ICES CM 2011/S:11

Assessment of collision risk for seals and tidal stream turbines

Ian M Davies[1] and Fiona Thompson[2]

[1]Marine Scotland Science, Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9DB, UK
[2]Marine Scotland Licensing Operations Team, Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9DB, UK

The development of marine renewable energy, including wave and tidal stream power, is a high priority for the Scottish Government. The environmental aspects of the licensing process has been brought together under a single Government body, Marine Scotland. Licensing requires that consideration is given to the requirements of the EU Habitats Directive, and this commonly leads to the need for an Appropriate Assessment of the potential risk to populations of protected species (notably grey and common seals) from collision with rotating turbines. An approach is described which combines a model of the foraging behaviour of seals with the probability of seals being damaged by passing through the volume of water swept by a turbine. The acceptability of the estimated potential mortality is assessed against an estimated Potential Biological Removal (PBR) for the relevant populations. The scope for improvements in all aspects of the models is discussed as a guide to research and developmental needs.

Key words: Tidal energy, seals, collision risk, Appropriate Assessment

Contact author: Dr Ian M Davies, Marine Scotland Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9DB, UK. Email : Ian.Davies@scotland.gsi.gov.uk

Assessment of collision risk for seals and tidal stream turbines

Ian M Davies and Fiona Thompson
Marine Scotland

Introduction

The Marine (Scotland) Act 2010 introduced a unified consenting process for development projects in the sae, based around the requirement for developers to obtain a Marine Licence for their proposed activities from the regulator – Marine Scotland. Marine renewables projects are not exempt from this process, and the Marine Licence process brings together the requirements under several items of legislation, which previously had been administered by separate, duplicative, and potentially inconsistent processes.

One of the main elements in the licensing process for renewable energy projects id the need to consider requirements arising under the EU Habitats (Council Directive 92/43/EEC) and Birds Directives (Directive 2009/143/EC) and their parallels in UK and Scottish law. In particular, Appropriate Assessments of the potential impacts on protected habitats and species are required, if it is considered that the significant effects are likely.

There are a wide range of potential impact mechanisms linking renewables developments and protected species. In the case of tidal stream turbines, particular consideration is given to the potential for collision between rotating underwater turbine blades and wildlife, such as seals and seabirds. Scotland holds populations of European importance of grey and harbour seals, and of a range of seabird species (such as guillemot, razorbill, shag, etc), and a number of Special Areas of Conservation (SACs) and Special Protected Areas (SPAs) have been designated for these species.

Many of these species have the potential to dive into the depth zone occupied by the turbines, and therefore be at risk of damaging collision with the moving parts of the turbines . Appropriate Assessment in this case must consider the likely scale of this interaction and the potential consequences for the protected populations. This paper is primarily concerned with estimating collision risk to grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) arising from horizontal axis tidal turbines. The method may also be applied to diving seabirds, where the characteristics of underwater behaviour are sufficiently well known.

Collision modelling

The need to take account of the potential for collision between tidal turbine blades and wildlife is a necessary, but relatively new, element of licensing marine renewable developments. However, concern regarding collisions between rotating turbine blades and wildlife is a key aspect of risk assessments for wind farms. There is clear potential for birds in flight to be struck by the rotating blades, and the consenting process for both terrestrial and offshore wind farms includes prediction of the number of collisions, and assessment of the consequences of these collisions.

In aquatic systems, some modelling approaches and been established, and observational data collected, relating to collision of fish with high speed turbines in hydro-electricity generating plant. However, there may be some more useful similarities between the processes leading to collision of birds with the relatively slowly rotating windfarm turbines, and those leading collision between diving marine wildlife such as seals, and tidal turbines.

The classical modelling approach employed in environmental assessment of wind farms (the Band model) was developed by Band (2000, 2007). The approach consists of three elements:

1) A description of the numbers and behaviour of birds in the vicinity of the wind farm
2) Calculation of the probability that a bird entering the swept area of a wind turbine is struck by the rotating blades
3) Population modelling of the vulnerable species

Part 3) is not considered in detail in Band's publications, but typically consists of Population Viability Analysis of the populations interacting with the turbines.

