The Development of Marine Based Wind Energy Generation and Inshore Fisheries in UK Waters: Are They Compatible?

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Abstract

Offshore wind energy is set to make an increasing presence in a number of European countries in the coming years. Developments potentially add to increasing pressures upon inshore fisheries, which raise questions about the compatibility of the two types of economic activity. We examine the potential ecological effects of the development of offshore windfarms upon fishery resources. We also study the direct effects upon fishing activity and techniques, by focussing on those effects occurring at each stage of a windfarm's development. Consideration is then given to how fisheries issues and industry concerns are represented and accounted for in national planning system decision making, drawing on early experience in the UK. In order to improve impact prediction, there is a need for further research to develop understanding of environmental and ecological affects upon fisheries, principally noise and vibration and electromagnetic field effects. However, of particular importance for the fishing industry is better understanding of the effects of installations on the range of fishing techniques undertaken. This would feed into judgements on restricting fishing activity for safety reasons, and assist in determining the socio-economic impact of developments on fishing communities so that the location of developments can be planned appropriately to maximise their compatibility with fisheries. Fishing groups should be involved in pre-development decision making as much as possible in order to build trust and maximise the scope for reconciling conflicting issues to the benefit of both wind energy developers and the fishing industry.

Introduction

Evolution of offshore wind energy

The 1970's oil crisis prompted a number of governments to encourage research and development into alternative energy sources to improve energy security. Later, recognising the need to reduce green house gas emissions, many countries viewed electricity generation by wind energy as an important strategy to meet their commitments to the 1992 UN Framework Convention on Climate Change and the Kyoto Protocol of 1997.

The European Commission (1997) responded to the Kyoto Protocol with the white paper on renewable energy sources, which set targets for the EU to increase the share of renewable energy production from 6% to 12% of total energy production by 2010. Legislative measures followed with the Directive on the promotion of energy produced from renewable energy sources (2001b) which targets the share of electricity consumption from renewable sources to increase from 13.9% in 1997 to 22.1% in 2010. The most recent industry projections set out at the 2004 renewable energy conference at Berlin claim that a target of 20% renewable energy consumption and 33% of electricity production could be achieved by the EU 15 member states[1] by 2020 (EREC, 2004). In the UK, the government under the Renewables Obligation, has obliged power suppliers to source a proportion of their supply to customers from renewable energy resources. This was set at 3 percent in 2003 and rises to 10 percent by 2010, and 15 percent by 2015 (British Wind Energy Association, 2004c).

Wind energy has contributed the largest share of the development of renewable energy sources to date, with an annual growth rate in excess of 35% between 1995 and 2002, making Europe the world leader in technological development of wind energy (ibid.). Onshore development has led the growth, but in densely populated European countries, the exhaustion of suitable sites and opposition to developments on the grounds of visual and noise concerns,

[1] Excluding accession states that joined the EU in 2004.

has prompted the development of offshore windfarms. Once away from the shoreline visual and noise issues are politically less sensitive and this allows the possibility to construct larger turbines that are more powerful.

This shift in emphasis has been supported by technological development (Gaudiosi, 1999) with demonstration windfarms from the 1980's onward, firstly on harbour walls such as at Zeebrugge in Belgium, and later offshore developments such as Helgoland in Germany in 1989, Blekinge in Sweden in 1990 and Vindeby in Denmark in 1991 (British Wind Energy Association, 2000). New developments are likely to migrate further offshore as the best inshore areas are taken up, and as technology develops, economic viability changes and legal frameworks evolve to enable development outside territorial waters. Regulation will also play its part and may modify these general trends (for example see section 0, 0 on current developments in the UK). Longer term, the most effective way of harnessing wind energy is likely to be through offshore wave power, and offshore wave projects seem certain in the future (Side and Jowitt, 2002).

To date, approximately 600 MW of offshore wind capacity has been installed in the EU (COD, 2004), and a projected 10,000 MW of capacity is planned by 2010 and 70,000 MW by 2020 in the EU 15 (European Wind Energy Association, 2003)[2]. In the UK As capacity will focus on coastal waters, at least in the short and medium term, it is the inshore fisheries sector that will primarily be affected by development.

[2] An individual onshore turbine has a typical capacity of 1.8 MW, whilst a larger offshore turbine currently has a capacity of around 3.6 MW, and still larger machines are being trialled (British Wind Energy Association, 2004a). Commercial windfarms currently planned in the UK have up to 90 turbines in each development, corresponding to a generating capacity of up to 300 MW (British Wind Energy Association, 2003). For comparison, the average coal fired, nuclear and hydroelectric power station in the UK has a capacity of 1600 MW, 930 MW and 22 MW, respectively (DTI, 2004).

European winds and potential wind energy resources

Good wind resources and relatively shallow coastal waters have also enabled development in the EU. Offshore winds are higher and less turbulent than onshore winds, and may be 25% higher ten kilometres from the coast than at the coast (British Wind Energy Association, 2000). Estimates vary, but there is general consensus that northern Europe has the highest most suitable wind regimes with wind speeds exceeding 9 m s^{-1} at a height of 50 metres quite close to shore. Suitable sites are located in Ireland, Scotland, Sweden and northern Denmark. Wind speeds of 8 m s^{-1} characterise other Baltic and Benelux countries, Germany, England, Wales, France and parts of Spain. The Mediterranean has lower wind speeds, although the Aegean has a good potential wind resource (ibid.).

Wind energy resource estimations have been derived from wind regime data and modelling. These make various assumptions on technology, physical limitations such as water depth and distance from shore, and economic factors. Such assumptions have changed over time according to trends in technological, environmental and social considerations. DEA/CADDETT (2000, cited in Garrad Hassan et al., 2001) estimate the total European resource (excluding Norway, Sweden and Finland), within a distance of 40 km from shore, and to depths of 30 metres, to be in excess of 3000 TWh yr^{-1}. This is greater than the total European electricity generation of the EU 15 in 2001 of 2670 TWh yr^{-1} (European Commission, 2003).

Offshore wind energy developments and the fisheries context

As already indicated, offshore wind energy developments, at least in the short to medium term, will be concentred in coastal inshore waters. Fisheries in this sector, although not as productive in terms of economic output as the offshore sector, often provide an important source of employment and support to local economies in rural areas dependent upon fishing (Symes, 2001). In many cases, options for alternative employment are limited, making such communities vulnerable to change. The sector also contributes to the social and cultural fabric of such communities, whose attractiveness is also valued by the tourism industry (see Rogelia, 2002).

From once having exclusive rights to inshore waters, because there was little other marine based human activity, inshore fishing today has become one among many different legitimate users of marine space, and offshore wind energy is the newest of these. Others include wildlife conservation, tourism and recreation, aquaculture and aggregate dredging, for example. Within the European fishing industry itself, diminishing stocks and over capacity in the offshore sector exerts further pressures as effort transfers to the inshore sector. These pressures raise issues over the long-term sustainability of inshore fisheries. Consequently, the question over whether or not offshore wind energy and fisheries are compatible is an important one, and the future challenge lies in sustaining fisheries as socio-economic support systems at both the local and regional level, whilst accommodating wind energy developments in ways that do not undermine the ecological underpinnings of fishery resources, nor the viability of fisheries.

The rest of this paper will first consider the ecological affects of windfarm developments upon fishery resources, and the direct affects upon fishing activity and techniques, by focussing on those occurring at each stage of a windfarm's development. Second, the planning processes that facilitate their development will be evaluated according to how fisheries issues and industry concerns are represented and accounted for in decision-making.

