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White Paper

WRITTEN BY

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The Environmental Implications of Offshore Wind Generation

Companies that are searching for "environmentally friendly" sources of energy should realize that the methods of extracting such energy are not without their own impacts on the surrounding environment. Two areas in which offshore wind farms may impact the environment are the noise effect on marine wildlife and the "artificial reef effect."

Introduction

The impact of climate change through global warming has been a concern for some time now. As a result of this concern, the United Nations Convention on Climate Change was developed at the Rio Convention on Climate Change and biodiversity in 1992. Following the Rio Convention, targets were set for ratifying countries to reduce their CO_2 emissions, as defined by the Kyoto Protocol (1997).

In order for countries to achieve this reduction in CO_2 emissions, there must be a move to the production of electricity from renewable sources other than fossil fuel combustion. Of these sources, perhaps the most realistic and economic is wind power. With this in mind, the United Kingdom has one of the largest offshore wind resources in Europe. The use of this "renewable" resource to generate electricity, through the development of offshore windfarms, is recognized as a key element in meeting the United Kingdom's commitment to reducing greenhouse gases, and is supported by a number of global conservation organizations, including Greenpeace, the World Wide Fund for Nature and Friends of the Earth. However, a number of areas of environmental concern remain in the development and utilization of this technology.

Some of these concerns, such as the possibility of birds striking the rotating blades of offshore wind turbines, have already been addressed extensively, while others have not. This paper draws upon research from a number of sources to consider the possible impacts of the noise and vibration generated by wind farms on the marine habitat: organisms ranging from whales to lobsters. In addition to this, we consider the possible, positive impact of wind turbines to act as an artificial habitat (the "reef effect") and so increase the diversity of species and biological productivity of windfarm locations.

Other than the issue of "bird strikes," the noise and vibration generated by constructing and decommissioning, and possibly through the operation, of offshore wind turbines, is likely to be one of the issues concerning the environmental impacts of offshore wind on marine wildlife. This issue is particularly important, as many marine organisms are known to use sound in a range of applications, from communication to sensing their surroundings. Thus, interference with the sounds marine organisms produce could disrupt their communication abilities, or the ability of an individual animal to sense its surrounding environment. Furthermore, there is the potential for noise and vibration generated by windfarms to have more adverse impacts, such as damaging the noise-sensing organs of marine life.

This paper will consider the existing noise sources present in the sea, the likely noise and vibration generated by offshore wind farms, the sensitivity of marine organisms to sound and finally, the possible impact of noise and vibration from offshore wind farms on the denizens of the sea.

Existing Sources of Noise and Vibrations in the Marine Environment

Physical (or natural) noise and vibration in the ocean can come from many different sources. These include geological disturbances, wave interactions, breaking waves and spray, wind, rain and hail. The range of frequencies associated with these natural processes can often be very broad. For example, noise produced by wind and rain can range from 1Hz to 25 kilohertz (kHz) with source levels of up to 100 decibels (dB). Conversely, some processes can produce narrow ranges of high-energy noise and vibration, such as earthquake events where frequencies are commonly between five and 15Hz with source levels as powerful as 240dB. Thus, the sea can be a very noisy environment even without human intervention.

The sound pressure levels given in Figure 1 are peak sound intensities in the sound frequency spectrum produced by several anthropogenic noise sources. As we can see, the sound produced by the Svante Offshore Wind Farm is relatively quiet when compared to some sources of noise in the marine environment.

Noise and vibration from human activities (anthropogenic sources) are generally of mid- to low frequency (between 10 and 1000Hz) and include: shipping and transportation, dredging, construction, hydrocarbon and mineral extraction, geophysical survey, sonar, explosions and ocean science studies, but could also have very high source levels, as described in Figure 1. For example, noise associated with geophysical and seismic surveying regularly produces sound levels above 200dB and low-frequency sonar may produce sound intensities that far exceed 200dB. These sounds are categorized as "transient" if their duration is brief, such as explosions of the pulse of a seismic airgun; or "continuous" if they persist for long periods, such as the noise generated by an oil-drilling platform or the anticipated sound of an operating offshore wind farm.

