Bridging the gap between biology (a rock) and physics (a hard place) for tidal energy research

T.H.E. Smith[1], B.E. Scott[1]

[1] School of Biological Science, University of Aberdeen. AB24 2TZ

Abstract

Marine turbine design and location may both influence the efficiency of the device and alter the potential for interaction with animals. The Isle of May is taken as a study site to investigate the utilisation of the water structure by the local marine community over the tidal cycle. Time dependant current profiles are quantitatively described (using ongoing data collection from an ADCP). Animal distribution and usage is explained using historic telemetry data and observation concurrent with oceanographic sampling.

Feeding hotspots are seen to occur in areas with particular oceanographic properties suggesting that foraging animals actively seek out certain environmental parameters. At the same time, it is thought that most marine animals use the dynamic nature of the water profile to enhance their foraging. In this way the distribution of actively foraging animals within the water column can be compared to the oceanographic properties and current regime to suggest optimal feeding conditions for the different species.

This information acts to highlight areas that would be unsuitable as sites for marine turbine location due to the increased risk of encounter with foraging animals. The 3-dimentional water column study is also used to advice device design in order to minimise the material and mechanical wear from oceanographic forcing.

Keywords: tidal energy, marine ecology, oceanography

Nomenclature

ADCP = acoustic doppler current profiler
CTD = conductivity, temperature and depth

1 Introduction

Interactions between tidal energy turbines and the marine environment need to be understood within the context of the interactions of the marine community with the environment as well as the environmental variables themselves. The Isle of May (East coast of Scotland) is taken as a study site to investigate these parameters and illustrate the importance of using temporal and spatial scales of oceanographic data that are relevant to the device, deployment area and local marine community.

The predictability of the tidal streams makes them highly viable for commercial exploitation [1] however present tidal data is based on surface measurements and assumes a constant subsurface velocity [2]. The spatial and temporal variations in tidal currents are derived from harmonics associated with the separate ocean basins and the different interference caused by local geography. This variation and vertical heterogeneity will produce varying forces on the turbine creating a dynamic shear strain on the individual blades that could significantly reduce the life time of the device through mechanical and material fatigue [3]. The risk of unpredictable cyclic loading is a major design challenge for all turbine developers [4] and will be exacerbated by any fluctuating environmental forces.

Environmental variability (e.g. topography, meteorological forcing, tidal variation, water density etc) produces water current characteristics that vary on a number of different spatial and temporal scales. For example, turbulent flows around islands can act to aggregate prey (such as within tidal convergences) but, in some areas, it can also increase the energetic cost of foraging (e.g. for deep diving birds). This causes spatial heterogeneity of animal distribution [5] around oceanographic features due to disparate use of the water profile between species.

Utilisation of the water profile is dependant on the opportunity for usage, which is related to species physiology, life history and distribution. The natural variability of the marine environment has caused the marine community to develop ways to quickly respond to resource fluctuations [6]. These varying interactions with oceanographic processes will alter the probability of turbine-animal encounter and thus affect the risk of collision.

A number of environmental parameters are known to influence the behaviour and distribution of seabirds including water depth, stratification, weather, tidal phase, prey type and distribution etc. Life history will also affect seabird population ecology, where different foraging behaviours are seen in different species at different life stages [7] due to different prey types (or age classes) being utilised by different life stages. [8] highlighted the feeding methods used by different seabird species due to their different ecological roles (body and clutch size, reproductive strategy etc.) that alter their interactions with the marine environment.

This project aims to describe the probable distribution of foraging animals around the Isle of May. This will be used to identify areas for future tidal turbine placement where the disruption to foraging animals is minimized. CFD techniques will be used so that the oceanographic information gained from this study is used to develop the most efficient turbine design for the conditions. The work carried out will be used to further develop environmental impact assessments for tidal energy turbine.

