 MW of Round 1 developments. The target is to generate 9.1 GW from OWFs and of this financing has been secured for 588 MW

(Liebreich, 2005). Many of these projects have identified the location and are at various stages of the application process. The application process itself has not yet been streamlined as yet; thereby contributing to the energy gap which is prompting the energy mix in the UK to favour nuclear energy, but for the nuclear waste that would be generated. Besides the above problems the sudden unprecedented requirement of offshore infrastructure and services has resulted in very high construction costs. The capital cost for offshore wind developments was estimated at USD 1.6 to 1.9m per MW two years ago. Recent estimates have shown that projects in planning will cost USD 2.1 to 2.6m per MW, according to Colin Morgan, Garrad Hassan and Partners Ltd. (Liebreich, 2005).

2.2 Aquaculture and seafood industry in the UK

The main UK aquaculture interests are in Scotland and the main species under cultivation is salmon. Aquaculture in Scotland is valued at over £310 million pounds at the farm gate and £ 600 million in retail (Randolph Richards, 2002). The only aquaculture enterprise on the east coast of the UK is a marine worm farm. On the west coast shallow and turbulent waters has not seen the growth of aquaculture except for a turbot farm in Wales and on bottom shellfish culture.

The shellfish species under aquaculture in UK waters are mussels, oysters, clams, scallops, and queenies. There are attempts at abalone aquaculture by the South West Abalone Growers Association and also in Wales and Scotland. The possibilities of aquaculture of Cod, Halibut, Haddock, Turbot, Lemon Sole, and Arctic Charr have been proposed by DEFRA and British Marine Finfish Association.

There are shortcomings in the UK aquaculture sector when compared to other major aquaculture nations in the world. Aquaculture has been promoted as an employer in the Scottish Islands which otherwise do not have many other sources of income. This has resulted in the absence of aquaculture in other regions. There is no national body here which looks after the promotion of aquaculture. The associations which exist today are classified based on regions or species cultured without an umbrella organisation. In the case of salmon there are multiple organisations with various mandates within the same region. This is a major hindrance to the growth of

aquaculture in the UK and even more so in the case of aquaculture in OWFs as there is no centralised body to pitch this idea.

From the business point of view aquaculture in the Scotland has been consolidating since 1999 and the latest mergers have sent shock waves across the industry. This is because each successive merger upsets the employability of local people with the rationalisation of processing factories which provide a lot of the jobs. The largest salmon farming company (and perhaps aquaculture company) in the world as of today is Marine Harvest which is held by Nutreco Holdings, Netherlands which owns a significant share of the Scottish Salmon farms. Nutreco is at present planning to sell its shares to Greenwich Holding Ltd, a UK based Norwegian company which eventually plans to take over Pan Fish Ltd another large salmon farming company in Scotland. This merger would give the new company almost complete control of fish farming from Argyll to the North Highland coast and in the Western Isles. Pan Fish and Marine Harvest already own most of the fish farming sites on the west coast, and Marine Harvest and Fjord Seafood which would become a part of the new company are the major players in the Western Isles.

2.3 Aquaculture in Offshore wind farms

The first attempt at technology development for aquaculture in OWFs can be seen from Germany which has no OWFs (Buck, 2002; Buck and Rosenthal, 2003; Buck et al., 2004). The legal aspect of multiple uses within the same ocean environment taking the specific example of aquaculture in OWFs has already been studied in the USA which again does not have an OWF (Firestone et al., 2005).

The concept of aquaculture in OWFs should be seen in the light of the on going efforts to develop offshore aquaculture. The offshore aquaculture concept developed out of aquaculture experiments in oil rigs in the US. The first such successful effort came from Ecomar in California which proposed a mussel harvesting operation from offshore oil platforms to be sold to restaurants. This concept though eventually successful took ten years to be accepted by oil companies.This has lead to many oil companies actively investing in offshore aquaculture experiments as evident from the International Conference in Open Ocean Aquaculture in Texas 1998. This was

followed by the Italians who used to SADCO cages from Russia to farm sea bass and bream in offshore locations (Fish Farming International 1999)

Offshore aquaculture has scientifically been explored in the USA through the works of the Gulf of Mexico Offshore Aquaculture consortium (www.masgc.org/oac/), and the University of New Hampshire Open Ocean Aquaculture Project (http://ooa.unh.edu/). The policy aspects of offshore aquaculture have been studied by the Mississippi–Alabama Sea Grant Legal program (www.olemiss.edu/orgs/SGLC/1aquaculture.html). The US has already brought out a National Offshore Aquaculture Act of 2005. But from the point of view of an investor it is the risk assessment of offshore aquaculture which would favour investments into offshore aquaculture. The best tool available till date which could be made use of to assess the risks involved in offshore aquaculture is the model of a firm level investment production model (Jin et al. 2005)

The background reason for the emergence of scientific considerations and semi-commercial trials for offshore aquaculture is the lack of inshore sites for aquaculture expansion in countries where capital for aquaculture development is available. Coupled with this the Food & Agriculture Organisation (FAO), has projected the world demand for seafood to increase by 40% to 180 million tonnes by 2030, representing a 40% increase on the 130 million tonnes available in 2001 from aquaculture and capture fisheries. The best management measures will see capture fisheries remain static at 100 million tonnes. This would eventually mean that aquaculture production levels of 37 million tonnes in 2001 will therefore need to increase to approximately 90 million tonnes amounting to 50% of total fish requirements by 2030. The development of offshore aquaculture can lead to an increase in production of 3.15 million tonnes valued at €9.5 billion in the Atlantic and an increase of 3.85 million tonnes valued at €11.5 billion, in the Pacific by 2030 representing an impressive overall figure of €21 billion opportunity for the offshore fish farming around the globe. (Hugh Byrne, Chairman, Irish Sea Fisheries Board, Farming the Deep Blue Conference, http://www.eventznet.ie/ev/ac/bim/deepblue/)

3. Method

A list of companies, industry associations, financiers, risk assessors, insurers, regulatory bodies, scientists, consultants and other profitable users of the sea was prepared to represent stakeholders within the offshore wind and aquaculture sectors in the UK. They were contacted on an individual basis at first and based on the information gathered OWF companies and aquaculture companies were contacted with a questionnaire and telephone interviews. A stakeholder meeting was conducted 1 March 2006 London. The results of the telephone interviews, questionnaire, and the stakeholder meeting are presented.

