PROGRESS REPORT

Studies of harbour seal behaviour in areas of high tidal energy:

Part 1. Movements and diving behaviour of harbour seals in Kyle Rhea.

Sea Mammal Research Unit
Report to Scottish Natural Heritage and Marine Scotland,

31/10/2013

Version 3

DAVE THOMPSON

1 Version Log

Version	Date	Author	Comments	Checked by
1	17/10/12	DT	First draft sent to J.Baxter,SNH.	
2	17/09/13	DT	Revised in response to SNH comments	
3	31/10/13	DT	Revised in response to J.B. comments	AJH

2 Executive summary

1. This report presents a summary of the data collected during the initial transmitter deployments on harbour seals in the Kyle Rhea study area in 2012. As such it forms one of a series of interim reports describing the movements and diving behaviour of seals in areas of high tidal energy. It is designed simply to present the information most likely to be of use in assessing the potential impacts of any tidal turbine deployments in an easily accessible format.

2. This report summarises the movements and dive behaviour of nine harbour seals caught and tagged at sites within the channel at Kyle Rhea. Seals were fitted with GPS equipped GSM phone tags that provided continuous tracking and dive behaviour data for a total of 506 seal days.

3. Tagged seals concentrated their diving activity within the channel (57% of location fixes) at Kyle Rhea.

4. All of the seals tagged in Kyle Rhea swam repeatedly through the channel in the vicinity of the proposed turbine deployments. We present an example of how seals were distributed in the water column as they passed through one section of the channel. The filtered data shows a clear bimodal pattern in transits with respect to distance from the shore, with transits being less frequent in the central, deeper section of the channel. In addition, there appears to be a reduced density of transits in mid-water through the central deep channel. This would be an expected consequence of the dive profile patterns and has clear and important implications for estimating collision risk. However, the interpolation error due to timing of GPS fixes and the small but significant GPS position error mean that the transit depth and location data will still contain substantial error.

3 Contents

4 Introduction

The UK is committed to a massive increase in renewable energy generation over the next 20 years and wind, wave and tidal power will play a major role in meeting these targets. The tidal energy in the waters around the Inner and Outer Hebrides and Orkney Islands represents a considerable resource that will necessarily form part of Scotland's offshore renewable energy programme. There is, however, concern over the potential for interaction between marine mammals and tidal turbines. The most obvious, and probably the most important interaction in terms of public perception, is the potential for injuries or fatalities resulting from direct contact with moving parts of tidal power devices (Linley *et al.* 2009; Wilson and Gordon 2011).

Devices and marine mammals must coincide in both space and time in order for any such effects to occur. Currently we lack any well-founded information on the behaviour of marine mammals during such proximate interactions so we can only estimate the potential for collisions. How animals act in terms of avoidance or attraction towards devices and their ability to evade collisions will scale the potential collision risk assessment. Gaining a better understanding of behavioural responses to operating tidal turbines is a priority.

In the absence of direct information on collision rates, risk assessments have relied on collision risk models. Two models have been proposed for estimating the risk of collisions between marine mammals and tidal turbines in UK waters: a modified version of a model developed to estimate the number of birds that could be expected to collide with onshore wind farms (Band *et al.* 2007) and a model based on a movements and interactions model developed to investigate predation by zooplankton ((Wilson *et al.* 2007; Gerritsen and Strickler 1977). A review of the existing models and an investigation into some of the basic assumptions of the effects of possible collisions has been commissioned by SNH.

Because of the lack of information on avoidance and/or evasion behaviour both models incorporate one important assumption: that the patterns of movement of marine mammals will be the same in a particular place irrespective of the presence or absence of an operating marine renewable energy device. That is, marine mammals show neither attraction nor avoidance behaviour nor make any attempt to evade the moving parts. Under this assumption the number of marine mammals impacted can be derived from an estimate of how many will pass through the footprint of a device scaled by the likelihood of being hit by a blade based on the transit time of the animal and the rotation rate and number of blades.

Several factors are likely to influence both the likelihood and severity of such contacts (Wilson *et al.* 2007). In a recent review for Marine Scotland (MR1 & MR2 of the MMSS/001/11 project available at http://www.scotland.gov.uk/Publications/2013/09/5811/3) we identified a set of information requirements to refine such estimates. To assess the probabilities of such occurrences we need information on:

1) Device characteristics, e.g. rotation speed, blade length and number, depth, turbine spacing etc.
2) The short term and seasonal movement patterns of animals.
3) The size of the population at risk.
4) The dive patterns, depth usage and small scale movement patterns of individuals.
5) Reactions to presence of devices.
    i. Avoidance/ Attraction of animals to the turbines.
    ii. Evasion behaviour in close proximity to devices.

The tidal energy in the waters around the Inner and Outer Hebrides and Orkney Islands represent a considerable resource that will necessarily form part of Scotland's offshore renewable energy programme. There are planned/potential tidal turbine developments on the west coast, particularly in the Sound of Islay and Kyle Rhea and in the Pentland Firth and waters around the Orkney Islands. All of these areas are known to be used by harbour seals. To date there is little information on the movements of harbour seals in the vicinity of these sites and there is a requirement for information on the behaviour of seals within these high tidal energy areas.

In response to these perceived data gaps Marine Scotland and SNH commissioned the SMRU to carry out a series of telemetry based studies of movements and diving behaviour of harbour seals in high tidal energy regions that will address aspects of items 2 and 4 above.

5 Aims and objectives

1. To describe the movements and diving behaviour of harbour seals in areas of high tidal flows, with particular emphasis on sites with proposed turbine deployments:
    a. Kyle Rhea, specifically those animals using the haulout sites within the Kyle Rhea narrows in close proximity to the tidal rapids.
    b. Pentland Firth, specifically those animals using haulout sites in the vicinity of Stroma and the proposed Inner Sound tidal array site.
    c. Islay, specifically those animals using haulout sites in the vicinity of the South East Islay SAC and in the Sound of Islay.
2. To determine whether there are similarities between the behaviours of seals in these different high tidal energy sites that will allow inferences to be made about behaviour at other similar sites

This report presents a summary of the data collected during the initial transmitter deployments in the Kyle Rhea study area. As such it forms one of a series of interim reports describing the movements and diving behaviour of seals in each area. It is designed simply to present the information most likely to be of use in assessing the potential impacts of any tidal turbine deployments in an easily accessible format. A comprehensive analysis of data from the combined study of both grey and harbour seals at various sites around Scotland will be presented to SNH and Marine Scotland in 2014.

6 Methods

In order to study the movement and dive patterns of seals at an appropriately fine scale, we used purpose built GPS Phone Tags, which combine GPS quality locations with efficient data transfer using the international GSM mobile phone network. These tags provide GPS quality (usually better than 10 m accuracy) locations at a user controlled rate, together with complete and detailed individual dive and haul-out records. They are small, weighing 370 g which is <1% of an average seal pup mass. Data are relayed via a quad-band GSM mobile phone module when the animal is within GSM coverage. This results in relatively low cost, high energy efficiency with a high data bandwidth.

Due to limited battery capacity there is a direct trade-off between the temporal resolution of the location data and the life of the transmitter. In order to produce location data from the tagging date to the moult when tags are expected to fall off we set the tags to collect a GPS location fix at 8 minute intervals.

An initial catching attempt in October 2011 was abandoned due to lack of available study animals. Seals were scarce or completely absent from the haulout sites within Kyle Rhea throughout the winter 2011-2012 and early spring 2012. Significant numbers began to appear in mid April 2012. This pattern of absence of seals in autumn and winter and increasing numbers using haulout sites in Kyle Rhea throughout the spring and summer appears to be a consistent annual pattern (A. Law pers. com.). Numbers of seals on the haulout sites varies widely, but peak daily counts during summer of 2013 averaged approximately 150 seals

Nine harbour seals were caught between 17th and 27th April 2012 using a combination of rush and grab techniques and tangle nets at haulout sites. Seals were anaesthetized with an intravenous dose of a Tiletamine-Zolazepam mixture (Zoletil) and tags were glued to cleaned, dried fur on the back of the neck using a cyano-acrylate contact adhesive (Loctite 422). Seals were released and left to recover on shore close to their capture site.