2 Method and site survey

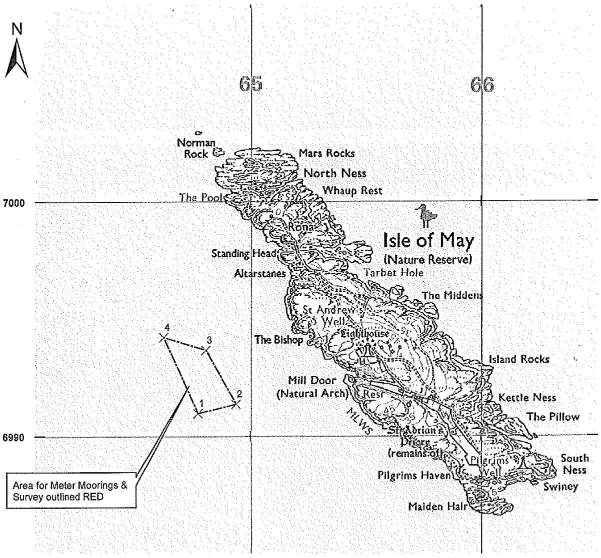

Figure 1: Admiralty chart of the Isle of May showing the study site area

The proposed tidal turbine support structure (the sea snail) is described in [9]. This will be developed by Alan Owen (Robert Gordon University) in parallel with the collection of site specific environmental data.

An initial visit to the Isle of May established the position of breeding seal colonies, bird colony sites (Therese Alampo, pers. comm.), battery hut position and observation areas and suggested that the West side of the island would be the most appropriate area for deployment. An ROV study to the West of the island found only sparse benthic fauna, the seabed type dominated by gravel and a depth range of 24-30m. In this way the West side of the island was considered a good area for eventual turbine location and a 'study area' was produced (figure 1).

The positions of foraging animals (most notably seabirds and seals) are noted by an observer positioned on the west of the island. In order to quantify the water column structure to an appropriate spatial scale, an oceanographic mooring was placed within the study site. The mooring includes an acoustic doppler current profiler (ADCP), CTD, CPOD (cetaceans acoustic listening device), fluorimeters and temperature loggers. The data downloaded from these loggers produce a 3-dimenstional picture of the water column over the tidal cycle.

3 Biology (the rocks)

Guillemots (*Uria aalge*)

Guillemot foraging locations and diving behaviour were analysed with comparable oceanographic data and will be discussed during the presentation. It was found that guillemots have an ability to change their behaviour in order to adapt to the variability of oceanographic properties. It also suggests that guillemots are actively seeking out foraging 'hotspots' [18] that have particular depth, turbidity, salinity and density characteristics and are avoiding extreme oceanographic conditions. This has large implications for tidal turbine deployment as turbines would need to be located in areas devoid of the favourable foraging parameters in order to reduce the encounter rate (thus reducing the opportunity for collision).

Grey seals (*Halichoerus grypus*)

Foraging patterns of grey seals (*H. grypus*) are seen to be broadly focused within certain locations (such as the Wee Bankie) but a large amount of individual behaviour is seen [10] which could be due to a number of different parameters including weight, sex, age and health. There is still considerable debate about exactly why seals choose to haul out and the amount of foraging that occurs close to haul-out sites. Problems of spatial scale arise due to the inaccuracy of Argos tags and the wide ranging foraging sites utilised by *H. grypus.* A large amount of individuality is seen in the more recent (and more accurate) tagging data developed by SMRU (McConnell pers comm.) which further illustrates the variable nature of animal behaviour at the mesoscale and microscale level.

4 Physics (the hard place)

In order to produce a quantitative description of the current profile to a scale that is useful for the turbine design we must look at a number of levels. The microscale movements of the water column will be important in the discussion of cavitation risk and small scale design issues whilst mesoscale current profiles will more fully describe the currents with respect to tidal variability, geomorphology and changes in weather. However, larger scale forcings (e.g. winds) will also cause variation in the currents over larger time and spatial scales.

The ‘physics’ of the marine environment is highly variable on a number of spatial and temporal scales. [11] highlighted the hierarchical nature of the varying heterogeneity in the marine environment and stated the importance of physical parameters in forming biological ‘hotspots’. The air-sea interface acts as a physical barrier, where diving birds can only dive so deep and marine animals can only jump out so high. This causes a concentration of foraging animals in the surface layers [11]. However, surface level foraging will be strongly influenced by weather (due to the heightened disturbance at the interface). This will not only affect each individual organism, but will have indirect effects through the trophic levels [12].