Life cycle of offshore windfarm developments and their implications for fisheries

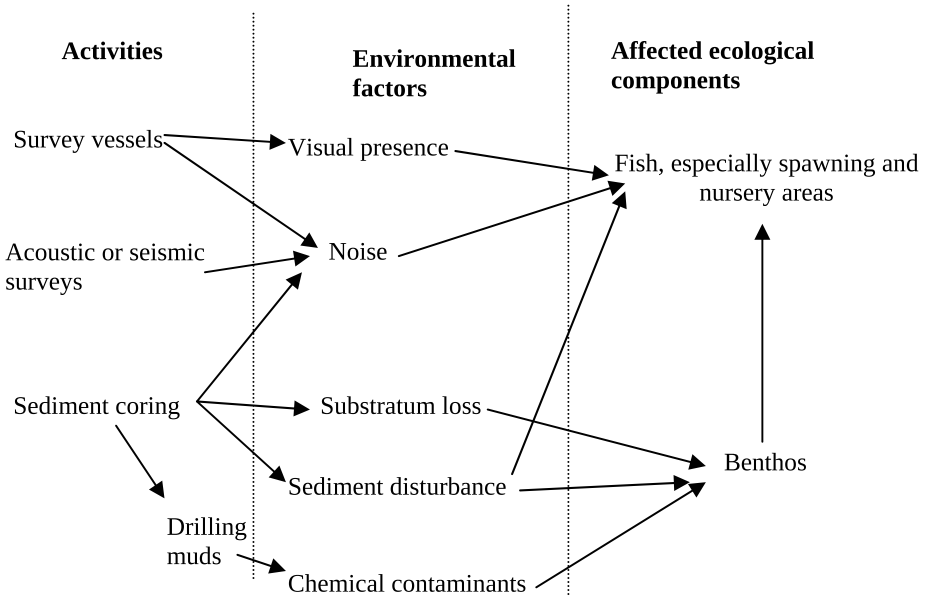
Impacts of windfarms on fisheries can occur at all stages of the installations development - that is during the exploration, construction, operation and decommissioning phases. They work through the physical, chemical and biological environmental factors that change ecological marine habitats and consequently the fisheries they support, as well as through the direct impacts upon fishing activities due to conflicting resource uses.

Exploration

Once preliminary studies have identified potential sites for windfarms, site surveys are required to define depth contours and sediment types in order to select suitable foundation techniques and routes for submarine cables. Surveys are likely to include sediment coring, entailing localised disturbance to sediments and associated benthic fauna, and acoustic and seismic surveys using sonar and air guns, which are powerful sound emitters (Hiscock *et al.*, 2002). Intermittent loud noise from air guns associated with geophysical surveying has an adverse impact on fish, invertebrate and planktonic species. High intensity seismic sounds kill or injure fish eggs and larvae in the near field, less than ten metres from the sound source, (Vella *et al.*, 2001), although crustaceans and benthic molluscs may be more tolerant (Hirst and Rodhouse, 2000). Behavioural impacts occurring over much grater distances may be of greater significance to fisheries, however, with catch effects resulting from horizontal and vertical dispersal of fish, and changes to activity levels and responses to fishing gear (*ibid.*) . Downward movements of a school of fish thought to be whiting (*Merlangius merlangus*) were observed by Chapman and Hawkins (1969, cited in, Vella, *et al.*, 2001) with a sound source of 220 dB although habituation was observed after an hour of intermittent firing. Trawl catches of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) were found to reduce by 70% within 1 nm of seismic shooting in the Barents Sea and effects were found to extend beyond 18 nm from the source (Engas *et al.*, 1996). Long term effects on fishing success beyond a few days, however, are poorly understood (Hirst and Rodhouse, 2000). To limit impacts, surveys should avoid times when spawning and/or large numbers of larvae are present in the area. Associated vessel movements will also generate noise that could affect fish.

For safety reasons, restrictions to fishing activity and navigation may be necessary during surveys.

Figure 1. Environmental and ecological effects of exploration to fisheries (adapted from Elliott, 2002; Hiscock *et al.*, 2002; Parkinson, 2002)



Construction

Windfarm construction includes the following stages (Metoc Plc., 2000; Hiscock *et al.*, 2002; Parkinson, 2002):

- transport of foundations and turbines to site;
- construction vessels on site, including transport, jack-up and drilling barges;
- site preparation and foundation installation;
- disposal of excavated spoil;
- installation of tower, turbine housing and or nacelle, generators, hub and blades;
- cable installation between turbines and to the shore.

For safety reasons, the physical presence of vessels and construction activity will necessitate exclusion zones around the construction site. Exclusion corridors into and out of the site will also be needed for transporting vessels in and with their cargos of construction materials and components, and for evacuation purposes. This will prevent fishing activity and navigation within these areas for at least the duration of the construction period, although some form of vessel restrictions are likely to be extended for the lifetime of projects Potential collisions between construction vessels could also create a pollution hazard.

There are four main types of foundation for shallow water installations, as well as designs for floating wind turbine systems yet to be employed at deep water sites (see Tong, 1998, for example). These include:

- Concrete gravity based foundations. A single concrete support structure with wide flat base of approximately 15 m diameter and used in depths of 4 -10 m. Seabed preparation will usually be required including removing silt, preparing a shingle bed and installing scour protection material such as rocks and boulders around the base of the foundation.

- Steel gravity foundations. Lighter to transport than the concrete version, they are weighted on site with dense materials such as olivine. They have a similar diameter and require similar preparations. They are more economically viable than concrete in deeper waters because the base does not have to increase in volume to the same degree in order to withstand the lateral forces from waves upon the structure.

- Monopile foundations. These consist of a single steel pile of between 2.5 and 4.5 m in diameter requiring no preparation and driven 10 - 20 m into the seabed. The presence of boulders may prevent its use. On rock strata, a hole is drilled to accommodate the pile and secured with grout materials.
- Tripod foundations. These structures have 3 or 4 legged small diameter steel jackets with each leg fixed with a steel pile of approximately 0.9 m diameter and driven 10-20 m into the seabed. They are not suitable for waters less than 6-7 m as the tripod structure can be

a collision hazard to shipping (Byrne Ó Cléirigh Ltd et al., 2000; Metoc Plc., 2000; Hiscock et al., 2002; Parkinson, 2002).

Concrete gravity foundations have been the most commonly used to date but monopiles are likely to be more important in the future. The construction of all types of foundations will have ecological effects upon fisheries, although the type and extent of impacts depend on the type of foundation used and the physical and biological context of the site. Table 1 compares the ecological impacts of different foundation.

The potential affects of sediment disturbance can be predicted using water quality and dispersion data as inputs into models developed to assess offshore and gas activities (Metoc Plc., 2000).

Noise associated with shipping causes avoidance or attraction responses in fish (Vella *et al.*, 2001). Studies of penned cod (*Gadus morhua*) and herring (*Clupea harengus*) found that both dived slowly in response to playback of recorded vessel noise and moved into dense structured schools (Engas *et al.*, 1995). From the existing research, it is not possible to draw conclusions about impacts to fisheries, and any negative effects of noise from construction need to be balanced against noise associated with normal fishing activity in a given area.