Table 1 gives the tagging details of seals caught at haulout sites in the high tidal energy site within Kyle Rhea in April 2012.

Table 1. Tagging data and morphometrics for harbour seals fitted with GPS/GSM tags in Kyle Rhea in April 2012.

Seal i.d.	Date	Tagging Location	Sex	Age.Class	Mass(kg)	Length(cm)	Girth(cm)
350	17/04/2012	Kyle Rhea, Skye	M	Adult	72	151	89
351	22/04/2012	Kyle Rhea, Skye	M	Adult	70.4	139	99
360	21/04/2012	Kyle Rhea, Skye	M	Adult	87	155	108
364	21/04/2012	Kyle Rhea, Skye	M	Adult	77.2	148	102
365	27/04/2012	Kyle Rhea, Skye	F	Adult	74.6	134	105
368	27/04/2012	Kyle Rhea, Skye	F	Adult	83	140	107
370	23/04/2012	Kyle Rhea, Skye	M	Adult	92	154	112
376	18/04/2012	Kyle Rhea, Skye	F	Adult	83.4	138	106
394	18/04/2012	Kyle Rhea, Skye	M	Adult	79.6	147	105

7 Preliminary Results

7.1 General movements

Figure 1 shows the tracks of all nine seals between April and July 2012. Only two seals moved out of the channels between Skye and the mainland. Seal Pv43-350 made an initial trip to the North, swimming directly to the Butt of Lewis where it remained for 4 days before returning to Kyle Rhea where it remained for the rest of the tracking period. Seal Pv43-394 moved south around the south coast of Skye to an area 10km east of South Uist before returning via the Small Isles. It then remained in the Sound of Sleet for the remainder of the study period. Two seals (Pv43-365 and 370) each made one return trip to a haulout site at the north end of Raasay. All other seals stayed within 20 km of their capture site and all seals made repeated transits through the narrows at Kyle Rhea.

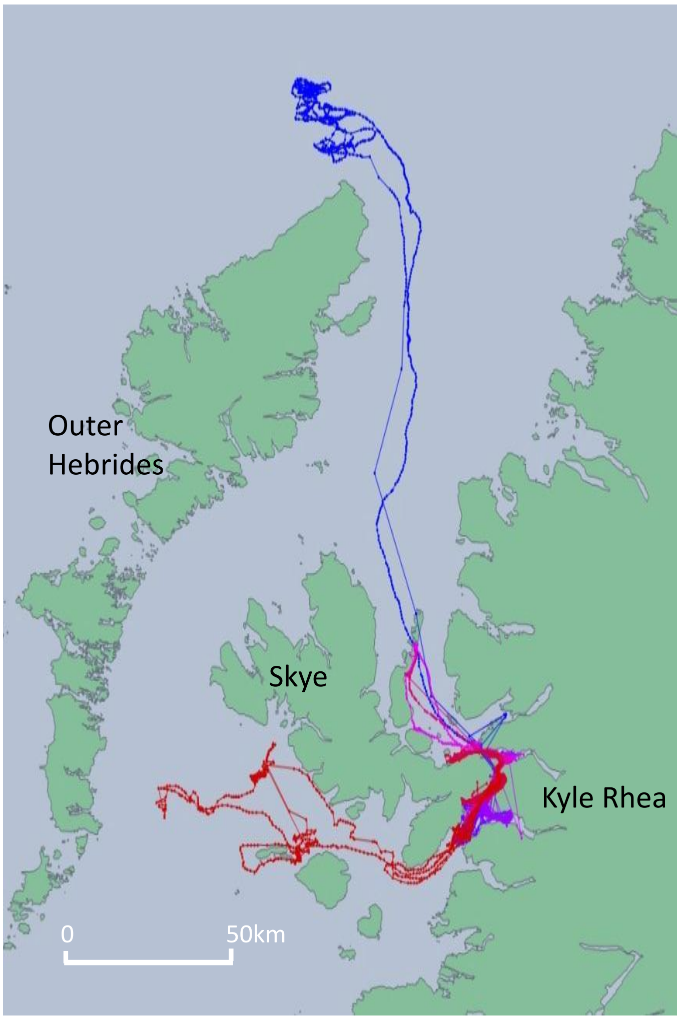


Figure 1. GPS positions and swimming tracks of nine harbour seals tagged in Kyle Rhea. The plot shows data from the tracking period between late April and late July 2012. Only two seals moved out of the channel between Skye and the mainland.

Figure 2 shows the very high density of tracks of animals moving through and/or foraging within the channels between Skye and the mainland. Figure 3 shows the distribution of GPS derived surfacing positions of all nine seals within the tidal rapids surrounding the proposed turbine array site in the southern part of Kyle Rhea. This area included the capture sites for all nine seals and therefore also includes a substantial number of haulout records. However, when filtered to only include location records while swimming, the nine tagged seals spent 57% of the study period within the narrows at Kyle Rhea (between 57°13'14"N and 57°13'N) and all seals spent at least 35% of their time in the narrows (Table 2).