Data

The ongoing collection of ADCP data will be used to quantify the physical variables within the scale of the study site, over the temporal scale of the tidal regime. A 4-dimensional map of local water movement will be developed and the presence and structure of local turbulence and wave effects will be assessed.

Historic data from moorings, cruises and model data will be assessed for their relevance to telemetry data. In this way oceanographic data of the appropriate temporal and spatial scale will be used to analyse animal-oceanography interaction for each telemetry dataset.

5 Collision risk

The risk of collision is an important consideration with respect to deploying turbines in the marine environment. However, avoidance methods employed by each species should be considered in the context of the observability of the turbine and the energetics of the avoiding animal [13]. In this way it is important to differentiate between the probability of encounters and the probability of collisions. The disparity between encounters and collisions will vary due to the approach angle of the animal (influenced by topography and water/tidal movement), evasion capabilities and perception (such as the differential use of acoustics, [14]) as well as the design of the turbine and the speed of the blades.

Visibility of the turbine will be important to different degrees for different species. [15] showed that fish species tend to avoid vibrating objects, however different turbines could either vibrate too little (so that evasion is not carried out early enough) or too much (resulting in habitat loss). The particular species at risk would vary through the season and with diel migrations. By placing the device slightly above the seabed (but not on the seabed) the risk to demersal fish would be greatly reduced and pelagic fish would only be at risk during diel migration). Very small (and larval) fish would have a relatively low collision risk due the high inertia they experience in the viscous flow regime which would cause them to follow the streamlines around the moving parts of the turbine. In this way it is suggested that species with a larger mass (or schooling species that would act as a super-organism) would be more at risk. In addition, if the surface of the turbine attracted fouling organisms or acted as an attractive refuge, it could actively increase the occurrence of inquisitive (or predatory) species and thus increase the collision risk [13].

6 Tidal energy: Between a rock and a hard place

The comparative analysis between the biological data and oceanographic data will be discussed during the presentation along with the implications for device placement.

The data gained from the oceanographic mooring describe the spatial and temporal variability of the environmental parameters within the study area. They call attention to areas with potential implications for mechanical and material wear (and thus the life span of the turbine) as well as providing a knowledge base that will inform decisions on device design. Design is particularly important as it changes the profile of the structure within the water column. This will affect the varying magnitude of the oceanographic forces acting on the turbine. Design will also alter the efficiency of the turbine in the local environment and potentially change its feedback on the water column structure. This would have implications for indirect interactions between the turbine and marine animals.

In a similar way, the position of the device within the water column will alter turbine efficiency, the feedback to local ocean energetics and potential animal encounters. [16] found that shallow tip emersion caused a significant reduction in the thrust produced which is due to the lower pressure higher in the water column increasing the risk of cavitation [17]. This suggests a requirement for turbines to be placed relatively deep, which would decrease the likelihood of an encounter with surface foraging birds, but the deeper the turbine is placed, the larger the pressure forces acting on it. Deep diving birds, such as guillemots, could still potentially encounter a turbine located to depths up to their maximum diving range (thought to be 180m).

Analysis of guillemot telemetry data strongly suggests that guillemots are actively seeking out foraging ‘hotspots’ as suggested in [18]. By locating tidal energy turbines in areas devoid of favourable foraging properties, the encounter rate (and the opportunity for collision) would be reduced. However, there is the possibility that the action of the turbine could induce local energetics that simulate these favourable water properties and thus encourage guillemot foraging. This possibility needs to be taken into consideration (as it could increase the opportunity for collision) and future experiments are planned to quantify the effect of turbines on flow profile.

7 Conclusions

Environmental impact assessments of tidal energy turbines need to be carried out in a way that incorporates the dynamic nature of the local area. Further study is still required to fully appreciate both the direct and indirect implications of tidal energy turbine deployment on the marine community. Ecological implications to the placement of turbines will include; the risk of collision, the energetic cost of avoidance, the change in the predation risk, refuge alteration and changing foraging habitats. The present project hopes to develop ways to include environmental assessment in the initial stages of turbine development. This should increase our understanding of water profile use by foraging marine animals and the environmental implications of turbine presence.

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