Impacts from noise, nevertheless, may be mitigated by timing construction to avoid sensitive feeding, spawning and nursery area/times of the year, and using underwater bubble curtains which limit the propagation of noise through the water column (Metoc Plc., 2000; Garrad Hassan and partners *et al.*, 2001; Vella *et al.*, 2001)

Further sediment disturbance and noise occurs during the installation of cabling between turbines and to the shore, and a considerable area of seabed could be disturbed when large numbers of turbines are being installed, potentially resulting in significant impacts in ecologically sensitive areas. Cable burial will limit potential impacts to fishing gear and anchors, and damage to cables themselves. This can be achieved by jetting or ploughing cables into position, or trenching prior to laying (Metoc Plc., 2000). Typically, a five metre corridor of seabed is directly disturbed in such operations, although sediment dispersal will widen the overall area impacted (Cooper and Beiboer, 2002). Over rocky substrata, cables may need to be laid on the surface and protected using unnatural hard substrata (Hiscock *et al.*, 2002). Impacts to intertidal communities will occur where cables cross the shoreline.

Excavated spoil from foundation construction needs to be disposed of. If at sea, it can result in smothering of seabed communities. If the dumped sediment is different from sediment type at the disposal site, it may result in long-term changes to the species composition of benthic communities (Metoc Plc., 2000; Hiscock *et al.*, 2002). Preliminary indications of seabed recolonisation rates are provided by studies on drilling associated with the oil and gas industry and aggregate extraction. Recruitment from the surrounding undisturbed area will start immediately, provided the seabed has not been contaminated and does not substantially differ after disturbance from original conditions (Metoc Plc., 2000). Depending on habitat stability, species groupings and natural disturbance levels (Jennings *et al.*, 2001), the area will typically take between 3 and 5 years to fully recover (Metoc Plc., 2000)[3]. The volumes expected in most offshore wind developments are not thought to be significant enough to pose a vessel grounding hazard by changing seabed depth (Hiscock *et al.*, 2002). However, mounds left by dumping, construction activity and even anchoring can present problems for some types of fishing using bottom gear. In the UK oil and gas industry this has resulted in developers having to return to level out mounds to enable fishing to recommence, and paying fishing exclusion compensation whilst work was completed (Traves, 1994).

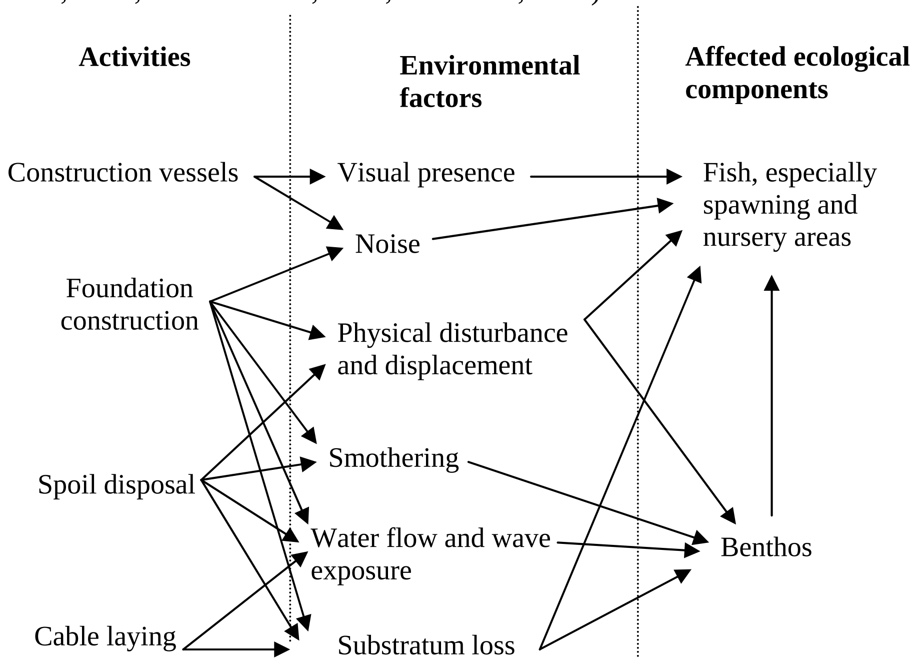
[3] Recovery from bottom trawling can take similar periods of time (Jennings *et al.*, 2001).

Table 1. A comparison of ecological impacts caused by the construction of foundations (Metoc Plc., 2000; Garrad Hassan and partners *et al.*, 2001; Hiscock *et al.*, 2002).

Type of Environmental / Ecological Impact	**Relative Impact due to Foundation Type**	
	Concrete/Steel Gravity Foundations	**Monopile/Tripod Foundations**
Foundation footprint leads to direct loss of marine life and habitat. Disturbed sediments smother and clog benthic organisms and reduce visibility for mobile fauna such as fish.	Footprint is greater due to larger diameter of foundation. Sediments will be disturbed in preparing the seabed.	Footprint is less than gravity foundation. Piling should disturb fewer sediments than preparations for gravity foundations. Where drilling is used, cuttings will be dispersed into the marine environment.
Noise affects the behaviour of marine fauna, particularly during breeding and spawning periods.	Seabed preparation and foundation construction produces sound but is less intense than from piling.	Short pulses of intense sound will result from pile driving and explosives may be used to remove boulders. Although temporary, fish can loose consciousness and drift of the water's surface. Noise will also be produced from any drilling into rock strata.
Chemical contaminants from drilling muds, and organic polymers and heavy metals associated with grouting and cementing, may be toxic to benthic organisms and those feeding upon them. Contaminated sediments inhibit recolonisiation of the area after construction.	Potential for accidental release from grout/cementing.	Potential for accidental release of drilling muds and grout/cement when piles are fixed into drilled rock strata.

To minimise chemical impacts, Metoc Plc. (2000) recommends using only chemicals approved for use in the marine environment by the relevant authorities and employing methods that minimise the release of polluting materials.

Figure 2. Environmental and ecological effects of construction to fisheries (adapted from Elliott, 2002; Hiscock *et al.*, 2002; Parkinson, 2002)



Operation

Given that the estimated life span of offshore windfarms of existing operational windfarms is around 20 years (Metoc Plc., 2000), the affects on fisheries are likely to be of greater importance than those generated during exploration, construction and decommissioning. We will first consider the environmental and ecological implications affecting fisheries. These are summarised in Figure 3. A discussion will follow on the compatibility between fishing activity and windfarm structures.

Hydrographic effects on substratum and fisheries

The foundations and base of towers will affect the current flow across the seabed. This can lead to localised sediment scour in the lee of foundations, and associated changes to the species composition of the seabed. Scour affects are likely to be greatest around gravity foundations due to their larger size, and may need protection using boulders. Boulder protection enables foundations to better function as artificial reefs offering potential ecological benefits for fisheries. The presence of multiple turbines could affect current flows around and through the development area and potentially the amount of wave energy dissipated at the shoreline, which would have implications for intertidal communities (Hiscock *et al.*, 2002). One study on early windfarm installations found small changes to current, wave and sediment conditions in the immediate vicinity of structures, but concluded that these were not likely to be significant in the far field away from structures (Cooper and Beiboer, 2002). Such work needs extending to incorporate new issues associated with larger installations and structures in deeper waters (*ibid.*).

Noise and vibration

Gearbox and generator movement produce mechanical noise and vibration, and the movement of blades through the air creates aerodynamic noise. It is expected that most noise transmitted into the water column will be of mechanical origin, transferred through the tower column and foundation (Vella *et al.*, 2001). The foundation type will modify the nature of the sound within the water column. Design innovations to improve efficiency and longevity have limited sound generation in modern turbines (*ibid.*; Parkinson, 2002). The most extensive review of the impacts of noise and vibration on marine wildlife to date has been undertaken by Vella *et al.* (2001) and the reader is referred to this report for an in depth analysis.