Part 2) is a deterministic calculation involving a range of parameters of the turbine, such as blade length and shape, angle of attack, frequency of rotation, wind speed, size and flying speed of the bird concerned etc.

Part 1) is normally derived from on-site pre-development monitoring to determine the abundance of each species using the wind farm area, flight behaviour (height, direction etc), seasonality of occurrence, etc.

Parts 1) and 2) are combined to give an estimate of the number of collisions per year, assuming that the birds concerned take no avoiding action, either at distance from the farm or close to the turbines, to limit their potential for collision. In practice, the avoidance rate applied in the calculation can be the dominant factor in the final conclusion.

An alternative approach has been applied to predicting encounter rates of marine mammals and tidal turbines (Wilson *et al.,* 2007). This is based upon 3 dimensional models for estimating encounter rates predators and prey in the pelagic environment (Gerritsen and Strickler, 1977; Bailey and Batty, 1983) and is based broadly on collision between turbine blades and mammals being essentially a passive process. The models seek to estimate the encounter rates, and require a number of critical inputs such the depth distribution of the density of the animals in the project area, information on the shape, size and rotation speed of the turbine, and the size, shape and behaviour (swimming speed, direction, orientation and depth distribution and time at depth of the species concerned. Typically, this detail of information is not available, and consequently various simplifications are made, such as assumption of random orientation and distribution with depth.

As testing of tidal stream turbines has increased in Scotland, and applications are received for demonstration and commercial scales arrays, it has become necessary to consider the potential for collision with protected species, including seals, in the context of Appropriate Assessment under the EU Habitats Directive. The competent authority for undertaking the Appropriate Assessments is Marine Scotland, through its Licensing Operations Team. Together with Marine Scotland Science, a simple model framework has been created, based on the approach pioneered by Band (2000, 2007), and covering the behaviour of the vulnerable species, the physics of collision with the turbine, and the consequences for the populations concerned.

An approach to collision modelling for seals and tidal turbines

Marine Scotland has employed a three stage process for the Appropriate Assessment of collision risk to seals from tidal stream turbine installations in coastal waters. The stages in the assessment are:

- Field monitoring data to characterise the site in terms of the use by vulnerable species, particularly seals, prior to application for a Marine Licence to develop the

site. This information is gathered by the prospective project developer and provided to Marine Scotland during the licensing process.
- Estimation of the numbers of collisions of seals with turbines at the development site.
- Comparison of the predicted number of collisions with the Potential Biological Removal values for the region in which the development is located (Scottish Government, 2010).

The model developed at MSS to estimate the number of collisions is based around the concept that the diving behaviour of seals (and some seabirds) is very strongly structured and of simple pattern. Seals tend to spend time at the surface, time on the seabed foraging, and to make rapid transits in both directions between the surface and the seabed. The dives may by U-shaped or V-shaped, but the pattern of behaviour is broadly consistent between animals. The key parameter of the exposure of a seal to the turbines is therefore the frequency of diving, which is directly related to the frequency (and number) of transits of the depth zone where the turbines are located.

A diagrammatic representation of the model is shown in Figure 2. This shows a horizontal-axis turbine with three blades, mounted on the seabed. The risk radius presented by the turbine to animals swimming in the water is the radius of the turbine blades plus the length of the “target” animal.

The velocity of an animal diving from the surface is parameterised as the vector sum of its vertical swimming speed and the current velocity. Assuming no positive avoidance behaviour, animals diving within a cylindrical projection of the area of risk defined by the risk radius of the turbine will encounter the area swept by the turbine.

The area of the elliptical section through the cylindrical projection at its intersection with the sea surface is combined with the surface density of seals obtained from site characterisation monitoring to provide an estimate of the number of animals diving within the area of risk. The same number of animals will also be at risk when returning to the sea surface from the seabed. The risk is not dependent on the depth of water.