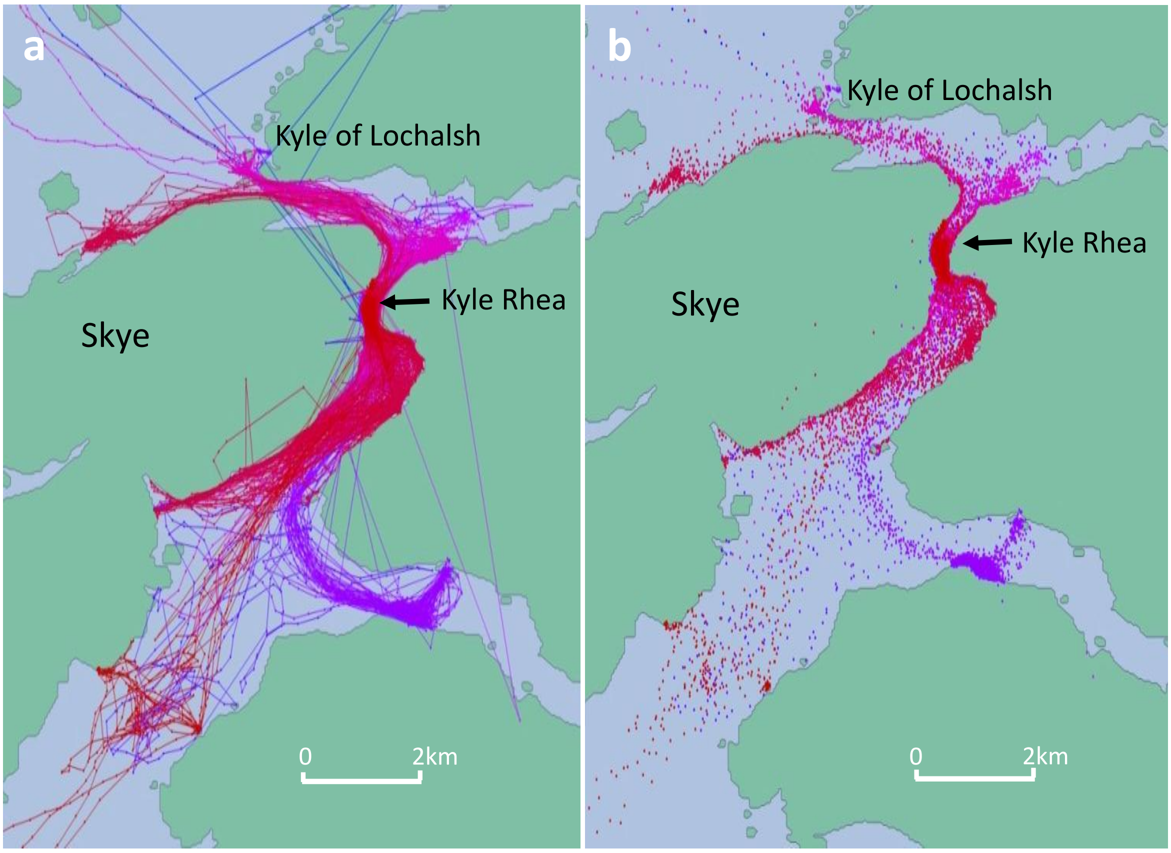


Figure 2. GPS positions and swimming tracks of nine harbour seals tagged in Kyle Rhea. The plot shows data from the tracking period between late April and late July 2012 and shows the intense movement activity within the channel between Skye and the mainland, with most activity occurring between the Kyle of Lochalsh and the northern end of the Sound of Sleat.

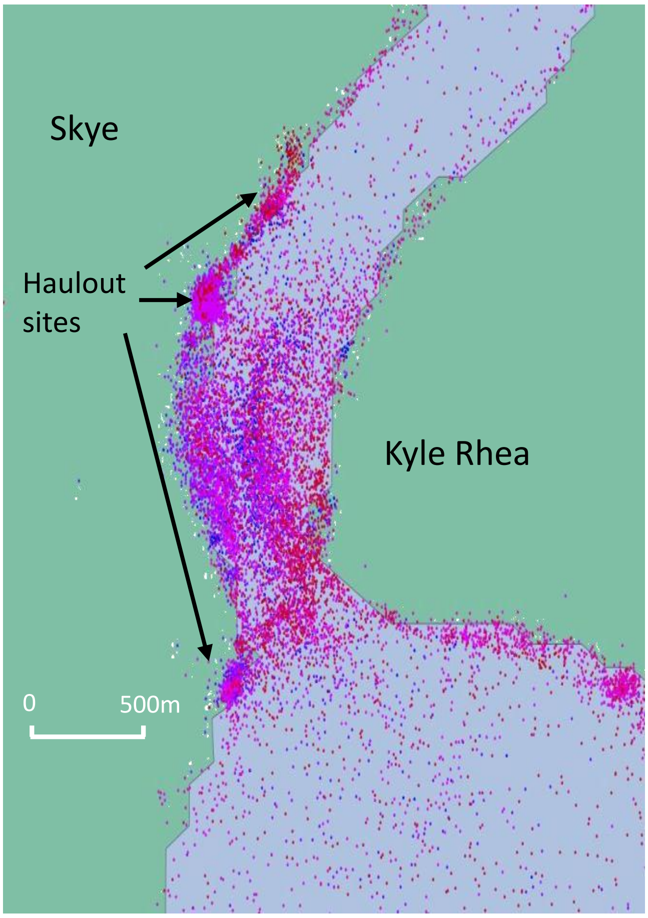


Figure 3. Distribution of GPS derived surfacing positions of all nine seals within the tidal rapids surrounding the proposed turbine array site in the southern part of Kyle Rhea.

Table 2. Estimated proportion of time spent within the narrows at Kyle Rhea (between 57°13'14"N and 57°13'N) between late April and late July 2012.

Seal i.d.	GPS Location fixes within Kyle Rhea	Total GPS location fixes	Proportion within Kyle Rhea	Duration of tag life (days)
350	916	1969	0.47	77.8
351	1692	2080	0.81	42.7
360	2779	5569	0.50	92.9
364	1696	1884	0.90	99.2
365	1993	2580	0.77	45.5
368	1792	4118	0.44	48.5
370	101	252	0.40	14.7
376	1631	4663	0.35	57.1
394	866	1874	0.46	30.6
total	**13466**	**24989**	**0.57**	**508.7**

7.2 Fine scale movements

The rate at which seals pass through the area swept by the blades of a tidal turbine is an important parameter which sets the upper limit on the potential for direct physical interactions with the device. The data from the GPS and depth sensors can be used to estimate the frequency of transits and the depth and geographical positions at which seals pass through a specific section of the channel.

The GPS position fixes obtained by the tag indicate the seals' XY positions to an accuracy of approximately +/- 10m. However, the tags were set to sample GPS only when at the surface and in order to conserve battery power and provide a useful tag life they were further restricted to sampling at intervals of at least 8 minutes. Not all surfacing events produce successful GPS fixes, and the combination of these restrictions produced a sampling rate of approximately one successful GPS fix every 13 minutes (Figure 4) but with 57% of gaps being between 8 and 11 minutes.

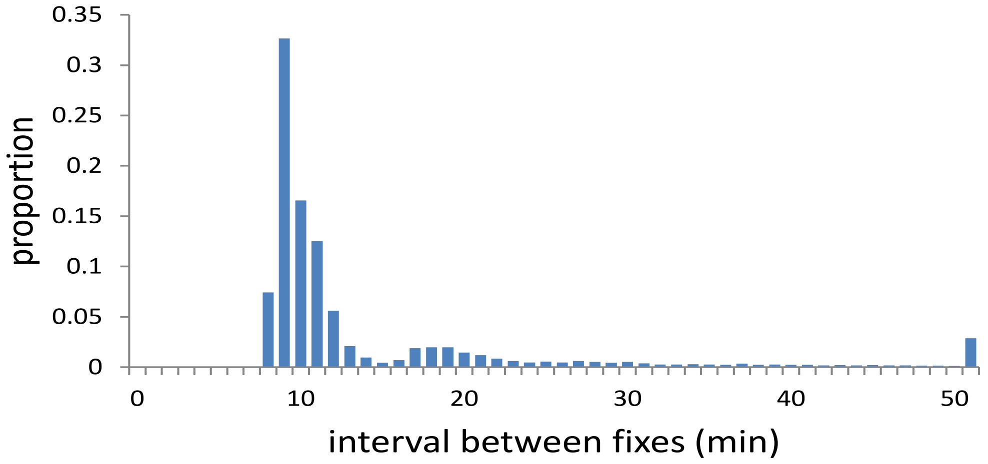


Figure 4. Frequency histogram of the intervals between successive GPS position fixes while seals were in the water. N= 24990, mean = 13.8 minutes.

The pressure sensors on the tags provide a 10 point depth profile for each dive with an accuracy of +/- 1m and the tags also transmit the start and end times of each dive. The location and depth of each seal can then be estimated at any time by interpolating the XY position assuming direct straight line movement between position fixes and linearly interpolating between successive time depth records.

As an example of the type of data available we estimated the number of times and the depths at which the tagged seals crossed an arbitrary line drawn across the narrowest point of the channel at Kyle Rhea. The example line chosen was an east west transect across the channel at the southern boundary of the array box drawn in the MCT Environmental statement (lat 57.229^{o} N, long 5.656^{o}W to 5.665 ^{o}W) (Figure 5). The resulting line was approximately 550m long. A depth profile for the transect was extracted from the SEAZONE-TRUDEPTH topography database.