The most extensive work on fish and invertebrate behavioural responses to noise has been undertaken for geophysical surveys and the operation of seismic guns, in particular. As the noise generated by operational windfarms is long term compared to that generated during exploration and construction, this source of impact is likely to be more important. However, investigations on the operational noise generated by offshore windfarms are limited to date.

Two studies were undertaken by (Westerberg, 1999, *cited in* Vella *et al.*, 2001) on the single turbine Svante Windfarm[4] in Sweden. The first tracked eel migrations past the turbine, both in operational and non-operational phases, and found no changes in behaviour that could be attributed to the turbine. An analysis of eel catches in an area along the migration route beyond the turbine site that it passes through, five years prior and five year after the construction of the turbine, found there was no significant reduction in catches. In the same area an analysis of catch-per-unit-effort (CPUE) of eels for different wind speeds before and after turbine construction found a 22% reduction after construction for the higher wind speeds (10-15m s^{-1}), suggesting the turbine may have an impact on eel migration at high wind speeds.

In a second study the CPUE for cod (*Gadus morhua*), roach (*Rutilus rutilus*) and shorthorn sculpin (*Myoxocephalus scorpius*) in two areas of radius 0 – 200 m and 200 – 400 m from the turbine, respectively, were analysed during operational and non-operational periods. CPUE was found to be greater for all species in the area closer to the turbine during both operational and non-operational periods, although CPUE within this area was lower during operational periods. This suggests that fish are attracted to the turbine structure (a tripod foundation), and although some are deterred when the turbine is in operation it is not of sufficient intensity to deter the majority of fish in that zone. Vella *et al.* (2001) postulates these results reflect the ability of the fish to habituate to a continuous noise stimulus, and corresponds to observations of other "noisy" structures such as oil platforms (Valdermarsen, 1979; Traves, 1994) and experience at Vindeby windfarm in Denmark and Ijsselmer in the Netherlands (British Wind Energy Association, 2000).

No similar studies have been undertaken for invertebrates or planktonic organisms such as fish eggs and larvae. The influence of noise intensity on invertebrates is poorly understood (Vella *et al.*, 2001). However, reports of fouling by invertebrate fauna of monopole turbines

[4] The peak noise generated by the Svante turbine at a distance of 100m is between 102 and 113dB for wind speeds of 6 and 12m/s (Vella *et al.*, 2001).

at the Horns Rev offshore wind farm in Denmark (Bio/consult, 2000b, *cited in* Bio/consult, 2000) suggests that noise and vibration does not have adverse affects on sessile invertebrate fauna.

Vella *et al.* (2001) concludes that although existing studies do not indicate any serious effects on fish, further site monitoring studies are needed on fish migration routes and population dynamics. One difficulty is that studies on windfarms appear not to have quantified the relationship between noise intensity and fish behaviour. In addition, the report recommends that further research should be undertaken to spatially characterise the air and underwater acoustic environment at offshore windfarms, taking into account site variables such as coastal morphology, seabed and sediment types, depth and distance offshore, foundation types, and numbers, sizes and arrangements of turbines (*ibid.*).

Electromagnetic fields

Submarine electric cables, which connect to turbines and take power to the shore, could affect fish that use electroreception to communicate and conduct social behaviour, detect prey, or navigate using the Earth's magnetic field (Gill and Taylor, 2001). Fish that possess electroreception primarily include to the elasmobranches, such as dogfish, skates and rays. As the electromagnetic field of a cable is predicted to decrease with increased voltage, medium voltage cables, which are the common choice for offshore wind farms, are likely to have the most acute effects on fish (*ibid.*).

Gill and Taylor (2001) reported on a laboratory based experiment designed to determine the presence of behavioural effects on the lesser spotted dogfish (*Cyliorhinus caniculus*) from an electric field equivalent to that produced by cabling from offshore windfarms. Individuals were attracted to the source when the electric field of was 0.1 μVcm^{-1} at 10 cm, which is similar to the biometric field produced by prey species. Some avoidance responses were observed to a field of 10 µVcm^{-1}, which is the maximum expected to be emitted from 3 core submarine 150 Kv / 600 A cables, although this was highly variable amongst the experimental population. This corresponds to research that found that the benthic shark (*Scyliorhinus canicula*) avoids electric fields of the same strength (*ibid.*), and other literature that shows that the sensitivity threshold of electroreceptive fish could be much lower than the electromagnetic field close to sub sea cables (Voitovich and Kadomskaya, 1997, cited in CEMAS, 2003). The migration paths of silver eels (*Anguilla anguilla*) across a high voltage direct current cable were found not to be significantly affected by the presence of a high voltage direct current cable (Westerberg and Begout-Anras, 1999, cited in CMACS, 2003). Such cables are not expected to be commonly used for windfarms except potentially for future developments further out to sea (Centre for Marine and Coastal Studies, 2003). Further field-based studies are planned for most offshore windfarms and CMACS (2003) concludes that the current state of knowledge is too variable and inconclusive to make informed assessments on impacts on electroreceptive species.

It may be possible that elasmobranches will either congregate around or avoid cables due to their electric fields. If the latter occurs, affects would be particularly significant if a cable runs through a breeding ground. Gill and Taylor (2001) and CMACS (2003) recommend that further research is needed at an ecological level to determine the behavioural effects on survival, gaining resources and reproductive potential, as well as to assess intraspecific variability in response, and the effects on habitat use by various species at different life stages. They also recommend further studies to improve the characterisation of electromagnetic field production by subsea power cables, and mapping studies to determine the extent of coastal marine habitat used by electroreceptive species.

In theory it might be possible to limit the strength of electromagnetic fields by laying two cables, each with an opposite currents, in parallel and close to each other (Gill and Taylor, 2001). Alternatively, shielding cables with materials of higher permeability (i.e. that reduce the strength of electromagnetic fields), or using thicker materials with higher conductivity values, such as copper, can have the same effect (Centre for Marine and Coastal Studies, 2003). Non-magnetic sediment is ineffective in dampening electromagnetic fields, but nevertheless burying cables will limit exposure to electroreceptive species due to the physical barrier of the substratum (ibid.). Burial also has the added advantage of minimising potential damage from anchors and fishing gear.

Windfarm structures as fish attraction devices and artificial reefs

The presence of windfarm structures and any associated scour protection are likely to result in significant changes to the surrounding marine wildlife communities. Species diversity in the area could increase, as could the size of individuals and the productivity of populations (Vella *et al.*, 2001; Hiscock *et al.*, 2002).

Structures provide a hard substrate for organisms to establish themselves. In UK waters, Hiscock (2002) indicates that planned offshore wind sites are in wave exposed areas of open sea with bottom substrate composed of sedimentary material. Where sites have waters of less than around 5 metres depth, scour conditions will most likely prevent the establishment of stable seabed communities. Introduced structures in such a habitat, however, will allow rapidly settling and fast growing species to establish above the seabed. At the Horns Rev offshore windfarm in Denmark, colonisation by invertebrates on mono-pile towers was observed five months after construction (Bio/consult, 2000b, cited in Bio/consult, 2000). Such colonisation will be limited where biofoulants are used. Hiscock (2002) describes in detail the typical process of colonisation of mono-pile towers and identifies the species involved in UK waters. Where foundation structures are more complex, for instance in the case of gravity or monopole foundations with scour protection, species diversity, biomass and productivity are likely to be higher.