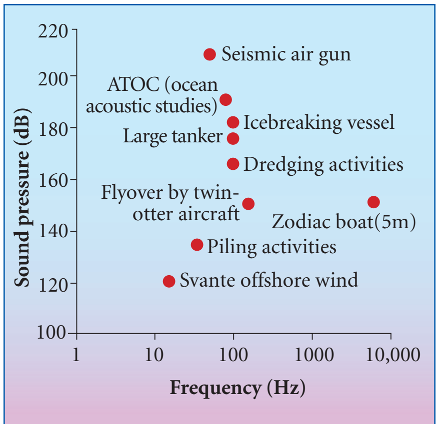

Figure 1 *A comparison of selected underwater anthropogenic noise sources (peak intensities taken from Richardson et al., 1995 and Westerberg, 1999)*

The Anticipating Noise Produced by an Operation Offshore Wind Farm

The probable noise produced above the water by operating offshore wind farms is expected to be broadly similar to that produced by onshore turbines and is of little environmental concern. However, there have been very few studies conducted to characterize the underwater noise environment generated by offshore wind turbines, although some data does exist. Measurements of the underwater acoustic environment of the Svante Offshore Wind farm (a single 220kW turbine, 35m tall on a tripod foundation) were taken in 1994 at a range of distances, depths and wind speeds. Beyond frequencies of 100Hz, sound levels were below ambient sea levels of around 80dB at 100m from the turbine (Westerberg 2001, pers. comm.). Below frequencies of 100Hz, the noise ranged from approximately 80 to 100dB in intensity with a peak of 103dB at 16Hz (Westerberg 1994, 1999).

While more modern turbines are expected to be much larger than the Svante turbine and may therefore be more noisy, the intensity of underwater noise produced by the Svante turbine is much lower than many other anthropogenic sources, as shown in Figure 1.

Sensitivity of Marine Organisms to Noise and Vibration

Figure 2 describes the known sensitivity of several marine species to noise and vibration. These sensitivity curves, termed "behavioral audiograms," are developed by subjecting an individual to noises of known frequencies and sensitivities. The behavioral reactions to specific noises are noted.

Many species cannot hear the very low-frequency noise produced by the Svante turbine. For example, the sensitivity of the bottlenose dolphin only extends to approximately 100Hz at the low-frequency end of the spectrum. For a bottlenose to hear the Svante turbine, the turbine would have to produce sounds at 100Hz in an intensity range greater than 130dB. Conversely, the sensitivity of the cod does overlap the sound frequencies and intensities produced by the Svante Turbine. Thus, we would expect the cod to be able to hear the turbine noise and possibly display some sort of behavioral reaction such as attraction of repulsion.

Behavioral audiograms have not yet been developed for the larger, mysticete whales such as the blue and grey whales. This is because the sensitivity of these animals has not yet been determined under scientific conditions. However, because they use very low-frequency noises for communication, it is very likely that they will be sensitive to the noise generated by offshore wind farms.

Audible sensitivity in the majority of invertebrate species, such as the squid and lobster, has also not been determined. This is because they do not hear in the conventional manner. The majority of invertebrate species do not possess organs developed to detect sound waves. However, many do possess structures and organs sensitive to pressure. Therefore, some invertebrate species may be able to detect the pressure component of a sound wave when they are very close to the source of the sounds (within meters).

Finally, it must be noted that modern offshore wind farms may be far louder in noise frequency and intensity than the Svante offshore wind farm.

Possible Reactions of Marine Species to Noise and Vibration Generated by an Offshore Wind Farm

The possible impacts of noise and vibration on marine organisms are considered for the following four marine wildlife groups: squid and lobster, fish, seals, and whales and dolphins.

Squid and Lobster

Evidence of noise- and vibration-related effects on invertebrates largely consider the effects of seismic investigations. Here, very high sound levels are produced which affect invertebrates in a very localized area (suggested to be within several meters of a very loud sound source) (Vella et al., 2001).

Apart from such seismic surveys, no adverse impacts are expected. Indeed, studies at the Horns Rev offshore wind farm in Denmark show colonization of turbine foundations by many marine species within five months of construction (Leonhard, 2000).

The likely effect of wind farm construction would therefore be locally increased numbers of hard-substrate colonizing species. At present, no use of anti-fouling substances has been proposed and thus, the extent of colonization will depend upon the number and size of turbine foundations and any additional habitat provided by foundation protection.

Fish

Intermittent noise associated with activities during the construction of wind farms (vessel movements, seismic survey, piling etc.) is well within the range of the behavioral audiograms of fish (Figure 1 and Figure 2). This is supported by observations of their reactions, which have commonly demonstrated changes in behavior, such as alarm and startle responses (Vella et al., 2001). Such responses may be of particular significance if a wind farm is in close proximity to spawning or nursery ground areas, and particularly if construction is prolonged.