This preliminary analysis of the data from the relatively small sample of nine tagged seals over a total of 391 seal days produced a total of 865 crossings/transits of the line. All nine tagged seals crossed the line several times during the study at an average rate of 2.2 transits per seal per day (Table 3)

Table 3. The number of times individual tagged seals crossed an arbitrarily chosen line across the south end of Kyle Rhea channel.

seal id	tag life (days)	crossings	rate(transits/day)
364	35.4	42	1.19
394	31.8	77	2.42
350	50.7	37	0.73
351	28.7	88	3.07
360	92.5	142	1.54
365	33.8	148	4.38
368	48.3	155	3.21
370	13.7	3	0.22
378	56.5	173	3.06
Total	391.4	865	2.21

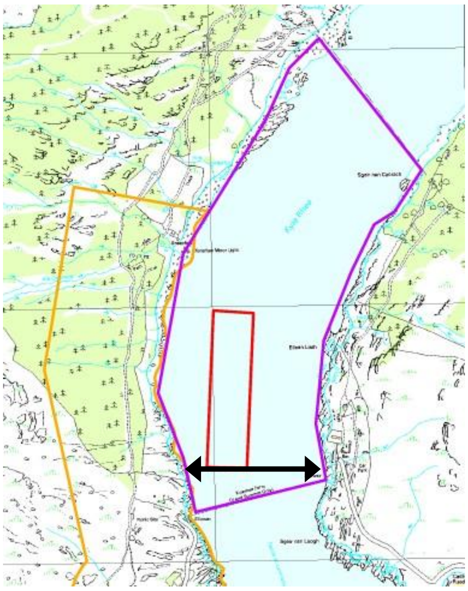


Figure 5 Map of the Kyle Rhea study site with the approximate locations of the proposed four turbine tidal array site indicated by the red rectangle and the arbitrary transect line indicated by the black arrow. (courtesy of MCT.)

Figures 6 and 7 show the estimated locations and depths of all the crossings by all nine seals. The points at which the seals were estimated to have crossed the line were roughly evenly distributed across the central section of the channel both in terms of distance from shore (Figure 6) and swimming depth (Figure 7). However, it is clear from the fact that a significant numbers of crossing points had estimated depths that exceeded the water depth that there must be substantial interpolation error in the location of the dives and therefore also in the water depth estimates assigned to each dive.

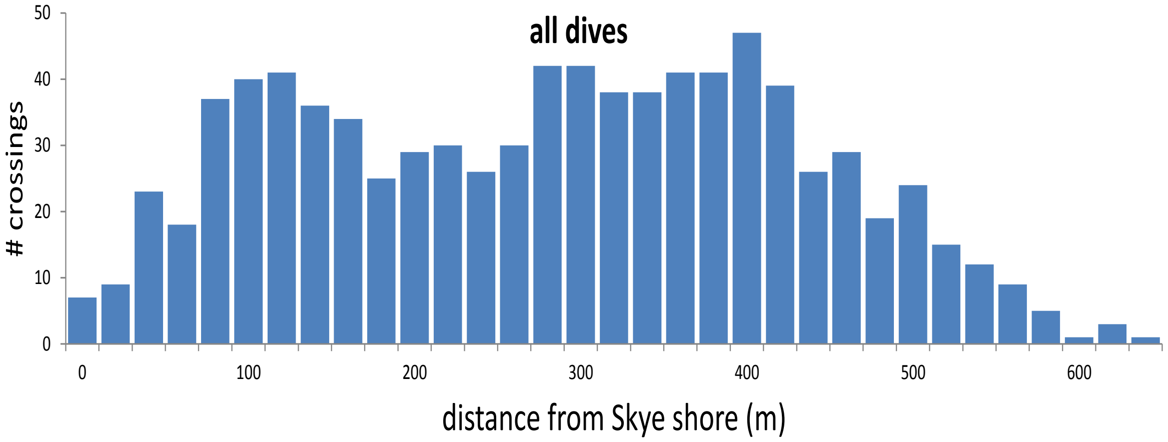


Figure 6 Distribution of distances from shore (defined as distance from the Skye shore) at which seals crossed an arbitrarily defined line stretching across the narrowest point of Kyle Rhea at the southern edge of the Array Box.

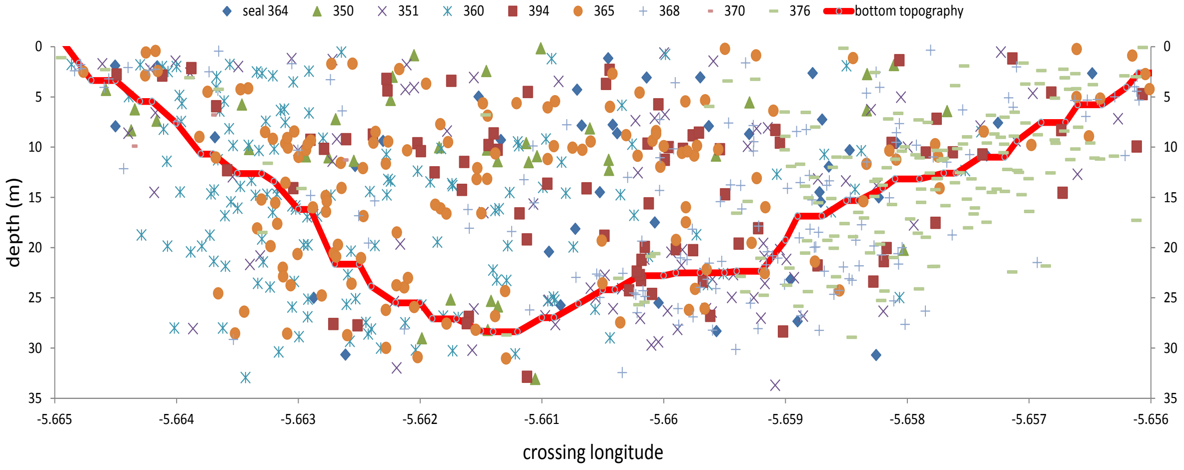


Figure 7 Depth and distance from shore of seals crossing an arbitrarily defined line stretching across the narrowest point of Kyle Rhea at the southern edge of the Array Box.

The rate at which GPS fixes are collected and transmitted is a compromise between spatial/temporal resolution and tag life. The sampling frequency was set to one GPS fix every eight minutes but often the gap between successful GPS fixes was higher (Figure 4). The intervals between locations and the relatively small errors in the position fixes from the Fastloc GPS (less than 50m) means that there can be potentially large interpolation errors in the locations and therefore also on the interpolated depths at any specific time between the position fixes. To reduce these effects we sub-sampled the data to include only those crossings that were estimated to have occurred in dives immediately before or after a position fix. In effect this meant those dives with a GPS position fix within approximately 2 minutes of the time they were judged to have crossed the line.

Figure 8 shows the frequency of crossings for this reduced dataset. There is a clear bimodal pattern with fewer transits in the centre of the channel. Figure 9 shows the depth distribution of the reduced dataset. Again the pattern of reduced transits in the deeper central section is apparent as is the low number of mid water transits in the deeper water section. This area of apparently reduced activity is both the deepest section of the channel and also the area with the highest flow rates (Figure 10).

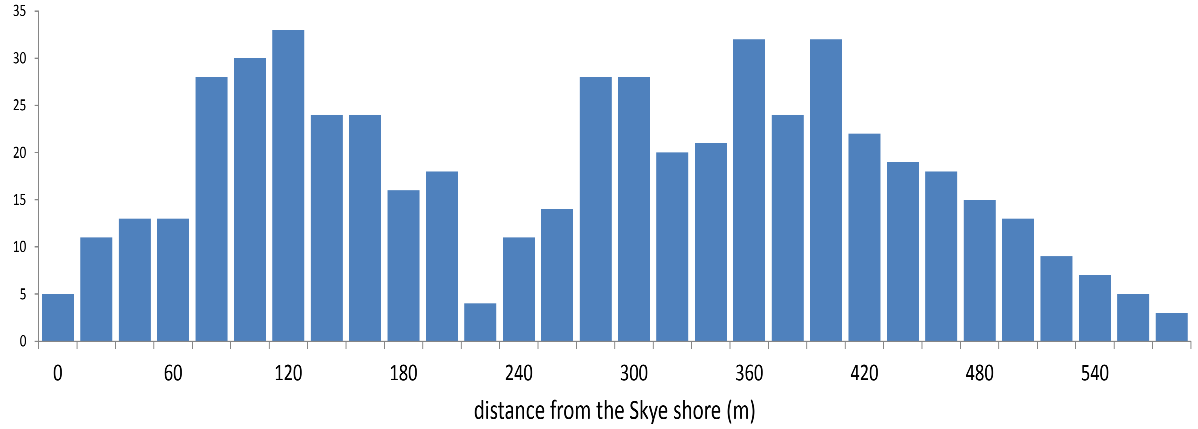


Figure 8 Distribution of filtered distances from the Skye shore at which seals crossed an arbitrarily defined line stretching across the narrowest point of Kyle Rhea at the southern edge of the Array Box.