4. Results

The results obtained from telephone interviews and questionnaires together with the information from the stakeholder meeting are presented. The OWFs were more responsive than the aquaculturists who did not show much of an interest probably because most OWFs are in England or Wales and most aquaculture is in Scotland.

4.1 Interview and Questionnaire Highlights

The OWFs listed on the website of the Crown Estate and the British Wind Energy Association was contacted. Some of the OWFs had been taken over by major energy utilities and all effort was taken to reach the right contact point. Out of the thirty (Fig. 1) different OWFs (not all of them currently commissioned) belonging to twelve different companies, eight replied. Out of those which replied only three sites (Greater Gabbard, Teeside, Norfolk) were found to be suitable for offshore aquaculture based on the depth at the site. It was widely agreed by aquaculture experts that it would be wise not to consider sites less than 15 m depth, as present day cages have at least 15m deep nets. Aquaculture in OWFs less than 15m deep would affect the benthic community due to wastes from the cage.

The area occupied by the wind turbine piles and the foundation together was found to be a small percentage (less than 3 %) of the total area leased for the OWF. Hence there is ample space (Fig. 2) between the piles to start aquaculture in OWFs without disturbing the safe and continuous operation of the OWF.

The possibility of using properly designed fish aggregating devices especially in shallow water offshore wind farms to deal with scour protection was discussed with a few offshore wind farms. At present loosely arranged stone boulders is being used as scout protection. Some of the wind farms which were being constructed welcomed the concept but had reservations as to the impact that it might have on fishing rights in the region if the fishes aggregate within wind farms. Many of the present offshore wind farms especially on the west coast being in shallow waters, aquaculture of shellfishes alone are possible at these sites. This is because of the exposure of finfish cages during low tides.