Due to the interference to water flow caused by the windfarm structures, tidal currents and wave actions will be accelerated in certain areas resulting in scour pits forming in the seabed. These can extend several metres from the structure, and appear to be attractive to crustacean species such as crabs and lobster, and fish such as ling (*ibid.*). Towers colonised by mussels could lead to scour pits becoming filled with cast off mussel shells that would then be dispersed across the seabed during storms, and attract scavengers such as plaice and flounder (Hiscock *et al.*, 2002).

Fish living in the water column tend to be attracted to submerged structures, apparently benefiting from the shelter from currents, wave action and predators (Vella *et al.*, 2001). In UK waters, species include wreck fish (*Polyprion americanus*), saithe (*Pollachius virens*), pollack (*Pollachius pollachious*), whiting (*Merlangius merlangus*), cod (*Gadus morhua*), ling (*Molva molva*) and wolf fish (*Anarhichas lupus*) (Aabel *et al.*, 1997, cited in Parkinson, 2002; Vella *et al.*, 2001; Hiscock *et al.*, 2002).

Foundations and associated scour protection can act as artificial reefs and are well established tools in many countries for fisheries management and enhancement, nature conservation and coastal protection (Byrne Ó Cléirigh Ltd *et al.*, 2000; Vella *et al.*, 2001). In southern California, Ambrose and Swarbrick (1989, cited in Vella et al., 2001) found that increases in catch-per-unit-effort (CPUE) were greater when fishing over artificial reefs compared with natural reefs. A number of studies found greater biomass on artificial vertical reefs than on natural reefs (Rilvo and Benayahu, 2000, cited in Vella et al, 2001).

Hiscock *et al.* (2002) postulates that well planned scour protection could provide a significant habitat for crustaceans shellfish, which in the UK waters could include lobster (*Homarus* *gammarus*), brown crab (*Cancer pagurus*), velvet swimming crabs (*Necora puber*) and various species of squat lobster (*Galathea* spp.) (Garrad Hassan and partners *et al.*, 2001).

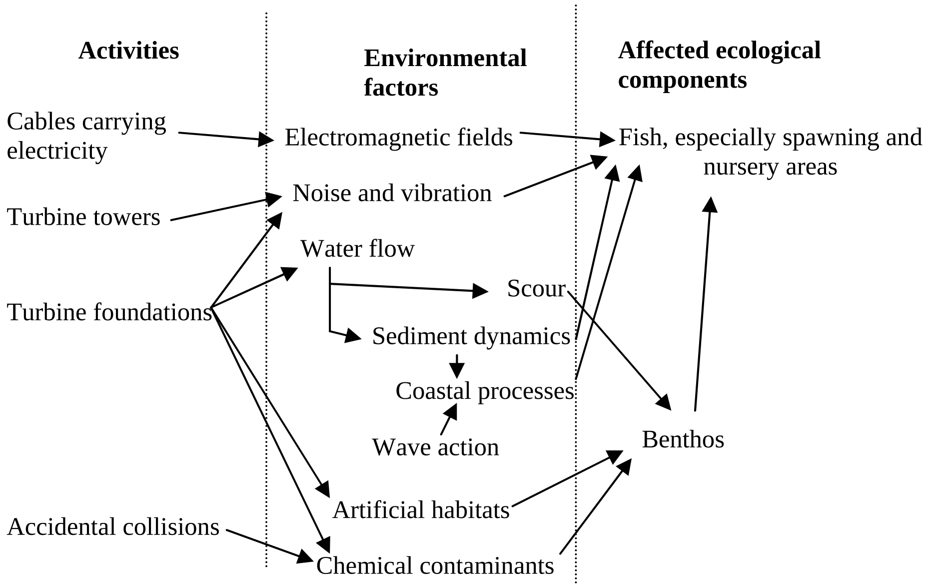


Figure 3. Environmental and ecological effects on fisheries of operational offshore windfarm (adapted from Elliott, 2002; Hiscock *et al.*, 2002; Parkinson, 2002)

The optimum size of stone to use in scour protection to attract shellfish has been researched by a number of investigators. (See Jensen and Collins, 1997, cited in Hiscock *et al.*, 2001; Halcrow Maritime, 2001, cited in Hiscock *et al.*, 2001)

3.2.5. Risk to navigation

Structures supporting turbines are a potential collision hazard that could threaten human life and result in adverse ecological impacts from the release of pollutants from vessels. Of the types of turbine foundation employed, the mono-pile can be approached most safely by vessels. Both tripod and gravity foundations present obstructions below the water line, and gravity foundations may induce considerable wave turbulence (Petts, 1999). Increased activity due to service vessels around installations will add an extra risk of collision. Garrad Hassan and partners *et al.* (2001) identify oil as the main polluting hazard, primarily diesel oil from ships, bunker oil from oil tankers and mineral oil used in isolating submarine cables. CMACS (2003) suggests, however, that lower voltage cabling will be used in order to avoid the need for oil insulation. Conversely, where shallow waters are selected for developments, that already represent a navigation hazard, carefully planned windfarms can increase maritime safety (Garrad Hassan and partners *et al.*, 2001).

Collision risk analyses are undertaken as part of the environmental impact assessment (EIA) process, but reliable risk models are difficult to develop due to the lack of experience in this type of collision scenario. The UK Marine and Coastguard Agency recommend that assessments are made of the consequences of ships having to deviate from normal routes due to windfarm structures (Maritime and Coastguard Agency, 2004). In Danish risk analyses of Middlegrunden and Rosand windfarms, a calculated risk of 1 collision every 10 years was accepted by the authorities as it was not higher than baseline conditions (Garrad Hassan and partners *et al.*, 2001). Where serious navigational hazards exist such as in the case of shipping lanes, or where ships may lay anchor before entering harbour, it would be unlikely that offshore windfarm developments would be permitted. Assessments should also be made of the potential for structures to cause radar or radio interference on frequencies used for positioning, navigation or communications (Maritime and Coastguard Agency, 2004).

To reduce the risk of accidents, location details of farms should be given to mariners and included on navigational charts. Collaboration between the oil and gas industry and the Sea Fish Industry Authority in the UK produces an information service that identifies all industrial infrastructure that could affect fishing. Such systems could be adapted to include information on offshore windfarm infrastructure (Petts, 1999) and were under consideration in the UK at the time of writing (British Wind Energy Association, 2004b). Structures need to be lit according to national and international guidelines (International Association of Lighthouse Authorities, 1998; 2000) and are equipped with radar reflectors/intensifiers and fog signal devices (Metoc Plc., 2000; Parkinson, 2002), although potential negative visual impacts and possible increasing risk of collision with birds could promote public resistance (Garrad Hassan and partners *et al.*, 2001). Monitoring by multi-channel VHF, radar, Automatic

Identification Systems (AIS) or closed circuit television may be appropriate depending on risk levels (Maritime and Coastguard Agency, 2004). Safety zones excluding different types of vessels and activities could be established around installations, and such zones could restrict fishing activity. Specific provisions for this type of exclusion have recently been legislated for in the UK's Energy Bill (2004), for example.

Fishing activity compatibility, restrictions and exclusion zones

The physical presence of offshore windfarms can directly affect fishing activity and may be incompatible with particular types of fishing techniques. The compatibility of fishing activity will vary depending on the types of fishing techniques and activities undertaken, the windfarm size and layout. Windfarms can be an individual or small number of stand alone turbines, turbines arranged in a line and turbines arranged as an array in lines and columns (Petts, 1999). The latter will cover relatively large areas and are therefore likely to have the most significant affect upon fishing activity. A turbine spacing of 10 x the rotor diameter is the rule of thumb suggested by technical literature (*ibid.*), giving a spacing between turbines of typically around 1 km.