The calculations described above can be undertaken through a simple spreadsheet.

In addition to the estimates of surface density of animals in the development area normally obtained from site characterisation monitoring, the key parameters of behaviour required for the model and the frequency of diving, and the swimming speed. Swimming speeds of seals are typically around 1.8 ms^{-1}. Grey seals make approximately 6 dives per hour, while harbour seals make around 12 (SMRU, pers.comm. 2010).

The final parameter required is an estimate of the avoidance rate, i.e. the degree to which the behaviour of the species of concern which occurs in the absence of the tidal turbines but acts to reduce the risk of collision (for example, reduced rate of foraging at the times of highest tidal velocity), and also behavioural changes that may be introduced by awareness of the presence of turbines. There are few direct observational data available on which to base estimates of avoidance rate, but the monitoring work at test sites such as the European Marine Energy Centre, and Strangford Lough, are beginning to provide useful information in this respect.

This output from this part of the model amounts to estimates of the encounter rates between seals and the volume swept by tidal turbines. In the Band models for wind turbines, a second spreadsheet is then used to estimate the probability of actual collisions occurring from the passage of birds in flight through the turbine swept volume.

The engineering characteristics of tidal turbines show many significant differences to those of the wind turbines parameterised by the Band models. Firstly, the blades of tidal blades are relatively short, broad and thick, compared to wind turbine blades. The default blade shape used in the Band model is derived from patterns in use at terrestrial wind farms 10 – 12 years ago, and is unlikely to be a good match for tidal turbine blades.

Secondly, the relative incompressibility of water results in complex flow patterns around the tidal turbine blades, and the consequences of these for collision is not clear. While large objects such as seals are intuitively unlikely to be greatly affected, smaller organisms, such as diving birds, may be affected to a greater degree and derive some protection from contact with the moving blades. In the absence of a turbine model that more closely reflects tidal turbines, the Band model for wind turbines has been used. In practice, this results in high probabilities of collision for large animals such as seals, and therefore is precautionary.

In the light of the uncertainties in dive frequency and avoidance rate, the output from the model covers a range of values for both of these variables (Figure 3).

Discussion

In the absence of strong observational data on the number of collisions between seals and tidal turbines – an inevitable situation at this stage in the development of the industry – it is important that the use of assessments of collision risk in Appropriate Assessments is precautionary, but not unduly so. It is therefore useful to examine the features of the model and to consider whether the approximations and processes used contain elements of precaution, or work to minimise the assessment of the risk.

a) Risk radius of the turbine. This is maximised through addition of the length of the animal to the turbine blade length, and therefore is precautionary.

b) Tidal current speed. This is taken as the mean spring tide peak flow rate. This will be precautionary as it emphasises high velocity currents, which result in the largest area of the risk ellipse at the sea surface and seabed.

c) Foraging behaviour. The suggested dive frequencies (6 per hour for grey and 12 per hour for harbour seals) are typical of observational data in Scotland. Dive frequency for seals will inevitably vary to some degree with location, water depth, prey density etc, and the model can accommodate any preferred dive frequency (for example, as may be observed during site monitoring). The default model assumes that seals exhibit diving behaviour whenever they are in the area of the turbines, and that they feed 24 hours per day. The model is therefore precautionary.

d) Operating time of the turbines. Turbines require a particular minimum current speed to operate. The percentage of the tidal cycle that exceeds this velocity is applied in the model. However, the turbines are assumed to be either stationary or rotating at maximum speed, and therefore provides further precaution to the model.

e) Dive frequency. This can be altered within the model, for example to match observational data from the development site.

f) Avoidance rate. Calculations are provided in the model for a range of avoidance rates, as is typically the case for assessments of collision risk for birds at wind farms. It is not yet clear how precautionary the range used (95 – 99.8%) may be.