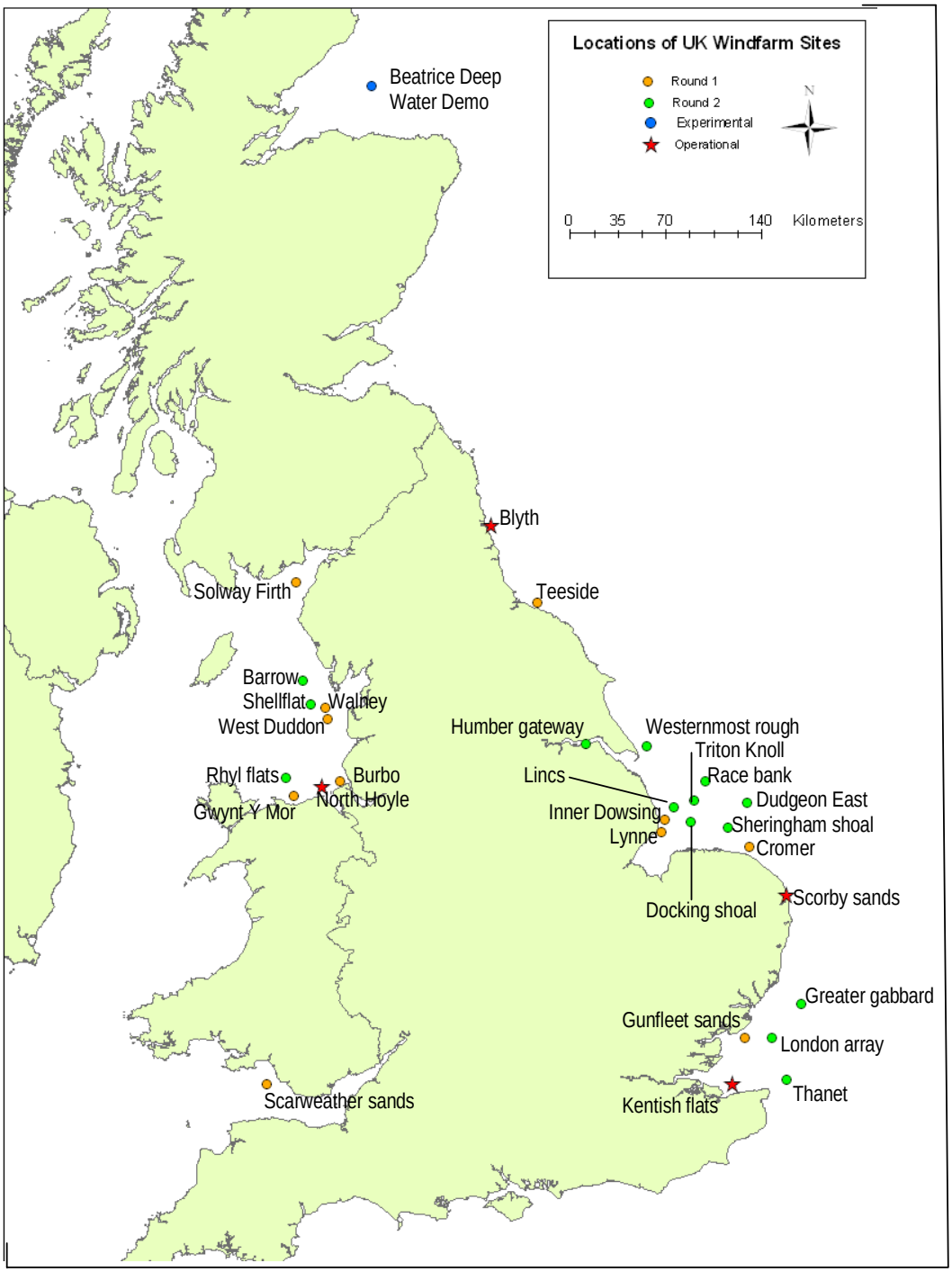

Figure 1 Offshore wind farm sites in the UK

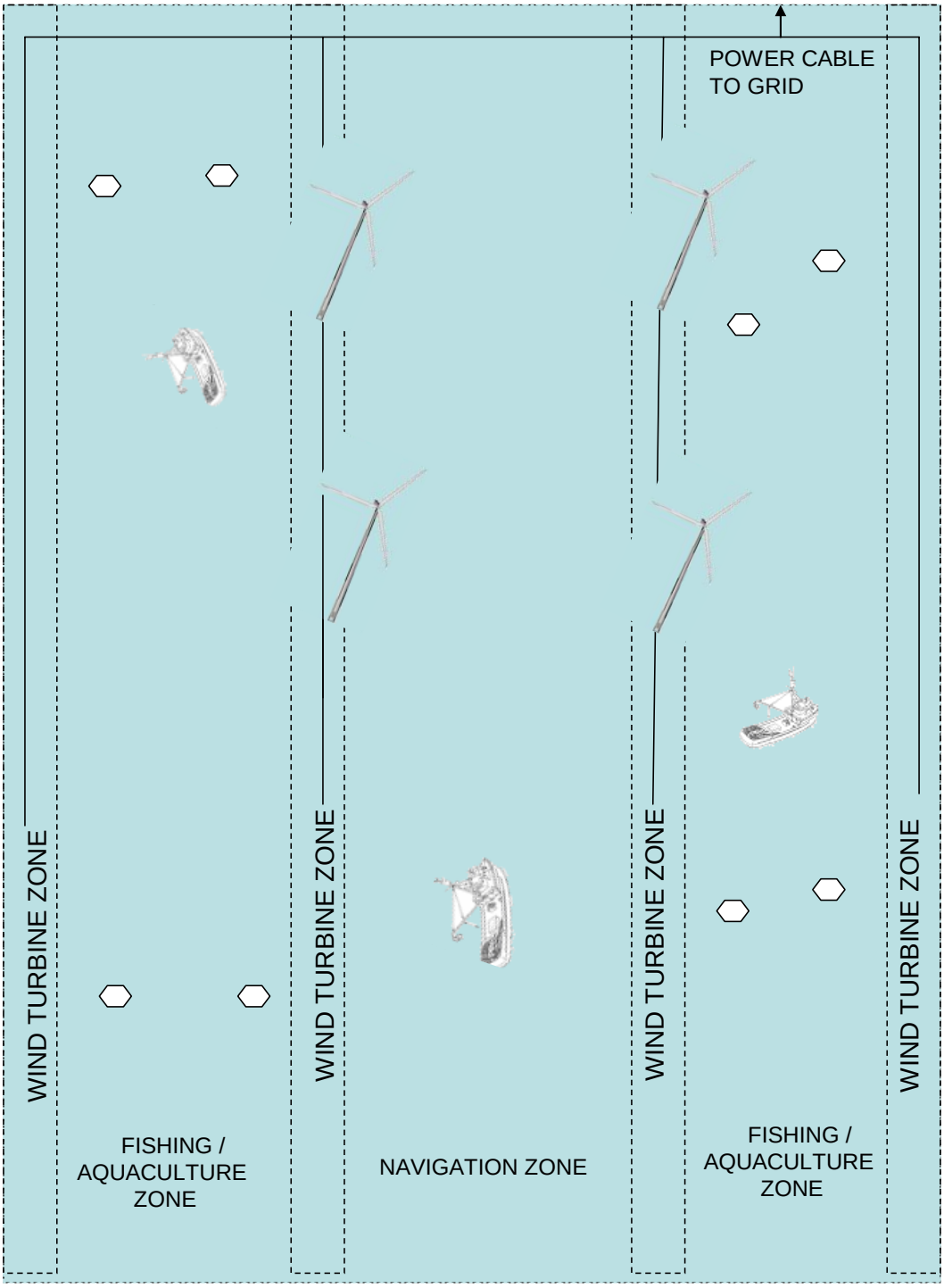

Figure 2 Diagram showing typical installations and multi use options at an offshore wind farm site

Name of the Wind Farm	Distance from the shore **(Km)**	Depth at the wind farm site **(m)**	Total area leased for the farm **(Sq Km)**	Area occupied by the Pile and foundation **(m)**		Total number of piles in the farm	Distance between the piles **(m)**
				Pile	Foundation		
Greater Gabbard	23 - 40	20 - 30	147	6.5	36	140	650
North Hoyle	6.5 - 8	6.5 - 12	10	4		31	350/800
Rhyl Flats	8	3.5 – 10.5	10			not yet designed	450/100
Lynn	5-8	10 - 15	10	2.5	10	30	728
Inner Dowsing	5-8	10 - 15	10	2.5	10	30	1000
Lincs		15	250 MW			46-84	
Teeside	2	10 - 20	10	6		30	300/600
Norfolk	9	20	10	6		30	

Table 1: Information obtained from OWFs regarding the sites

Data obtained from wind farms have been converted to standard units with approximation. Some of the wind farms are not fully constructed and hence all of the data is not available. For Lincs OWF it is not the area that has been leased but the capacity which is 250 MW. The pile to pile distance within a row of piles and between the rows of piles often varies which has been represented with a forward slash in the last column of the above table.

The opinion of OWFs with regard to starting aquaculture is given below.

1. Aquaculture in OWFs will bring in additional returns leading to maximisation of value realisation from unit area of leased waters. How would you as an OWF company view the concept of fish farming in OWF locations?

OWF 1: We believe that the principle of the idea is a good one as there is a large unutilised area in an OWF
OWF 2: As a company we support sustainability and therefore in principle would support such a scheme if approved by the regulating authorities (English Nature) Health & Safety issues would have to be considered as part of any plans for fish farming. Should the project be consented and ultimately be constructed, this re-stocking the area with potential species would be done. Rock dumping used to provide scour protection around the turbine bases, is considered to provide a suitable habitat for lobsters.
OWF 3: General view is that a wind farm is a power station and its main purpose is to generate electricity. Anything that would interfere with operation and maintenance, such as fish farming, would not work well with a wind farm. Additionally the Crown Estate lease does not allow operators of the wind farm from making income from any other source in the wind farm area.
OWF 4: We have considered it already to a very limited extent. We suspect that our lease with the Crown Estate does not give us rights in these matters and apart from potential conflicts with our ongoing maintenance work an initiative such as this may add problems to the existing sensitive relationship with the local fishing community.
OWF 5: I am not aware of the licensing/ environmental/ physical requirements for aquaculture. It could not impact on the normal operations of the windfarm: access to subsea cables, 360 degree access around turbines etc. Would need to understand the parameters in aquaculture which overlap with wind farms to understand the benefit obtained by the aquaculture business. To summarise probably sceptical
OWF 6: The applicability of wind farms for aquaculture will very much depend on the specific environmental parameters of a specific wind farm in the species the area will support. Many have postulated feasibility for *Mytilus edulis* in the splash zone of turbine foundation – this will depend on what anti-foulants are used (if any) and consideration will have to be made of how mussels will affect 'drag' on the turbine/engineering stresses etc. Scour protection around turbines in the form of rock piles would benefit lobster and crab nurseries through provision of nooks and cranies/micro habitats, but not all wind farms will require scour protection (depending on outputs of coastal processes modelling).