Information is lacking on the implications of offshore windfarms on specific fishing activities and techniques. Petts (1999), however, provides the most detailed account to date.
Vessel anchoring and the use of bottom gear is likely to have most scope for conflict as power cables and gear present a mutual hazard in terms of damage to gear and cables, and in some cases the safety of fishing vessels. Cabling between turbines will normally use single-wire armouring that can withstand only small scale activity such as small boat anchors and marker buoy moorings (Centre for Marine and Coastal Studies, 2003). Double wire armouring, which is more resilient, may be used on cables between installations and the shore (ibid.). To mitigate this problem, cables could be buried in the seabed (Byrne Ó Cléirigh Ltd *et al.*, 2000) (see also section 0) and/or clear lanes could be specified with interconnecting cable positions

protected by rock dumping (Petts, 1999). Single vessel trawling may therefore be permissible in some circumstances where this is undertaken. Pair trawling may not be practical except on a very small scale, and scallop dredging may not be compatible at all (*ibid.*). Even where cables are buried, it could be possible for seabed movement to leave cables spanning submerged sandbanks with the potential to place a fishing vessel towing bottom gear in serious danger (British Wind Energy Association, 2004b).

Purse seining may be possible on a small scale, although turbine spacing may be overly restrictive. Long lining would be possible, although line length may need to be limited for the same reasons. Similarly, static netting, gill and drift nets may need to be limited in size and positioned to avoid entanglement with turbines (Petts, 1999; Parkinson, 2002). Potting should be largely undisturbed assuming the pots are not laid too close to turbines (Petts, 1999). For safety reasons and to prevent potential damage to landing stages, Petts (1999) suggests that a no landing rule could apply to prevent turbine landing stages from being used for amateur line fishing or the tying off of pots, as well as the emergence of techniques such as the deployment of gill nets between towers.

The practicality of undertaking specific fishing activities, as well as navigation and safety issues will influence decisions on whether fishing restrictions or exclusion zones will be applied to new developments, and if so the type and extent of restrictions. On safety grounds, the UK requires the establishment of 500 metre exclusion zones around offshore oil and gas platforms (Traves, 1994; Petts, 1999; British Wind Energy Association, 2004b). Although there is a lower risk of explosions and oil fires around windfarm installations, the UK Energy Act 2004 provides the legislative basis for establishing similar safety zones. These will be applied on a case-by-case basis and judged by the Secretary of State on safety grounds (Department of Trade and Industry, 2004, pers. comm.). Restrictions could also be considered for submarine cables going to shore. In the USA, AT&T and Pacific Telecom recommend that fishermen keep at least 1 mile away from their communication cables resulting in a two mile no-fishing zone (Byrne Ó Cléirigh Ltd *et al.*, 2000).

Clearly, there is a delicate balance to achieve between the need for safety and damage protection, and the permission of fishing activity. The current lack of knowledge on the compatibility of offshore windfarms and layouts with particular types of fishing techniques and activities, make determining the appropriate level of restrictions difficult, and research on this should be a priority. At the time of writing, in the UK, the Department for Trade and Industry were planning to commission a study on the feasibility and safety of different fishing techniques within developments (Department of Trade and Industry, 2004, pers. comm.). The Maritime and Coastguard Agency (2004) have considered assessment of navigational safety issues and the application of safety zones under the Energy Act 2004. The proposed guidance note recommends that a traffic survey for all vessel types, of at least four weeks duration and taking into account seasonal variations, should be undertaken as part of environmental impact assessments (EIA). Amongst the range of general recommendations, those having particular reference to fisheries include assessing:

- traffic usage by different types of vessels of the proposed development area relative to the wider area;
- the numbers, types and sizes of vessels using the development site;
- non-transit uses of the proposed development area such as fishing;
- the proximity of the proposed development to existing fishing grounds, or routes used by fishing vessels to those grounds;
- whether structural features of the development could pose any type of difficulty or danger to vessels performing their normal operations or anchoring.

In addition, an assessment of accessibility and navigation within or close to the site should be undertaken including:

- assessing all areas of the development site to determine whether navigation would be safe, or should be prohibited or recommended to be avoided for different vessel types, sizes and operations, directions of travel, and under the range of expected tidal, weather or other conditions;
- determining whether site exclusion could cause navigational, safety or routing problems for vessels operating in the area.

For the fishing industry, the impracticality of continuing particular fishing activity, and/or the effects of fishing restrictions or exclusion zones may impede access to grounds, affecting profitability by reducing catches directly or making it harder or more costly to achieve the same catch. Even where rights of navigation are allowed, fishing vessels may prefer to avoid navigating within and through windfarm installations (Department of Trade and Industry, 2002). Smaller less mobile vessels located close to such zones are likely to be disproportionately affected, as they are limited in their ability to fish elsewhere. In addition, the knock-on effect of restrictions could result in increased space competition in other accessible areas (See also Traves, 1994) which, depending upon circumstances, could also increase resource pressures.

A strategic environmental assessment (SEA) for offshore wind energy generation in the UK found a risk of significant impact to the viability of certain fisheries and indirect affects on families and communities, highly dependent upon fishing (BMT Cordah Limited, 2003). However, restrictions can offer benefits to fisheries in some circumstances, and the experience gained in the establishment of marine protected areas offers further insights into how restrictions could affect fisheries (see Box 1).

Box 1. Marine protected areas

The concept of marine protected areas (MPAs) has been applied principally to sedentary reef fisheries in the tropics. Proponents claim that they can result in increased diversity of fish species, and greater abundance of both larger and smaller fish of a given species. Fishing interests often fear that catches will substantially reduce due to exclusion.

The applicability of observed benefits in tropical areas to northern European temperate seas needs careful consideration. There are few examples of MPAs to manage fisheries, and those that do exist have been poorly monitored (Fisheries Society of the British Isles, 2001). Particular impacts will be case specific and depend upon the proportion of stock maintained within the boundaries of the MPA, the biological characteristics of fish, their spatial distribution, the level of fishing effort employed and the relative catchability of fish outside of the MPA, and the other fisheries management systems that exist (ibid.).

In general, many commercial species such as mackerel (*Scomber scombrus*), cod (*Gadus morhua*) and herring (*Clupea harengus*) are highly migratory and are unlikely to benefit from MPAs, unless they covered large expanses of their migratory ranges. On the other hand, more sedentary and sessile species such as lobsters, oysters and mussel populations could benefit from even small protected areas (ibid.; Hart *et al.*, 2004, this volume). In order to benefit a fishery, however, a build up of spawning biomass needs to occur within the MPA that results in spill-over effects beyond the MPA boundaries. This has yet to be demonstrated (ibid.), but in cases where it is, it opens up the prospect for more relaxed regulations outside of MPAs (Horwood *et al.*, 1998).

In the case of offshore windfarms, their size would imply that any exclusion zones would represent relatively small MPAs. It is unlikely that most sites would coincide with those most suited as MPAs from a fisheries management perspective, though that does not mean they could not have fisheries benefits. Although bottom trawling or dredging could be prevented for example, the elimination of seabed damage from these practices could offer opportunities for other types of fishing, enhancing shellfish stocks (Byrne Ó Cléirigh Ltd *et al.*, 2000; Hart *et al.*, 2004, this volume). Furthermore, artificial reefs created by turbine foundations could add further enhancement to fisheries (see 0) and may be viewed as a trade off for having fishing exclusions. What is clear is that, as in the case of MPAs in general, any potential benefits or disadvantages to fisheries from the imposition of exclusion zones around offshore windfarms need to be examined on a case-by-case basis.