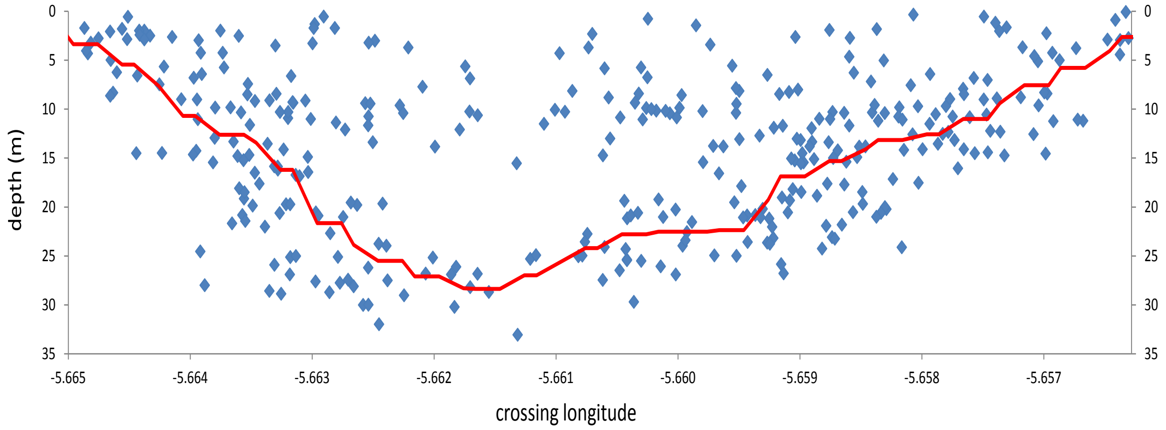


Figure 9 Depth and distance from shore of seals crossing an arbitrarily defined line stretching across the narrowest point of Kyle Rhea at the southern edge of the Array Box, for filtered data.

Although these data do not provide sufficient spatial resolution to identify direct passage through a small window equivalent to a turbine, they can be used to estimate the general pattern of transits through a specified area.

7.3 Dive behaviour

Figure 11 shows examples of dive profiles for three individual seals. The depth profile itself is generated from eleven depth points (two start and end points at the surface and nine evenly spaced through the dive). The plot also shows the times of haulout periods between bouts of diving. The plots also include an index of tide height and of flow. For this initial examination we estimated local HW and LW times as being equidistant between the HW and LW times at the Kyle of Lochalsh and Glenelg Bay (the average difference between the times at these two sites was only 24 minutes). The index of tidal flow was derived in a similar way, but assumed that the minimum flow occurred around 45 minutes after local HW or LW times. No attempt was made to assign an estimated speed because local flow conditions vary over short ranges within the range of movements between successive location fixes. The red trace on each plot in Figure 11 is therefore simply an index of higher and lower flow rates. Plots of the seal’s swimming tracks for the periods shown in the depth profiles are presented alongside each time depth profile.

The initial impression is that the dive patterns are highly variable both in terms of the shapes of dives and the depths of dives within particular dive bouts/foraging trips.