2. If feasible, would you be interested in starting aquaculture farms in the unutilised waters around the piles within your wind farm?

OWF 1: In principal yes
OWF 2: The company would consider working with organisations interested in establishing such ventures. This is subject to no interference with the operation of the OWF, approval by the statutory authorities such as English Nature, DEFRA. Also approval of those bodies responsible for marine navigation.
OWF 3: No
OWF 4: We will look at this again once operations start and the maintenance process has settled into a pattern
OWF 5: Would need to see the business case for it.
OWF 6: Possibly, but it would require very serious consideration

3. If feasible, would you like to do it yourself or sublease it to an aquaculture company?

OWF 1: Can't say at this time until some figures are compiled
OWF 2: This is not a core business for us and there are organisations better placed and experienced to establish such businesses. A sublease and approval would be required from the Crown Estate, who leased the wind farm sites to us.
OWF 3: Cannot do it.
OWF 4: Probably sublease
OWF 5: Sublease
OWF 6: Could not comment at this stage

4. If subleasing it to an aquaculture company would you prefer them to pay you a part of the rent (payable by you to the leasing authority), or would you rather prefer to have a share in their profits instead of the rent.

OWF 1: Can't say at this time until some figures are compiled
OWF 2: It would seem more practical for the aquaculture to pay their share of the lease.
OWF 3: N/A
OWF 4: Not sure yet
OWF 5: Would offer it to the market and award to the highest bidder for a Fixed Rate of Return
OWF 6: Could not comment at this stage

5. Do you have any concerns in considering aquaculture in OWFs?

OWF 1: -
OWF 2: Statutory approval and access restrictions and health & safety.
OWF 3: If it will interfere with operation and maintenance
OWF 4: Yes lots – safety, access to turbines, damage to cables, navigational issues etc etc
OWF 5: Loss of access for us. Survivability of aquaculture farm.
OWF 6: I would expect I would have a very long list, but without more details on the type of aquaculture proposed, I couldn't comment beyond saying that consideration on the practicalities of operating within a wind farm will warrant very close consideration

4.2 Species selection for aquaculture in offshore wind farms

The main finfish species being farmed in the UK are salmon and rainbow trout. Aquaculture of other species like carp, brown trout and recently Asian Sea Bass is also taking place. Among the shellfishes mussels, oysters and clams are being farmed. There are several species of marine fish that are suitable for cultivation in UK waters and some of this has already undergone trials. These include cod, haddock, and halibut among finishes (http://www.bmfa.uk.com/species.htm) and abalone (South West Abalone Growers Association) among shellfishes.

While considering aquaculture in offshore wind farms the immediate opportunities are to select those species for which technology development has already taken place or for which farming methods have been established somewhere in the world. The distribution of present day OWFs (Fig.1 page 12) are in locations not suitable for many of these species as they are too cold for Mediterranean fish like sea bass and sea bream and too warm for species like salmon or cod. This situation would of course change as offshore wind farms come up in other locations.

There is an immediate possibility to consider sea bass aquaculture in offshore wind farms on account of that fact that European sea bass has begun to move north (Dr. Mike Pawson, CEFAS, as reported on http://ukbass.com and Dr Jonathan Coleman as reported on www.oceanflies.com) The farming of European Sea Bass is already well established in Greece and farming it here in offshore wind farm locations may not yield the same level of profits there. But as the demand for sea bass is increasing in the UK, sea bass farming in offshore wind farms can help in saving foreign exchange by a lesser dependence on imported seabass.

Abalone aquaculture in offshore wind farms can be tried out on the west coast offshore wind farms. The winter temperatures on the east coast is not suitable for abalone. The experimental phase of abalone aquaculture in the South West has given valuable information on the constraints involved in abalone farming. The high value of abalones in the international market could help in overcoming the costs towards mitigating these constraints.

4.3 Equipment selection for aquaculture in offshore wind farms

Aquaculture in offshore wind farms will require new equipment which can co-exist with the deep water conditions where many OWFs are located. In addition equipment design has to facilitate alterations to different OWF designs in order to avoid entangling with the power cables and the safe operation of offshore wind farms. There have been some efforts at developing offshore aquaculture equipment in the backdrop of the interest shown towards offshore aquaculture. Some of these efforts are Shellfish Submersible Mussel Raft Project of Seafish Industry Authority, UK; Ocean Globe of Byks, Norway (www.byks.no); SADCO cages, Russia (www.sadco-shelf.sp.ru/); SAFE system Neptune Industries, USA (www.neptuneindustries.net/) and Maris Fish Ranches, UK

The design trend in these developments is suitable for offshore wind farm locations. The main features included in these designs are resistance to wind, wave and tide actions preventing breakage common to present day cages; waste collection units incorporated into the cage system itself instead of releasing into the open water creating environmental and regulatory problems as seen in present day cages; seclusion of aquaculture crop during predator attacks and adverse weather conditions; automated feeding; submersible to optional depths which is useful to offshore wind farms to position in accordance with cable layout; capable of being raised to above sea level during maintenance operations avoiding diving for maintenance and reduction of collisions with navigational users.

4. 4 Stakeholder meeting highlights

The opinions expressed at the stakeholder meeting are presented based on the sessions and the main questions addressed therein.

Is aquaculture at OWF sites technically and economically feasible?

Aquaculture in OWFs would be site specific based on species and environmental conditions. The OWFs are sceptical with regard to the entire idea of aquaculture in OWFs on account of earlier instances of fish farms coming loose of the anchor in present day inshore aquaculture locations. The chances of this happening are even more in deeper waters.

Aquaculture in OWFs will not obstruct the safe and continuous operation of the wind farms, if done properly. This is so because OWFs require maintenance boats to go through the area for their regular maintenance. Similar types of vessels or smaller will be used by aquaculture enterprises for running the aquaculture operation.

Aquaculture in OWF regions is going to be capital intensive and perhaps not within the grasp of the fishermen community. Fishing is a way of life and its value cannot be viewed just in economic terms until and unless the fishermen find it difficult to make both ends meet.

Fisheries are subsidised whereas aquaculture is not. The relative value of aquaculture in OWFs when compared to electricity generation has to be looked into. Given that the economics of OWFs is not yet known it would be worthwhile to find out what value aquaculture can bring out of the same space.