Decommissioning

Operational offshore windfarms currently have a design life of around 20 years (Metoc Plc., 2000). Decommissioning entails the removal of turbines, blades, foundation and associated cables. Foundation and cable removal will result in disturbance to the seabed and the same types of ecological impacts as described in section 0. Mitigation of environmental impacts can be achieved through careful removal methods and seasonal timing to avoid the worst impacts to communities. In the UK, the Crown Estate require a comprehensive removal of foundation structures as is possible. However, where foundations support productive communities and potentially fisheries, then leaving foundations in place is more likely to be an environmentally friendly option and cost effective alternative (Hiscock *et al.*, 2002), although they could continue to pose a navigational hazard.

Fisheries considerations within the planning process

Among all marine based economic activity, fishing is likely to be affected most by the development of offshore windfarms. How fisheries and offshore windfarm interests are reconciled will depend on a range of issues including the determination of impacts from site location and those occurring at each stage of the development, the subsequent determination of fishing exclusion levels, and how fisheries and other stakeholder interests are addressed within the planning and consents process.

Two central procedures for dealing with these issues are the environmental impact assessment (EIA) and strategic environmental assessment (SEA) processes, which set requirements for identifying and assessing environmental consequences of developments and the involvement of the public in planning processes.

The strategic environmental assessment, SEA Directive 2001/42/EC (European Parliament and Council of the European Union, 2001a) applies to regional and national level planning. Adopted by the EU in 2001, member states were required to transpose the directive into national laws by July 2004. Offshore wind programmes are likely to be subject to the Directive's requirements. The UK has been early to implement SEA for offshore windfarm developments, and initially has focussed on assessing three strategic areas for developments.
At the project level, arrangements for obtaining consents for construction also require an EIA to be undertaken, which in the case of offshore developments will include consideration to fisheries concerns. These arrangements vary among EU countries, but generally speaking offshore wind energy developers need consents to authorise them to (British Wind Energy Association, 2000):

- construct an installation that may cause an obstruction to shipping or navigation;
- undertake an activity which will have an environmental impact;
- connect to the electricity network.

Given that the offshore wind energy industry is relatively new, the planning framework to enable its development is still under construction and unclear in many EU countries. With the intention of harmonising the consents process across the EU and streamlining it by removing non-technical barriers, the UK, Ireland, Sweden, Denmark and the Netherlands established the concerted action for offshore wind energy deployment (COD) group (Offshore Windenergy Europe, 2004). Such moves to support the industry are backed by a very positive political attitude to offshore wind energy in many EU countries (British Wind Energy Association, 2000; Garrad Hassan and partners *et al.*, 2001).

The Directive 85/337/EEC (Council of the European Communities, 1985) amended in Directive 97/11/EC (European Parliament and Council of the European Union, 1997) provides the minimum assessment requirements for undertaking an EIA in EU countries. Annex 2 of the Directive 97/11/EC specifically includes offshore windfarms, and this obliges member countries to screen such projects to determine whether they should be subject to an EIA. Member states may therefore exempt projects, but given the size of offshore wind energy projects and public interest, it is unlikely that consent will be given without an EIA requirement (Garrad Hassan and partners *et al.*, 2001). The EIA process requires that direct and indirect impacts of a project are identified, described and assessed covering the developments effects on:

- human beings, fauna and flora;
- soil, water, air, climate and the landscape;
- material assets and the cultural heritage;
- the interaction between the factors mentioned above.

(European Parliament and Council of the European Union, 1997)

Directive rules also provide an obligation for public consultation by requiring the results from an EIA to be made public, and for public views to be taken account of during the consenting procedure (Garrad Hassan and partners et al., 2001). Fisheries implications can therefore be covered both within the EIA process and represented by fisheries stakeholders during the consents process at public consultation meetings and in writing to the consenting authorities. The aim from a fisheries). perspective is to minimise the negative effects to the fishery resource and associated industry. Where it is not possible to reconcile conflicting interests by amending development arrangements or finding alternative solutions, then arrangements for compensation will be required (See Box 2).

Box 2. Compensation

Arrangements for any compensation are generally undertaken between individual fishermen, fishermen's representative organisations and developers. It is likely that forming agreement over appropriate levels of compensation for fishing grounds exclusion issues will be more achievable than for any claims associated with environmental impacts to fisheries, due to the uncertainty in defining and quantifying such impacts, and the trade off between negative and positive impacts from the development. In the case of fisheries compensation connected to the UK oil and gas industry, (Traves, 1994) indicates that fishermen may need to submit proof of earnings, registry certificates, and audited accounts or tax returns.

The whole concept of compensating fishermen for exclusion from fishing grounds, however, is a contested area. In the establishment of marine protected areas, the position statement of US-based Pacific Coast Federation of Fishermen's Associations states that compensation should be proportional to the reduction of the fishery (Grader and Spain, 1999). On the other hand, conservationists argue that if the fishing industry can claim compensation, when fishing activity is shown to be damaging ecosystems and fish stocks, the industry should compensate other stakeholders who depend or have responsibility for the marine ecosystem – divers, tourists, conservation groups, aboriginal groups and management agencies, for example. Furthermore, if a fisheries exclusion zone results in stock recovery and increased viability of the industry, they argue that the industry should be asked to pay for the upkeep of the reserve (O'Brien *et al.*, 2002).

Claims may also arise once the installation is in operation from the sacrificing or damaging of anchors or fishing gear on windfarm infrastructure. The UK Submarine Telegraph Act (1885) provides for the compensation of vessel owners where a cable owner is liable for damages/losses (British Wind Energy Association, 2004b). In cases of operator rejected claims connected to debris from the UK oil and gas industry, the United Kingdom Offshore Association Compensation Fund, financed by the industry and managed by the Scottish Fishermen's Federation (SFF) and National Federation of Fisherman's Organisations (NFFO) will consider claims (Traves, 1994). A similar system between offshore wind energy operators and fishing representatives could be appropriate in reconciling fishing related conflicts. At the time of writing, the British Wind Energy Association was working on guidelines to detail the claims process (British Wind Energy Association, 2004b).

Evaluating the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) processes

There are a number of criticisms on the ability of Environmental Impact Assessment (EIA) to adequately take account of fisheries issues in planning decision-making processes, both conceptually and in practice. When undertaken in isolation of SEA, in its application to individual development proposals, its main criticism is that it cannot effectively inform decisions on the location of a development; such decisions on the general area for a development have been taken already and are difficult to change at this stage of the planning process. This narrows the scope for considering alternatives and mitigation measures that could limit the ecological impacts on a fishery or socio-economic impacts on a fishing dependent community, for example. Furthermore, it cannot effectively consider the affects of cumulative impacts from more than one development, or in-combination impacts from the combined effect of different types of developments in a given area, both of which could have serious repercussions for fisheries.

These difficulties are magnified by the lack of provisions for early and effective public consultation in the EIA Directive (Barker and Wood, 2001), and the common practice by developers to carry out the minimum obligations and passively inform public stakeholders of proposed developments once the Environmental Statement (EIA report) has been produced (Sørensen *et al.*, 2002). Developers often perceive that public participation will be inefficient and worsen the situation, believing that outside concerns will be irreconcilable and will only result in widening the scope for conflict. In addition, fishermen themselves often find it difficult to engage in such processes due to abnormal working hours and self-perceived disadvantages when it comes to presenting their case in public debate (Piriz, 2001), and in general public stakeholders can experience consultation fatigue if the process is demanding on their time.