The main areas of uncertainty in the model and for which new research work is required fall into two main areas – the physics of the rotating turbine and the behaviour of the animals at risk. Firstly, a more realistic parameterisation of the engineering features of tidal turbines is required. As noted above, it is likely that the current descriptions based on terrestrial wind turbines introduce errors into the estimation of probability of collision for seals entering the swept volume of a turbine. The significance of flow patterns round turbine blades for collision also needs to be clarified.

Behavioural studies of the animals at risk can be considered as elements in improving the estimates of avoidance rates. Spatial avoidance on macro-scale can arise if animals tend to avoid the aquatic space resource that is of interest for tidal turbine developments. Temporal avoidance of turbines can occur if, for example, seals avoid areas of high flow when foraging. Information is coming available to suggest that is the case in some areas, and this will act as macro-scale avoidance and tend to reduce their risk of collision with moving turbines.

On a micro-scale, there is little information on the details of behaviour of seals and diving birds in the immediate vicinity of turbines. It may be possible to parameterise avoidance at this scale through consideration of the sensory (hearing, sight, vibrational) capabilities of vulnerable species, and their ability to take action to avoid (e.g. swim away from) approaching blades. However, there also needs to be direct observational evidence of the frequency of collisions of mammals with turbine blades to validate model-based approaches to risk assessment.

Conclusion

The model described here provides a simple approach to a precautionary estimate of collision risk for tidal turbines and marine mammals, particularly seals. The method has been used in Appropriate Assessments of interactions between seals and tidal turbines in Scottish coastal waters.

The complexity and reliability of the model could usefully be increased in various ways:

- Improve the description (parameterisation) of tidal turbine blades used in the estimate of probability of collision.
- Improve the estimates of availability of seals for collision by relating the density and diving activity of seals at sea to tidal state or current velocity.
- Improve the estimate of probability of collision by linking site-specific variation in tidal current within tidal and spring-neap cycles to turbine rotation speed, and integrating over longer periods of time.
- Improve understanding of macro- and micro-scale behaviour of seals and their implications for avoidance rate estimates.
- Review of information on the behaviour of other protected species, such as porpoise, dolphin and other cetaceans and extension of the model to assessment of risk to vulnerable species.
- Review of information on the diving behaviour of seabirds and extension of the model to assessment of risk to vulnerable seabirds.

References

Bailey, K.M. and R.S. Batty, 1983. A laboratory study of predation by Aurelia aurita on larval herring (Clupea harengus): Experimental observations compared with model predictions. Marine Biology,72, 295-301.

Band, W., 2000. Windfarms and Birds: calculating a theoretical collision risk assuming no avoiding action. Scottish Natural Heritage Guidance Note. http://www.snh.gov.uk/planninganddevelopment/renewable-energy/onshore-wind/assessing-bird-collision-risks/

Band, W., Madders, M. and D.P. Whitfield, 2007. Developing field and analytical methods to assess avian collision risk at windfarms. In: De Lucas, M., Janss, G. and Ferrer, M. (eds) 'Birds and Wind Power'. www.quercus.pt

Gerritsen, J. and J. R. Strickler, 1977. Encounter probabilities and community structure in zooplankton: a mathematical model. J. Fish. Res. Board Can. 34: 73-82.

Wilson, B., Batty, R. S., Daunt, F. and C. Carter, 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for Marine Science, Oban, Scotland, PA37 1QA.

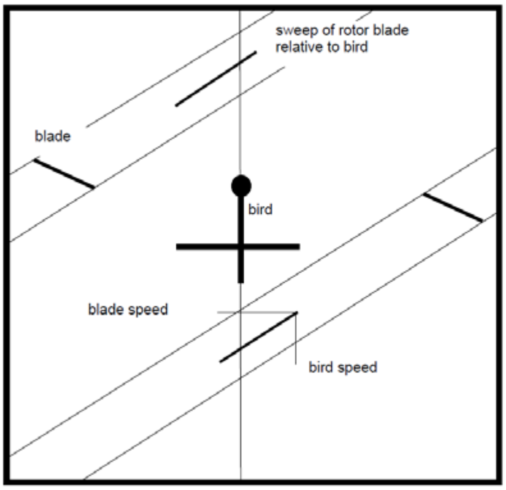
Scottish Government, 2010. Provisional Regional PBR for Scottish seals 2010. (http://scotland.gov.uk/Topics/marine/Licensing/SealLicensing/PBR)