There is no clear cut policy with regard to permitting recreational angling within OWF waters. This has a direct bearing on fisheries also as fishing with unobtrusive gear should be viewed as similar to recreational angling.

The level of offshore technology available as of today would make it possible to do aquaculture in OWFs. The intensive technology required might make it economically unfeasible.

What about the environmental impact?

The environmental impact of present day aquaculture especially with regard to salmon which is the main species under aquaculture in UK waters has shown that there can be catastrophic impacts owing to waste disposal from fish farms, pathogenic introductions, impact on small pelagic species used as fish meal, and shellfish toxins when the activity is poorly managed. In addition there are problems due to clustering of farms, improper site selection and high stocking density. The possible re-emergence of these problems should not be allowed to happen if aquaculture in OWFs becomes a reality.

The marine protected area or fish aggregating effect of OWFs need not necessarily result in better fisheries. This is because if the fishes from the surrounding fishing zone come into the OWF location this would result in displaced fishing effort from the OWF zone affecting the fisheries outside (i.e. with the same fleet size, pressure in fished areas would increase).

The OWFs have a lease period. At the end of the lease period or during the lease period they can repower the system. This would involve new foundations and piles for heavier turbines or to replace foundations and piles suffering from erosion and degradation. Re-piling will result in damage to the associated benthic community, re-suspension of the sediment and other physical disturbances. Hence the marine protected area effect will be intermittent.

The impact of OWFs on fisheries has been recognised by the OWF developers who are now looking at conservation projects like habitat enhancement with a view to mitigating the impact on fisheries. Further increase in productivity in OWFs from aquaculture should be seen in the light of balancing the socio-economic needs of the fishermen community, the need for additional aquaculture sites, the relative potential benefits to the UK in terms of uninterrupted renewable energy, lack of dependence on imported seafood and environmental consideration.

Many environmental problems of today resulted because we were thinking only in isolated components of the total ecosystem. In order to avoid this situation marine spatial planning based on the ecosystem approach is the way forward.

Can the legal and commercial constraints be overcome?

Under the present lease conditions for OWFs, aquaculture or any other profit making activity is not permitted within the leased area. The British Wind Energy Association has a position paper on the Marine Bill and views marine spatial planning as “It is the idea that areas of marine space are allocated for different uses taking into account present use and also possible future use. The idea being that this will help solve conflict.” In contrast the seabed owner (Crown Estate) does not have a position paper

on Marine Spatial Planning. Hence the concept of aquaculture in OWFs will depend on how marine spatial planning is implemented in the UK.

New investments into aquaculture have to been seen in the backdrop of the present situation wherein which salmon is the only species immediately available for profitable aquaculture. The other candidate species that are being considered (Cod, Halibut, Haddock, Turbot, Lemon Sole, and Arctic Charr, abalone) have not had a development pattern favouring commercialisation. Hence new thought has to go into their economic, environmental and social performance when new aquaculture situations like aquaculture in OWFs emerge.

The trend in EU seems to be to import seafood from other regions of the world. While the EU is receptive to seafood produced abroad there is no corresponding demand for EU seafood abroad in scales that would require the EU to produce seafood for export. Hence any future growth of aquaculture in the UK has to come from the main species farmed or fished within the EU. The possibility of farming those species with a declining fisheries catch in the EU exists. But the technology development has not reached a phase which would favour financing these new species projects.

Even if OWFs become available for aquaculture, market economics would allow only the farming of molluscan shellfishes within OWFs. There has to be significant trials before any new species of finfish can be farmed. The present trend at consolidating salmon production within the EU can still make it profitable to farm salmon within OWFs in cold waters especially in the North Sea or new deep water developments in Scotland.

4.5 SWOT Analysis

SWOT (Strength, Weakness, Opportunity, Threat) analysis has been used since the 1970’s as a tool for making investment decisions. Recently it is also being used in development strategies in European regional policy (Scapini et al., 2002). It has been used here to find out the opportunities for strategic action by the offshore wind farm industry, regulator and aquaculture stakeholders.

4.5.1 Offshore wind farms

Strengths	Weaknesses
Free and inexhaustible energy source Emission free, helps to reduce green house gases Technology is available. OWFs already up and running Improvements in wind turbine technology promises to produce more electricity at a cheaper rate. Favourable government policy in the UK	Round 2 franchises have told the UK government that they cannot proceed due to increasing costs (Liebreich, 2005) Conflict with fishing, shipping, marine aggregate extraction, communication cables, sailing, marine archaeology, radar, oil and gas, tourism Impact on organisms (fish, marine mammals, benthos, birds etc.) especially from noise, construction debris. Re-piling can destroy the benthic habitat multiple times during the lease of an OWF (Stakeholder meeting/ L Mee, UoPlymouth) Intermittency in wind and wind speed changes (Sinden, 2005) Economics not yet known here in the UK (Stakeholder meeting)
Opportunity	**Threat**
Most suited for islands which do not have many other sources of energy due to logistics problems Reduction in cost of construction due to improvements in technology and scale could result in more OWFs (SDC, 2005) Decrease in fossil fuels creates a need for alternative energy Climate change scenarios creates a need for clean energy Employment for people trained in offshore and marine sciences (Greenpeace, 2004)	Decrease in costs is envisaged not guaranteed. (SDC, 2005; Liebreich, 2005) Rough seas, cyclonic conditions can damage the infrastructure. Intermittency in wind creates gaps in supply to the grid. (Sinden, 2005) Navigational accidents can damage the infrastructure. Energy policy in the UK is being reviewed at present to compensate for the energy gap with a shift towards nuclear energy. Repayment of debt may not reduce production costs over time

4.5.2 Aquaculture

Strengths	Weaknesses
Fisheries exhausted and in decline. The only other source of seafood protein is from aquaculture Seafood protein has been found to be good for human health more than other animal proteins Aquaculture technology is well developed and the industry has expertise and experience Seafood in the human diet is very low in developing countries which are often aquaculture production centres. Increase in aquaculture production alone can increase the per capita availability of seafood (IFPRI 1999) Maximisation of production from unit area of agricultural land has already been achieved. There is a great scope for maximization of production from unit area under aquaculture	Negative image due to earlier mistakes within the aquaculture industry (High stocking density, pollution from cages) (Naylor et al. 2000) Development of vegetable protein sources as fish feed is necessary in order to reduce the dependence on fish meal which is an exhaustible resource (Naylor et al. 2000)
Opportunity	**Threat**
Helps to increase food supply Employment in fishing communities threatened by fisheries collapse Foreign exchange savings by reduction of seafood imports	Uncontrolled growth can lead to problems in shallow waters. Candidate species not available immediately for aquaculture expansion. (Stakeholder meeting) Aquaculture industry is not being promoted in locations other than in Scotland.