Nevertheless, early and sustained open dialogue with concerned stakeholders can be illuminating in a pedagogic way to all concerned, eliminating misinformation and maximising the scope for reconciling conflicting issues, resulting in outside stakeholder acceptance. Furthermore, in the case of fisheries, where formal data sources are usually limited or lack detail, especially in the small boat inshore sector, local fishermen usually offer the most detailed source of data available. BWEA (2004b) suggests that developers and fishing representatives should agree an approach to EIA preparation and the undertaking of site surveys, and where both parties are unable to agree on issues they should be prepared to accept a ruling from an independent body. Conversely, the lack of sustained trust building dialogue can be counterproductive to the developer and lead to frustrated parties resorting to direct action (Glasson, 1999) and/or legal challenge. This was starkly apparent, for example, in demonstrations by UK fishermen over a proposed offshore development in the Wash (BBC News, 2004).

SEA offers the possibility to alleviate some of the problems of relying on EIA to consider fisheries issues. In its application to government policies, plans and programmes at a regional or national level, it pre-empts individual development proposals and can therefore give greater consideration to alternatives, cumulative and in-combination impacts, and can determine which areas are appropriate for development and which are not (WWF and The Wildlife Trusts, 2004). Unfortunately, the early application of SEA to offshore windfarm developments in the UK has produced mixed results concerning its ability to address fisheries issues (see Box 3).

A common problem for both EIA and SEA for offshore windfarms, due to the infancy of the industry, is the lack of experience and scientific knowledge in predicting impacts. Many of the knowledge gaps have been highlighted earlier in this paper. The accumulation of monitoring studies of operational windfarms should improve this situation. In addition, further research studies are also needed. Probably the most important of these, as far as determining impacts to the fishing industry are concerned, is improved understanding of the compatibility of fishing techniques and activity with offshore windfarms.

Box 3. The practice of SEA and offshore windfarm developments: The UK case

The UK has been early to apply SEA to offshore windfarm developments. The first SEA focussed on three strategic areas including Liverpool Bay, the Greater Wash and Thames Estuary.

Cumulative impacts were recognised in the environmental report, both in terms of ecological impacts to the fisheries resource, but more significantly through possible fisheries restrictions that could affect the viability of certain fisheries and have indirect socio-economic impacts upon families and small communities highly dependent upon fisheries (BMT Cordah Limited, 2003). The report also recognised the lack of detailed baseline knowledge of the characteristics of inshore fisheries and distributions of targeted species (*ibid.*).

Unfortunately, except for the designation of an coastal strip prohibiting development, 8km extending to 13km in sensitive areas (Department of Trade and Industry, 2003), the SEA did not zone areas suitable or unsuitable for development based on a thorough spatial analysis of the strategic areas. Developers have been left to address such issues through EIA studies and public consultation processes. Accordingly, in each of the strategic areas developers have formed groups with objectives among others to facilitate collaborative working on cumulative impacts, including meeting and liaising with local fishing representatives (Department of Trade and Industry, 2004, pers. comm.). However, as already indicated impacts that could be avoided or reduced by careful consideration of location, are generally not well considered at the project planning level, where decisions on the general area for a development have already been undertaken. Moreover, by focussing on only three strategic areas, the SEA process may have geographically focussed the programme of planned windfarm developments, there by inadvertently increasing the risk of cumulative impacts occurring to fishing communities.

As already indicated, the Department of Trade and Industry in the UK are planning to commission a study on this (Department of Trade and Industry, 2004, pers. comm.), but given its importance, such research has been slow to come online. Studies on this, in addition to informing decisions on the levels of fishing restrictions that should be imposed, would feed into the design of installations so that mitigation measures could be applied to improve compatibility. Furthermore, such knowledge would be invaluable in predicting impacts including cumulative and in-combination impacts occurring due to the location of installations.

To be most effective in this respect however, more detailed knowledge is needed on the spatial distribution and intensity of fishing activity. This is a particular problem for inshore fleets, where official data is lacking and difficult to collect. Consequently, in some regions of the UK where it is possible, mapping of fishing activity is being undertaken using sighting records of patrol vessels (North Eastern Sea Fisheries Committee, 2004, pers. comm.). Where this is not possible, effective liaison with the industry should allow this information to be assembled. In addition, in areas potentially affected by installations or fishing restrictions placed around them, information on fishing activity should linked together with available data on the dependency of coastal communities upon fishing activity. With this information, it would be possible to identify the most important fishing areas in order to eliminate these from development and/or apply specific mitigation measures where the cost-benefit is favourable, such as, for example, selecting foundations that will act as artificial reefs to enhance fisheries, or burying cables in order to allow certain types of fishing to continue.

In order for this to happen, however, authorities need to ensure that this work is completed at the strategic planning level, and compel developers when appropriate to apply mitigation measures, which can entail significant additional costs to developments. In the drive for offshore energy, the danger is that this will not occur, reflecting a lack of suitable integrated strategic planning processes that van Ginkel and Steins (2001) suggest are needed to support local arbitration over multiuse conflicts in inshore waters, and ensure that offshore windfarm developments are as compatible as possible with pre-existing fisheries.

Conclusion

The drive to develop offshore windfarms by a number of EU countries including the UK will affect fisheries, primarily the inshore sector as the most suitable coastal sites are developed. This occurs at a time when inshore fisheries are already under increased pressure by developments in the offshore sector. Implications for fisheries occur in the form of ecological effects to fish populations, which can be both positive and negative, and through the direct effects of windfarm structures upon fishing activity and navigation. How these issues are reconciled will depend on the state of the art in assessing impacts and on how fisheries concerns are addressed and fisheries stakeholders represented in planning and consents processes, both at national and regional strategic levels, and as part of individual project proposals.

Further research into environmental and ecological impacts affecting fisheries is needed to improve the scientific basis of impact prediction. This includes better characterisation of both the air and underwater acoustic environment and of how windfarms produce of electromagnetic fields. In addition, associated ecological level studies on acoustic impacts to fish and shellfish and electromagnetic impacts to electroreceptive species are necessary. Further knowledge is also needed on the extent of fisheries impacts from large windfarm developments due to changes in current, wave and sediment conditions. Probably of most importance to the fishing industry, however, is the need for studies on the potential effects of different windfarm layouts and structures on a range of fishing techniques and equipment. This would allow guidelines to be designed on restricting fishing activity for safety reasons, and enable fishing industry impacts to be predicted due to restrictions on fishing activity.

Strategic assessment of windfarm policy should be ideally undertaken, first at national levels, with the aim of identifying areas most important for fisheries and other existing economic interests. This would select areas for more detailed assessment, based on technical and economic viability, but also eliminate areas where clear significant conflicts of interest exist. Focusing down on these areas, fishing intensity should then be assessed to show the differentiation in activity at a regional level by using available data sources, and by liaising with the fishing industry. This assessment should also be linked to available data on the dependence of coastal communities on fisheries. Through this, and with knowledge on how fishing activity would be restricted, it will be possible to assess the implications to local areas of individual windfarms, as well as the cumulative and in-combination affects they would have on communities. Consequently, the most appropriate sites can be selected and mitigation measures applied in order to minimise conflicts of interest.

At the project planning level, conflict can be minimised between developers and fishing interests, if affected fishing groups are involved in the pre-development decision making processes in order to avoid misinformation, build trust and maximise the scope for reconciling conflicting issues amicably. This can be supported by objective, clearly defined and agreed procedures for dealing with compensation issues.

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