Models of collision risk: "The Band model"

Combines:

Physics of collision

Behaviour of species of concern



Size of bird

Flight speed

Size of blades

Speed of rotation

Angle of blades

Figure 1 The structure of the collision element of the Band (2000, 2007) model interactions between wind turbines and birds in flight showing the relative movement between birds in flight and rotating turbine blades.

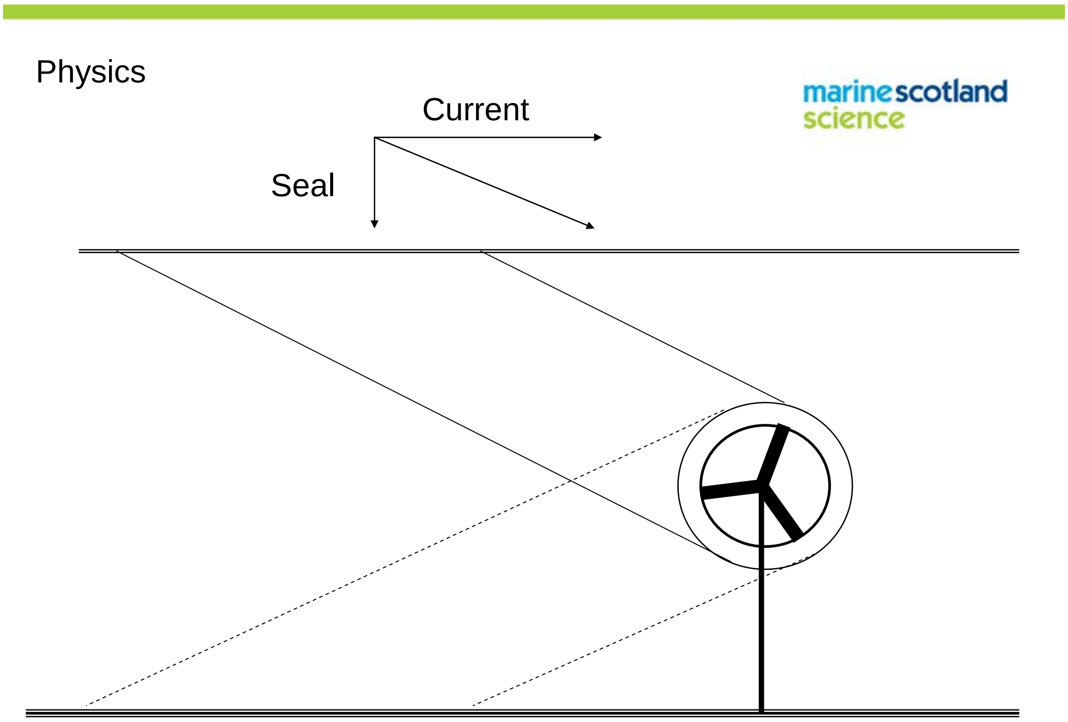


Figure 2 Relationships between turbine size, seal dive and current speed, and projection of the turbine face on the sea surface and seabed.

Output:

Predicted number of collisions per year

	Dives	per	hour		
	6	12	20	30	60
Avoid. %					
95	0.097	0.194	0.323	0.484	0.968
98	0.039	0.077	0.129	0.194	0.387
99	0.019	0.039	0.065	0.097	0.194
99.5	0.010	0.019	0.032	0.048	0.097
99.8	0.004	0.008	0.013	0.019	0.039

Figure 3 Example of output from the model showing variation in predicted number of collisions per year with dive frequency and avoidance rate.