4.5.3 Aquaculture in Offshore wind farms

Strengths	Weaknesses
Maximisation of production from unit area of sea is in the best interest of any nation Reduction of the impact on fishermen's livelihood from OWFs Lack of aquaculture sites in inshore waters creates a requirement for new sites (Crown Estate website) Sustainability of OWF depends on co-existence with other profitable users of the sea.	No previous history. A legislative problem as the seabed owner (Crown Estate) prohibits any other income earning activity by the OWFs in the leased area. OWF development is looked after by offshore managers and environment managers who do not have specific domain expertise in aquaculture. Hence it is difficult for them to understand that aquaculture equipment need not interfere with OWF operation. Traditional aquaculture equipment not well suited to OWF locations.
Opportunity	**Threat**
Example for the implementation of the ecosystem approach and marine spatial planning. Income from the OWF lease can be increased. Objections to OWF development from the fishermen community can be managed by offering employment. Marine spatial planning requires the co-existence of as many activities as possible within a given space. Aquaculture in OWFs areas is better than fishing, shipping or marine aggregate extractions which are non static activities and thereby would disturb the safe operation of the OWF.	Conflict with fishing, shipping and other profitable users of the sea is imminent once aquaculture is allowed to take place within OWFs. This is a new concept which has to undergo semi commercial trials before full scale commercial production can be undertaken. There is a legal void as the seabed owner (Crown Estate) does not have a policy for marine spatial planning and other economic activity within OWF locations. This will put off any new investor. Financiers require real time successful examples of aquaculture in OWFs before they can finance such projects.

5. Discussion

5.1 Factors affecting the development of Offshore wind farms

In view of the potential benefits to the carbon emissions target, the UK government had extended capital grants to the Round 1 OWFs. The generation costs for offshore wind power is around 5.5p/kWh compared to a wholesale price for electricity of around 3.0p/kWh (SDC, 2005). The Round 2 OWFs are struggling to proceed without any capital infusion from the Government. (Liebreich, 2005). Besides this, the Round 2 OWFs are in difficult locations thereby increasing the costs. The Government is considering the idea of increasing nuclear energy in the UK in view of the impending energy crisis. In this background it is interesting to note that UKP 56 Billion has been already approved by parliament to recycle the already existing nuclear fuel (WMN, 2005), whereas just EUR 90 Billion is the capital required for the EU to construct all its OWFs in planning today (Liebreich, 2005).

While the costs for offshore wind power is high economic benefits in not having to pay for costly recycling as in the case of nuclear energy justifies offshore wind energy. Marginal reductions on the capital cost of OWF projects could be achieved by joint consents for a third generation of OWFs along with other profitable users of the sea. The possibility of supplying electricity to other profitable users of the sea like aquaculture farms also exists. Such an important source of energy should not be allowed to run into problems with other profitable users of the sea. Instead zoning options (Fig. 2, page 13) for all these activities in the UK marine space should be developed.

The number of people employed in the offshore wind energy sector as of now is around 4000 (DTI 2004) and in salmon farming is about 7000 (Randolph Richards, 2002). If 30% of the UK's electricity supply is provided by offshore wind by the year 2020 (Renewables Obligation is 3.5 to 5.5 % by 2010, Hollister, 2003), additional employment would be created at around 17,000 full-time equivalent jobs by 2010, and 76,000 by 2020 (Greenpeace, 2004). In contrast in the UK fishing sector, vessel decommissioning and EU quota cuts has resulted in a 44% decline in employment

from 1994 to 2004. (www.aberdeenshire.gov.uk/statistics/economic/fishing/fleet.asp) While the OWFs are not responsible for this job loss, they are taking the marine space previously used by the fishermen and other profitable users. But given the fact that fisheries are depleted it is highly imperative to start aquaculture in OWF locations whereby the fishermen can either be employed in the aquaculture operation in view of their sea going skills or earn an additional income by farming fish as hunting may no longer yield the desired result.

5.2 Factors affecting the Development of aquaculture in wind farms

In contrast to the present day OWF locations, the main aquaculture interests in the UK are limited to Scotland. The candidate species available as of today are not suited to the present day OWF locations. The large scale growth in salmon production in Scotland has resulted in most available near shore finfish sites being used up for finfish farming. The development of new sites and new candidate species alone hold the key for the sustained growth of the UK aquaculture industry. The only exception to this is the possibility of farming warm water species like Sea Bass which is at present moving north.

The creation of the world's largest salmon farming company (as discussed under 2.2 Aquaculture and seafood industry in the UK) has created a situation in which any further investments into aquaculture either in Scotland or at OWF locations in the UK would essentially be dictated by market economics and finance which will take insights with regard to the future of the aquaculture industry from this company.

Hence unless new entrepreneurial interests develop, aquaculture in OWFs might become a late starter. Evidence of such entrepreneurial efforts can be seen in the company Aquabella (http://www.aquab.com/index.html) in New Forest, Hampshire, UK which has converted a pizza factory into an indoor recirculating fish farm to produce Barramundi (*Lates calcarifer*, Asian Sea Bass) at lower than the international price. The entrepreneur who invested in it is not from the sector.

New entrepreneurial interests could be put off by the seabed owner (Crown Estate) since it does not have a declared vision or position on marine spatial planning. While

the UK government agencies are pushing ahead with marine spatial planning, the key to its implementation and thereby aquaculture in OWFs is that the seabed owner should have an opinion in these matters. At the moment there is a void. Unless and until this void is filled, this idea will be a non starter from the point of view of aquaculture finance.

5.3 Fishing/aquaculture like activities within offshore wind farms

The urgency in developing OWF projects resulted in a lack of foresight in developing a suite of acceptable conditions for the co-existence with other users of the sea like fishing. The economic value of fishing in OWFs may not match that of electricity generation. Yet, it is often an important source of employment in rural areas (Symes, 2001). Petts (1999) explained that vessel anchoring and the use of bottom gear is likely to create conflict as power cables and gear can entangle with each other unless cable burial systems function properly. Recent studies (results not reported communicated by an offshore wind farm) indicate that fixed gear fishing and trawling by vessels under 10m can coexist with offshore wind farms.