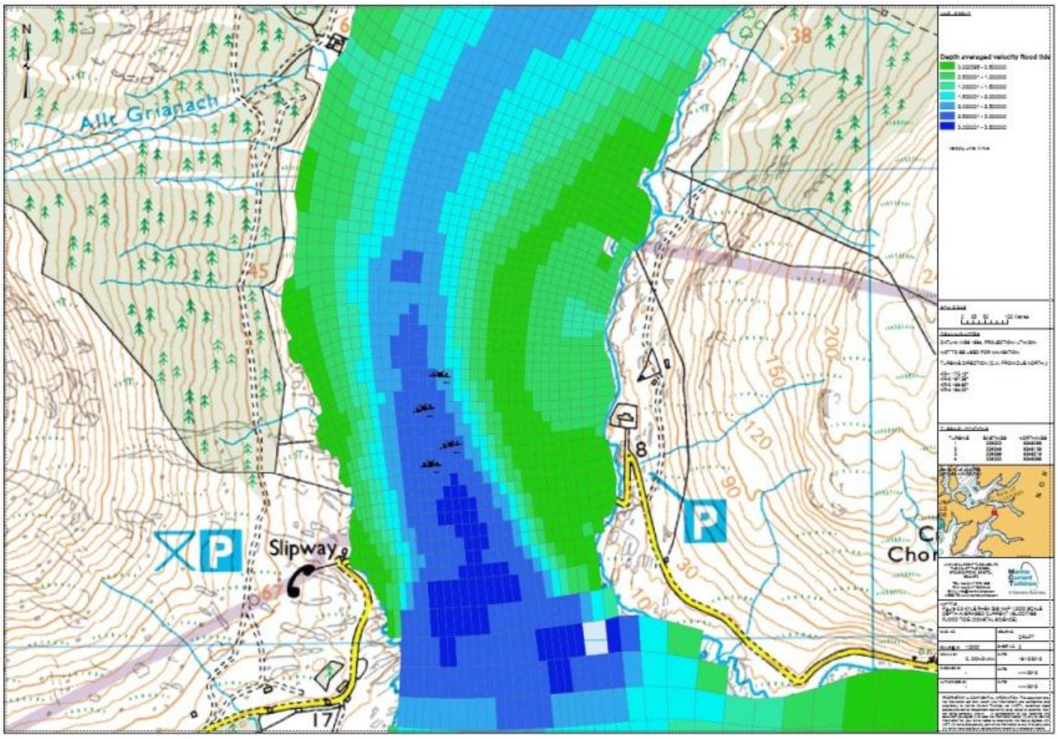


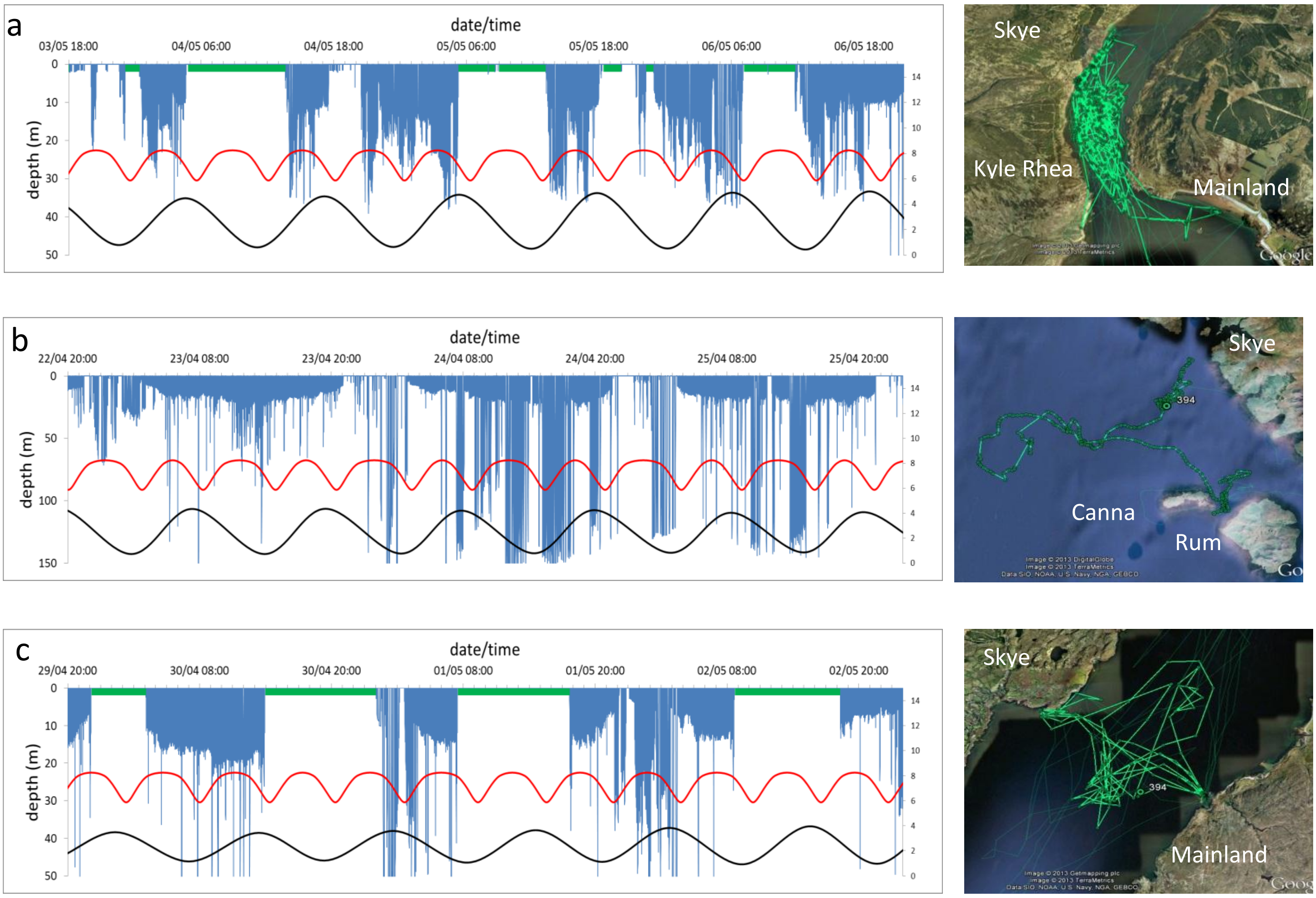
Figure 10. Map of the rates of flow at peak flood tide in the Kyle Rhea study site with the approximate locations of the four proposed tidal turbines indicated by the black symbols and current speed indicated by colour, with green representing low flow rates and blue representing higher rates. (reproduced from MCT.)

The seals that spent some time outside the core study area in Kyle Rhea performed dives to the local sea bed depth, with regular diving to depths of 150m+ (Figure 11 seal 394: b & c) . However, within the Kyle Rhea narrows dives were restricted to depth of less than 40m (Figure 11 seal 394 a; seal 351 a; seal 364 a & b), consistent with the local bathymetry in Kyle Rhea. Within individual dive bouts there appeared to be little or no consistent pattern to the diving with rapid and frequent changes in maximum dive depths (Figure 11 seal 351 b; seal 364 c,d & e). In each case the changes in depth profiles were at least consistent with benthic diving given the pattern of movements within Kyle Rhea narrows. The only significant periods of continuous shallow diving to depths of <10m were associated with periods spent close to the haulout sites ((Figure 11 seal 364 d).

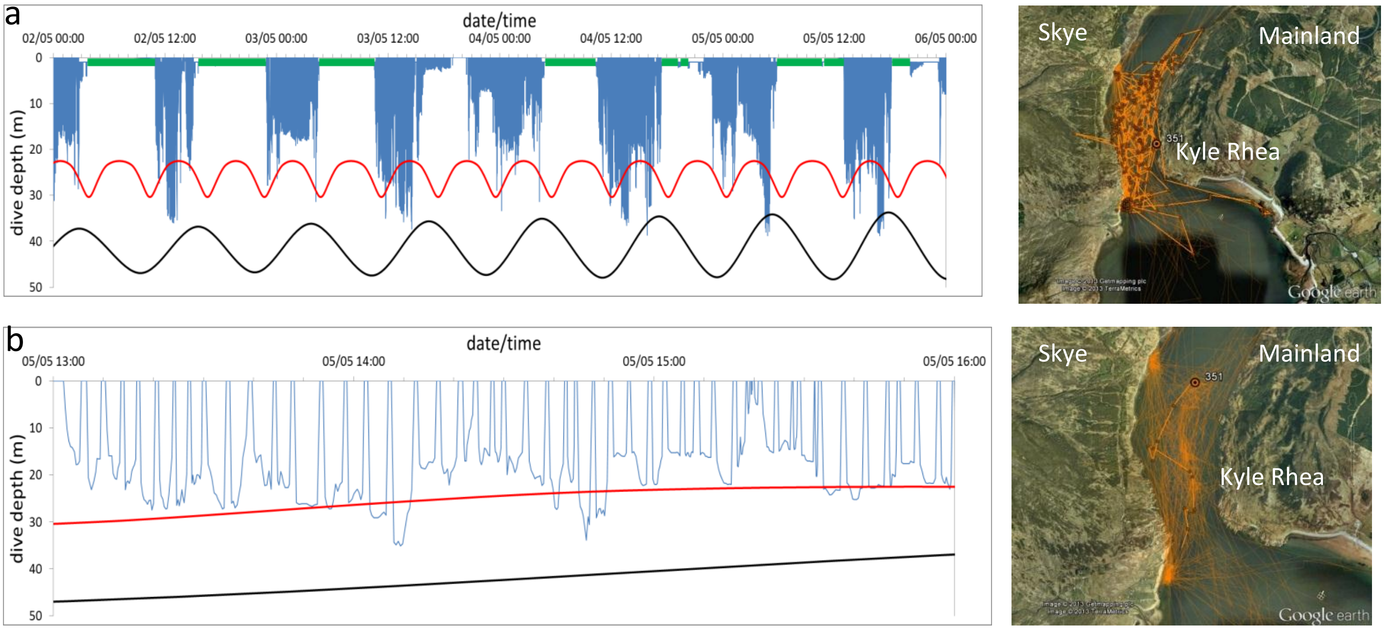
Figure 12 shows the proportion of time spent at different depths, expressed as a proportion of the maximum depth, within individual dives. This clearly demonstrates that the majority of time is spent at the bottom of the dive (41% of time within 90% of max depth) or at the surface (21% of time at the surface). However, the complexity of the topography and the interpolation errors in location of each dive makes it impossible to determine what proportion of these dives reached the seabed and it is therefore not possible to say where exactly in the water column the dive activity occurred.

Figure 11 Examples of dive profiles for three individual seals. Blue lines represent time depth profiles, green bars along the top axis represent haulout periods, black sine waves are an index of tide height and red lines are an approximate index of flow speed. The Google Earth plots show the seal's swimming tracks for the periods shown in the depth profiles. Details given in the text.