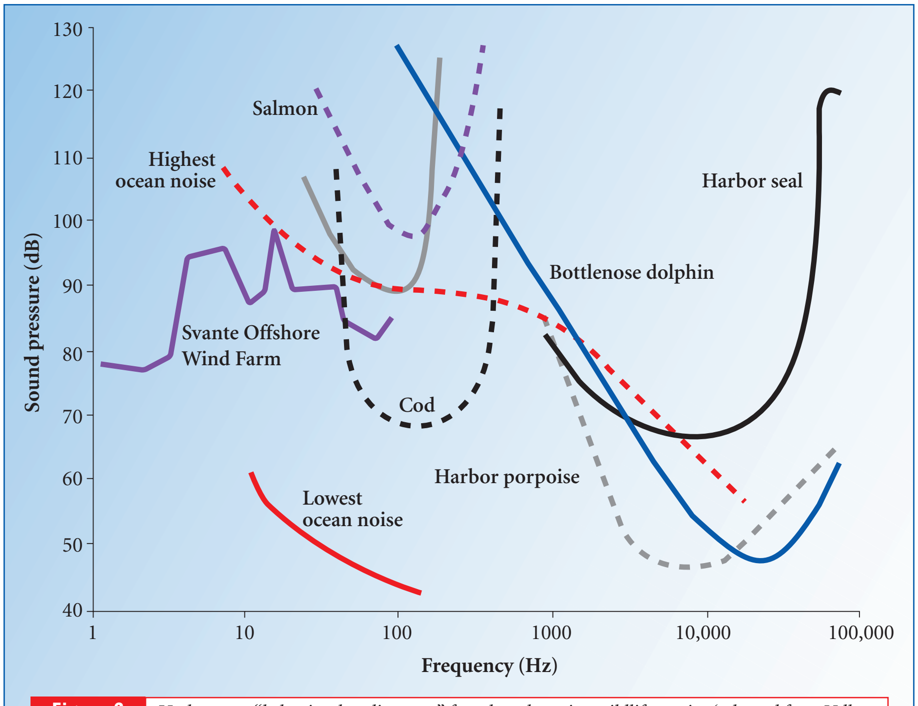

Figure 2 *Underwater "behavioral audiograms" for selected marine wildlife species (adapted from Vella et al., 2001).*

Of the fish species included in Figure 2, only the audiogram of cod falls within the noise range of the Svante turbine, suggesting that some sort of behavioral response would be expected. Investigations at the Svante wind farm have shown that the number of cod in the local area of the operating turbine are greater than in the surrounding area (Westerberg, 1999). This presumably reflects the ability of animals to habituate to a continuous noise stimulus. Similar effects have been observed around other "noisy" structures such as oil platforms (Valdemarsen, 1979).

Intermittent, loud noise may therefore have an adverse effect on local fish populations, causing alarm responses and probable movement of fish away from construction areas. This could be significant if construction affected spawning or nursery areas. But when wind farms are operating normally, fish appear to readily habituate and utilize wind farm sites at higher than normal densities, taking advantage of the shelter provided and probably also the additional food resources provided by colonizing animals (Vella et al., 2001). Furthermore, a study of the effects of operational noise on migrating fish (Westerberg, 1999) did not show a significant effect of the Svante wind farm on migrating eel direction.

Seals

In general, seals show avoidance reaction to anthropogenic noise and activity when it is close, and is probably perceived to be a threat. However, this is most probably a response to visual cues rather than noise. In general, both harbor and grey seals (both found on U.K. coasts) seem to habituate to most anthropogenic sounds and activities.

While on land, the most common reaction to construction noise and activity will be alarm behavior. If disturbance is sufficient, seals will leave and re-enter the water. In general though, this behavior is triggered by very close human approach (tens to hundreds of meters, depending on frequency of exposure to human activity).

Studies have shown that the most common reaction to construction activities when seals are already in the water is avoidance, but again, this may be a reaction to visual cues rather than any noise produced by the construction. This avoidance behavior may result in seals being excluded from feeding grounds or areas of importance. However, it is likely that this exclusion will only be during the short construction period. Furthermore, there is some evidence to suggest that seals will quickly habituate to construction activity and noise, as was observed during construction and production at the Näsrevet Wind farm in Sweden (Westerberg, 1999).

The ability of seals to detect low-frequency sound (<1000Hz) has not been clearly demonstrated. It is therefore unlikely that seals will be able to hear the underwater noise produced by turbines. It should also be noted that seal audiograms have only been developed for a few individuals, and so may vary considerably. Also, seals are inquisitive in nature, and it is likely that they will investigate local wind farms and may use these areas as feeding grounds, particularly if fish population densities are higher around offshore wind turbines.