The development of appropriate gears for fishing within offshore wind farms was suggested at the stakeholder meeting. Low impact gear like pots can be used in OWFs along with a GPS identification to find good underwater terrain on which to drop their pots and retrieve it later. This would relieve the concerns of offshore wind farms with regard to the propellers of their maintenance vessels getting entangled with the ropes of lobster pots. The system is already being used in the North East (David McCandless, North Eastern Sea Fisheries Committee). The possibility of habitat enhancement for oysters within offshore wind farms in the Thames estuary region was also suggested (Dr Clive Askew, Shellfish Association of Great Britain).

Once the impact on fisheries began to create hindrances to offshore wind farm developments, the positive side of offshore wind farms to conservation like the reef effect began to be explored. While there are reports as to the MPA (marine protected area) effect and FAD (fish aggregating device) effect of OWFs (Byrne Ó Cléirigh Ltd 2000), the possibility of displaced effort from OWFs leading to increased pressure on fishing banks outside the OWF area will negate any such positive effect. (as discussed

in the stakeholder meeting). In addition the destruction of the seabed during the construction phase can be repeated as and when there is a re-piling of the system during the lease period.

Hiscock *et al.* (2002) had proposed properly designed FADs (fish aggregating devices) as a habitat enhancement option at offshore wind farms for crustacean shellfish, especially lobsters. The response of offshore wind farms to this idea was not encouraging (Antony Jensen, University of Southampton). The possibility of sea angling and stock enhancement exists within offshore wind farms.

5.4 Marine Spatial Planning and the way forward

Hence it is important that OWFs improve their environmental image by co-existing with fishermen, aquaculturists, navigation and other profitable users. The final reality would depend on government policy. The Irish Sea Pilot Project (JNCC 2004) has explored the relevance of marine spatial planning for the UK seas. The Marine Bill (http://www.defra.gov.uk/environment/water/marine/uk/policy/marine-bill/index.htm) will take lessons from the Irish Sea Pilot Project. The consultation process for the Marine Bill has just begun. All the users of the UK marine space (oil and gas, defence, shipping, fisheries, ports, telecommunications, crossings and aggregates extraction) have to coexist as much as possible in order to bring maximum economic benefit and stability to the nation. The possibility for joint use consents for OWF locations along with fishing, aquaculture, and navigation exists and would depend significantly on the Marine Bill.

A total of 1307.5 Sq. Km (based on data available on Crown estate website) has already been leased to offshore wind farms, fifteen of the leases coming out of Round 1 and another fifteen out of Round 2. However, only four farms have been completed. Policy steps encouraging the development of offshore wind farms will lead to conflict with other profitable users as and when new offshore wind farm space is leased. The only way to avoid this is to develop joint consents for multiple uses co-existing with each other. Perhaps the first step towards this could be to calculate the opportunity costs associated with alternative uses within offshore wind farms.

5.5 Visualisation of the economic value from aquaculture in offshore wind farms

	Area leased Sq.Km	Value realised	Actual area used
Offshore wind farm	1307.5 (Crown Estate)	Out of 30 leased sites four have been completed. To complete the rest finance is not available. In order to fulfil the renewables obligation it will cost 1 Billion Pounds to the UK tax payer. (House of Commons Report HC413, 15 September 2005)	Turbine piles and foundations together occupy less than 3 % of the leased area*. (39.225 Sq. Km)
Aquaculture	79.66 (Crown Estate)	300 million £ farm gate price 600 million £ retail price (Randolph Richards, 2002)	Some sites are used for spat collection only. Some sites are not farmed always. Most sites are used for salmon farming. Others include halibut, cod, saithe, trout, oyster, mussel.

Table 2. Distribution of area and value of offshore wind farms and aquaculture

* Based on data obtained from offshore wind farms (Table 1, page 14) around 1% or less area is taken by turbine piles and foundations. An extra 2% has been added to this to accommodate for future requirements of larger foundations and other technical reasons which might vary from farm to farm.

Area available within offshore wind farms for other profitable uses

Area leased (1307.5 Sq. Km) – Actual area used (39.225 Sq. Km) = 1268.275 Sq. Km

Allocation of unused area around the offshore wind turbine piles and foundations for other profitable uses (visualisation)

Total unused area available	1268.275 Sq. Km
Navigation channels (10%)	126.8275
Fishing (10%)	126.8275
Aquaculture (50%)	634.1375
Other users (30%)	380.4825

634.1375 Sq. Km is more than seven times the present area under aquaculture.

If 79.66 Sq. Km of present area under aquaculture can produce 300 million £ worth of salmon alone at the farm gate (Randolph Richards, 2002), then irrespective of the species that can be farmed in offshore wind farm locations, the technology and market realities, 634.1375 Sq. Km. can produce seafood perhaps to the tune of (300million £ X 7) 2100 million £. This of course will take a lot of time to be achieved. Even if half of this is achieved the burden to the tax payer having to pay 1 Billion £ for the renewables obligation (House of Commons Report HC413, 15 September 2005) could be balanced.

6. Concluding comments

This report was meant to identify the problems and prospects that would emerge from this concept and to suggest a way forward.

The prospects identified are as follows.

1) Aquaculture in OWFs will reduce the impact of OWFs on fisheries.

2) This will help in reducing multi user conflicts in high priority offshore developments like wind farms which is a source of clean energy. This example would be a harbinger to marine spatial planning in the UK.

3) The lack of inshore sites for aquaculture has necessitated moving to offshore regions. The infrastructure available with OWF developments would become a site of choice without any disturbance to the main purpose.

4) As global fisheries production has stabilised aquaculture alone can supply the 40 million tonne extra seafood requirement by 2030. Regions of the world which can supply this demand will earn significantly in global food trade. Seafood has been found to be the better animal protein than meat (IFPRI 1999) on account of the presence of eicosanoids (http://www.alaskaseafood.org/health/facts/pages/misc-omega3.html).

The problems identified are as follows.

1) There is no previous experience of aquaculture in offshore locations except through semi commercial experiments associated with oil rigs in the US and other open ocean areas. Hence semi commercial trials have to be done before financiers can be convinced about the economic prospects.

2) The OWF personnel who look into the concept of aquaculture in OWFs lack domain expertise in aquaculture technology and equipment leading to conclusions that

aquaculture would affect the safe, continuous and uninterrupted operation of the wind farms.