Seal 394

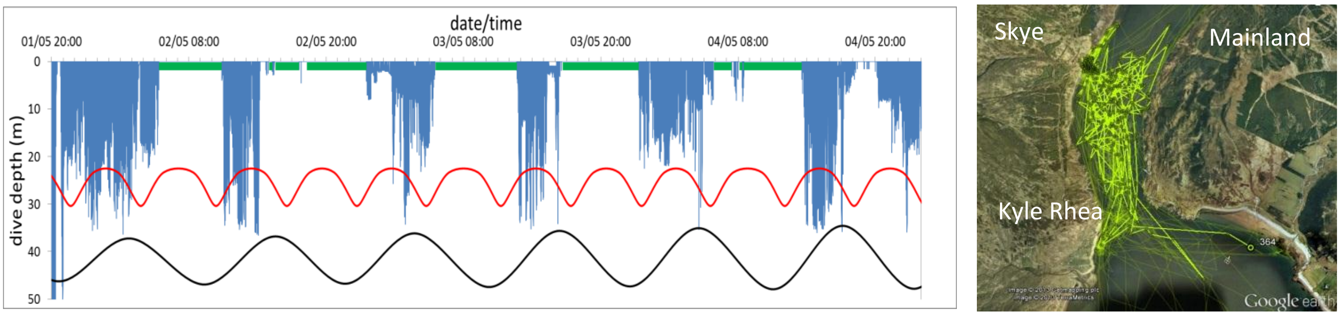


Seal 351

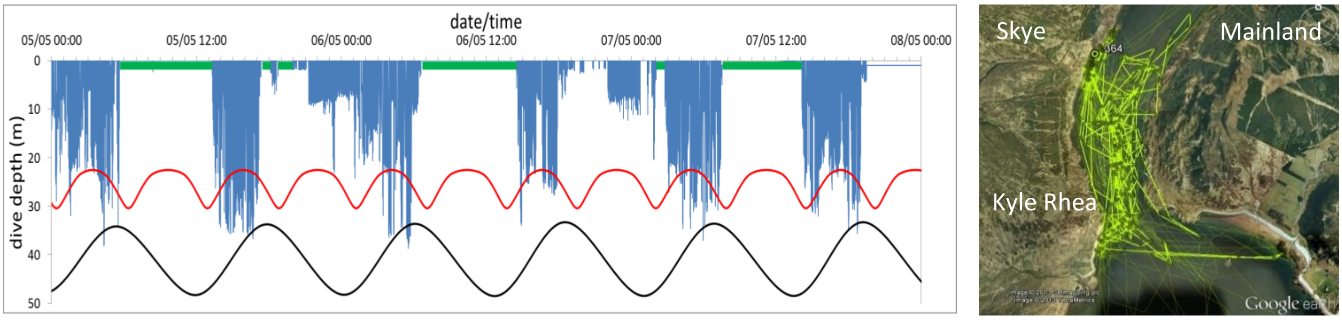


Seal 364

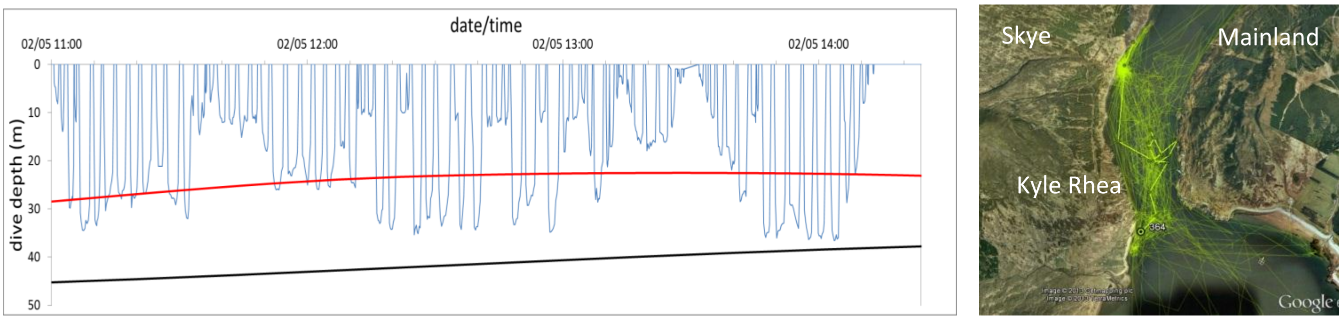
a



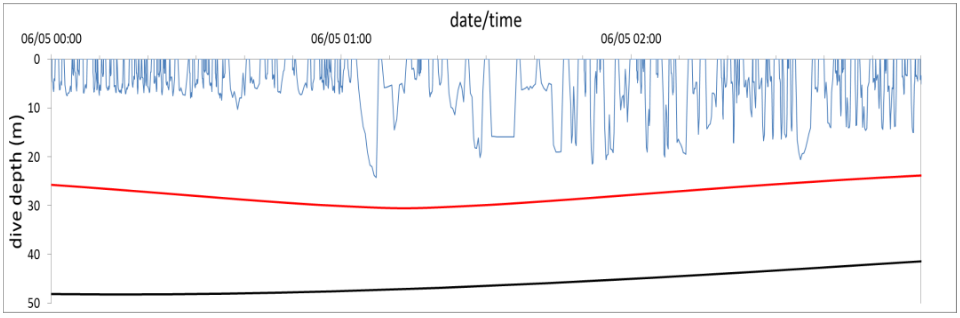
b

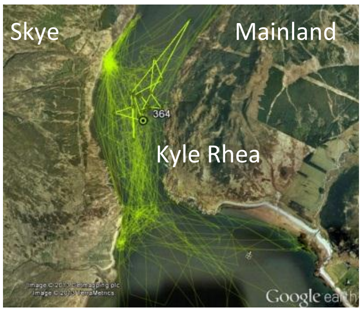


c

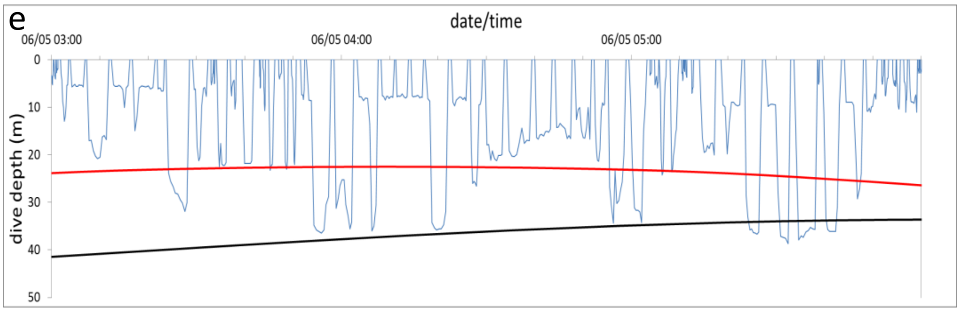


d





e



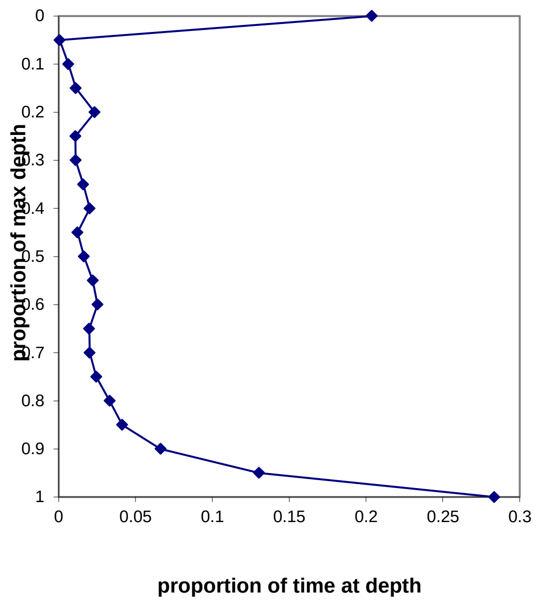


Figure 12. Proportion of time spent at depth expressed as a percentage of the maximum depth in each dive for dives >2minutes duration in Kyle Rhea.