Whales and Dolphins

The cetacean species most likely to be affected by wind farm construction and operation around the United Kingdom are the dolphins and porpoises. Other whale species are much less likely to be affected, due to their absence in large numbers, although some species are regularly observed in inshore waters, including the minke whales found off the Northumberland Coast.

As we have discussed earlier, the noise generated during constructional activities at sea is generally of low frequency (mostly under 1000Hz) and where very high sound levels are produced (such as during seismic surveys), noise production is intermittent.

Dolphins do not appear to be sensitive to low-frequency sound (Figure 2) and often approach vessels. The reaction of individuals to noise may, however, vary with their activity and motivational state. For example, when socializing, dolphins may approach vessels but avoid them during feeding (Richardson et al., 1995).

When exposed to sudden loud noises, dolphins are therefore likely to show responses ranging from subtle changes in behavior to avoidance reactions.

Although the sensitivity of mysticete whales has not been measured, they are thought to be sensitive to low-frequency noise over considerable distances. They will almost certainly, therefore, be sensitive to constructional noise and will most probably show avoidance reaction or give construction sites a wide berth. As with odontocetes, however, responses may be mixed and males in search of mates, for example, may ignore or tolerate noise that females with young may avoid.

The noise and vibration of an operating wind farm is only expected to exceed ambient levels at very low frequencies, possibly under 100Hz. As described above, there is little evidence that animals such as the bottlenose dolphin and harbor porpoise can perceive sounds at these frequencies. After familiarization with wind farms and habituation to any noise which is perceived, they are unlikely to be adversely affected and indeed may exploit wind farm sites as feeding grounds.

It has been suggested that behavioral audiograms for mysticete whales such as the minke may be centered in the vicinity of 100-200Hz (Potter and Delroy, 1998). If this assumption is correct – and it is likely that it is – then there is a possibility that communication or other behavior could be affected in these majestic creatures.

The environmental implications of offshore wind are not all negative. One positive aspect currently under debate is the issue of new habitat creation and the artificial reef affect.

New Habitat Creation

Fish tend to aggregate around objects placed in the sea. This phenomenon has been widely used in the development of Fish Aggregating Devices. However, the attraction of fish to objects is poorly understood. It is postulated that fish are attracted to submerged objects as they provide shelter from currents and wave action and safety from predators.

Oil and drilling platforms in the North Sea have also been shown to provide a hard, stable substrata for colonization by a diverse range of marine organisms including seaweeds, mussels, barnacles, tubeworms, hydroids, sponges, soft corals and other invertebrates. These organisms, which require a hard surface upon which to attach, attract various free-living invertebrates and small fish. These in turn attract larger organisms, thereby increasing species diversity, biomass and general productivity. This may be particularly so if hard-substrate structures, such as offshore wind farms, are placed in sandy environments.

Conclusions

On the basis of the available data, it is likely that seals and dolphins and porpoises will show initial avoidance to wind farms, followed by habituation and possibly attraction to these sites as feeding grounds. The reaction of the blue, grey and minke whales is unknown in the absence of data regarding their audible sensitivity. However, it is possible that they will show a behavioral response to the low-frequency sound that wind farms are likely to produce. The significance of this response will depend upon the proximity of wind farms to areas of importance for whales and migratory routes.

From the information available for operating offshore wind farms and other "noisy" offshore structures such as oil and gas platforms, it is expected that effects on fish population dynamics will be determined by immigration/attraction of fish to wind farms following construction. No adverse impacts on marine invertebrates are expected by the noise and vibration generated by turbines.

However, the full effects of offshore wind farms on marine wildlife, particularly mammals, fish and migratory fish behavior and ecology can only be usefully determined through monitoring. Additional studies into the effects of offshore wind farms on marine species are desperately required. To some extent, this data may soon be available with the monitoring programs planned for various Scandinavian wind farms. These include such programs as satellite tracking of seals and whales and dolphins in the proximity of the Horns Rev Windfarm in Denmark. Data from this program would identify whether or not marine mammals avoid wind farms or whether they use them as a feeding ground.

Offshore wind is a good idea. Certainly, when considering the bigger picture – the reduction of greenhouse gas emissions and subsequent reduction in global warming – it is difficult to find any argument to impeded the progression of this novel technology. However, we must take care not to overlook the smaller picture – the possible impacts on the local environment and the organisms that live there.

The Centre for Marine and Coastal Studies, University of Liverpool, intends to maintain its position at the forefront of this new field in the utilities industry, both in continuing its research into the environmental implications of offshore wind and in providing services such as Environmental Impact Assessments. ■

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