3) The bulk of today's aquaculture industry in the sea is geared to cage culture in inshore locations. The aquaculture equipment used for inshore aquaculture cannot essentially be used in deeper waters and thereby in OWF locations.

4) The seabed owner (Crown Estate) does not allow any other profit making activities within the OWF lease.

While there are solutions for most of these problems this report cannot solve all of them. But with respect to the concerns of OWF companies on aquaculture activities disturbing the safe and continous operation of OWFs the following options can be looked into.

1) An acoustic barrier (technology available at University of Plymouth tried out in the US; Fish Guidance Systems Ltd. Hampshire, UK) can be created around the OWF locations by which fishes can be released inside this acoustic barrier.

2) Neural implants into fishes (Jelle Atema, Boston University, USA) can also be used to deliver a warning signal to the fish brain, possibly by mimicking a bad smell when they leave the OWF aquaculture area. In this way the intrusion into the OWF locations will be that of sound waves and not by an engineering structure. The ethical issues behind neural implants will have a bearing on the actual use of this system.

3) There are four aquaculture equipment systems which have been suggested under results (4.3) of this report. Out if these Maris Fish Ranches have been designed for the purpose of collecting from wild fisheries for rearing within the fish ranches. This is particularly suited to the present UK aquaculture scenario as there are not many candidate species immediately available for aquaculture in offshore wind farms which can be farmed in cages.

References

Bergen Declaration 2002 Ministerial Declaration of the Fifth International Conference on the Protection of the North Sea. Bergen, Norway. 20-21 March 2002

Buck, B. H. 2002 Offshore-Windparks and Green Aquaculture, In: Fascination Offshore - Use of Renewable Energies at Sea. Övermöhle, K. und Lehmann, K.-P. (Eds.). Report 2002. 70-74.

Buck, B. H. and Rosenthal, H. 2003 Multiple Resource Use in Offshore Habitats: Combining Wind Farms with Offshore Extensive Mariculture, In: Realizing The Potential: Responsible Aquaculture for a Secure Future, World Aquaculture 2003, Book of Abstracts, May 19-23, Bahia Convention Centre, Salvador (Brazil). 1, 126.

Buck, B. H., Krause, G. and Rosenthal, H. 2004. Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints, Ocean & Coastal Management, 47(3-4), 95-122.

Byrne Ó Cléirigh Ltd, University of Southampton 2000 Assessment of Impact of Offshore Wind Energy Structures on the Marine Environment. www.marine.ie/industry+services/technology/renewable+energy/303x001.pdf

Defra 2002 Safeguarding our Seas – A Strategy for the Conservation and Sustainable Development of our Marine Environment. Defra, London.

Department of Trade and Industry 2003 The Renewables Obligation. www.dti.gov.uk/energy/renewables/policy/renewables_obligation.shtml

Department of Trade and Industry 2004 Renewable supply chain GAP analysis, available at www.dti.gov.uk/energy/renewables/renewables_uk/publications.shtml.

Ernst & Young 2004 Renewable Energy Country Attractiveness Indices, Ernst &Young Renewable Energy Group.

European Commission 2002 Towards a strategy to protect and conserve the marine environment. Communication from the Commission to the Council and the European Parliament. COM (2002) 539 final. Brussels, 02.10.2002

Firestone, J., Kempton, W., Krueger, A. and Loper C.E. 2005, "Regulating Offshore Wind Power and Aquaculture: Messages from Land and Sea," Environmental Law Reporter (Environmental Law Institute), 35:10289-10307 (May 2005)

Fish Farming International 1999 Italians go offshore with SADCO October 1999 p34

Greenpeace 2004 Offshore wind, onshore jobs. A new industry for Britain 40 pp

Hollister, A. 2003 OWF opportunities in the UK. International Market Insights Report No. 122055. Industries Canada. http://strategis.ic.gc.ca/epic/internet/inimr-ri.nsf/en/gr122055e.html

IFPRI 1999 Livestock to 2020 The next food revolution. Food, Agriculture, and the Environment Discussion Paper 28 http://www.ifpri.org/2020/dp/dp28.pdf

Jin Di, Kite-Powell, H. and Hoagland, P. 2005 Risk assessment in Open-Ocean Aquaculture: A Firm-Level Investment-Production Model. Aquaculture Economics & Management, 9:1–19

JNCC 2004 The Irish Sea Pilot Project. Marine Nature Conservation and sustainable Development Report to Defra by The Joint Nature Conservation Committee 172 pp

Liebreich, M. 2005 Offshore wind: Europe's Euro 90 billion funding requirement. white paper, New Energy Finance, London

Pugh, D. and Skinner, L. 2002 A New Analysis of Marine-Related Activities in the UK Economy with Supporting Science and Technology. IACMST Information Document No 10. August 2002

Macaskill, A. 2004 Minutes of the meeting of the Aberdeen Mechanical Society. 1 December 2004. www.abdn.ac.uk/ams/minutes/dec04.doc

Naylor, R., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. 2000 Effect of aquaculture on world fish supplies, Nature 405, 1017-1024

Petts, J.W. 1999 Effects of Offshore Wind Energy Developments on Navigation and Commercial Shipping. Report from BMT Edon Liddiard Vince Ltd. to the Department of Trade and Industry (ETSU) New and Renewable Energy Programme. ETSU W/35/00532/REP.

Richards, R. 2002 Strategy for Aquaculture. Submission from Professor Randolph Richards to Enquiry Committee of the Scottish Parliament 25 March 2002. http://www.scottish.parliament.uk/business/committees/historic/x-transport/papers-02/trp02-10.pdf

Scapini, F. et al., 2002, Baseline Research for the Integrated Sustainable Management of Mediterranean Sensitive Coastal Ecosystems, Ed. Istituto Agronomico per l'Oltremare.

Sinden, G. 2005 Assessing the Costs of Intermittent Power Generation. Presentation at the Intermittency Stakeholder group 5 July 2005. http://www.eci.ox.ac.uk/pdfdownload/energy/IntermittencyStakeholderGroup-050705.pdf

Sustainable Development Commission 2005 Wind Power in the UK 166 pp

Symes, D. 2001 Inshore Fisheries in Europe at the Turn of the Century. In: Inshore Fisheries Management, Reviews: Methods and Technologies in Fish Biology and Fisheries, Vol. 2. (eds D. Symes and J. Phillipson) Kluwer Academic Publishers, Dordrecht, pp. 3-23.

Western Morning News 2005 Blair Blows hot on the nuclear option. Cover story 30 November 2005