7.4 Dive behaviour relative to tidal flow.

Figure 13 shows frequency histograms of dive durations for dives within Kyle Rhea. Figure 14 shows an index of dive squareness (the area of the time-depth profile expressed as a proportion of the area of a profile assuming the seal spent all the time at the maximum depth). In both cases the data have been split into dives occurring during low flow (i.e. 2 hr periods within +/- 1 hour of slack water) and high flow (4 hr periods between the low flow periods). Time of slack water was estimated by assuming that it occurred approximately one hour after local high or low water times (assumed to be equidistant between HW and LW times for Kyle of Lochalsh and Glenelg Bay).

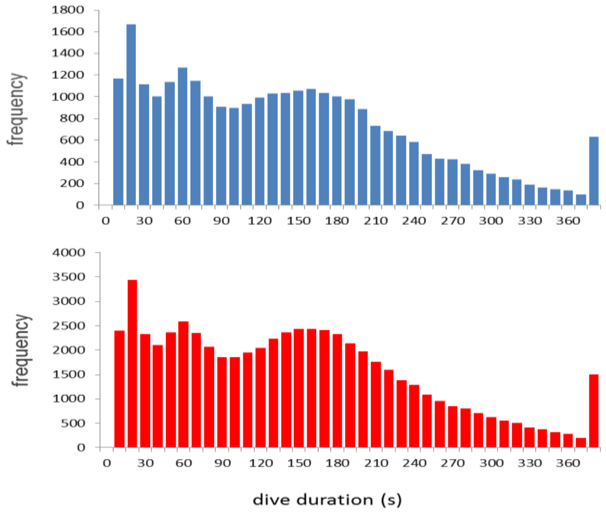


Figure 13. Frequency histograms of dive durations for all dives occurring within Kyle Rhea. Blue represents dives in low flow and red represents dives in high flow periods (see text for details).

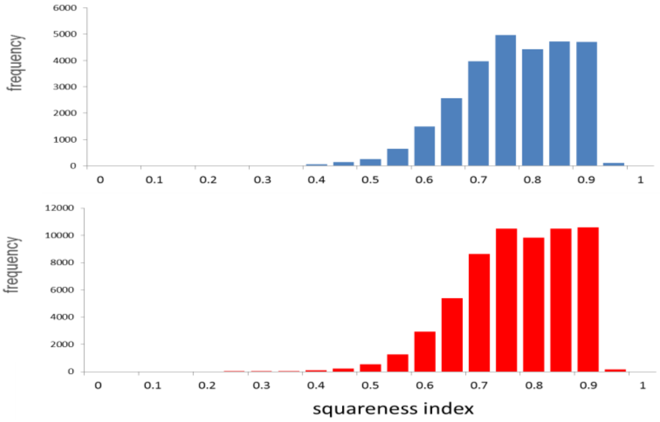


Figure 14 Frequency histograms of dive squareness index for all dives occurring within Kyle Rhea. Blue represents dives in low flow and red represents dives in high flow periods (see text for details).

In both cases the pattern for the two states of tidal flow were similar, suggesting that dive behaviour in terms of dive durations or proportion of time spent at the bottom of the dive does not vary with stage of tide.

7.5 Timing of haulouts and foraging trips within Kyle Rhea.

An examination of the timing of diving bouts and haulout events in Figure 11 suggests that there may be a relationship between haulout times and local HW times. The timing of swimming and hauling out within the high tidal flow area is important for scaling collision risk. The transmitters log the start and end times of haulout events and transmit these along with a haulout identifier number to show when haulout events have been missed in the data record. To examine the relationship between haulout events and local tidal flow we plotted a frequency histogram of haulout start times expressed as time from nearest HW time (Figure 15).

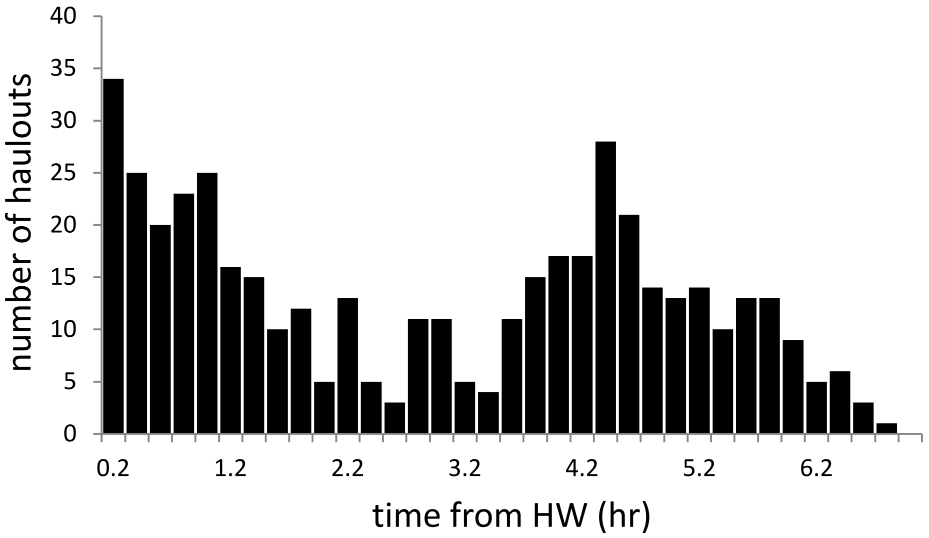


Figure 15. Frequency histogram of the start times for all haulout events within Kyle Rhea, relative to time of local HW, by all seals.

There is a clear bi-modal pattern to the times of haulout relative to the stage of tide, with one peak centred on local HW and another centred around 4.5 to 5 hours from HW. The simplest inference is that the seals were tending to haulout at or close to slack water in Kyle Rhea during April to July. However, that period includes the pupping and breeding season for harbour seals. We therefore split the haulout data into pre-breeding (defined as April and May) and breeding (June and July). The bimodal pattern appears to be largely due to a shift in timing of the start of haulouts from around HW in April-May to LW in June July (Figure 16).

Commensurate with the change in haulout timing there was also a shift in the durations of haulout events (Figure 17) and foraging trip durations (Figure 18). The mean durations of haulout events in Kyle Rhea increased from 3.9hr in April-May to 5.2hr in June-July and the durations of diving bouts/foraging trips increased from 9.1hr in April-May to 18.1hr in June-July.

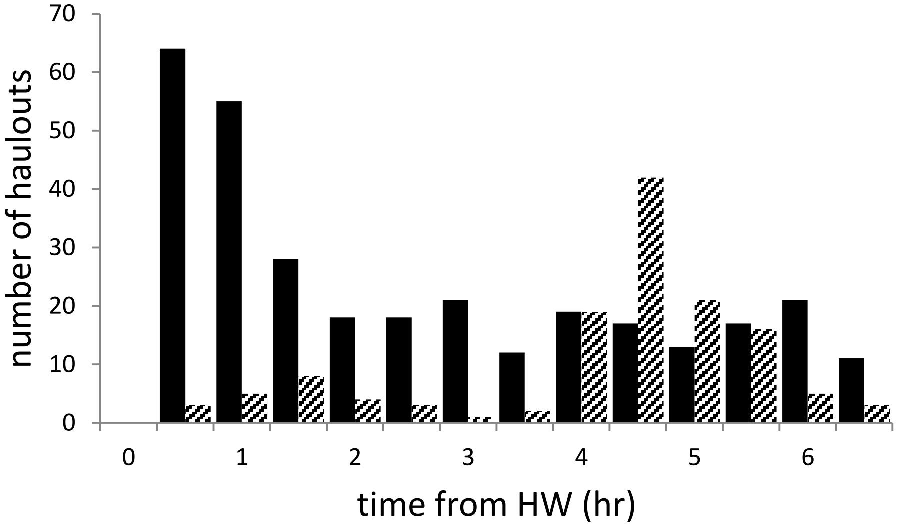


Figure 16. Frequency histogram of the start times for all haulout events within Kyle Rhea, relative to time of local HW, split into pre-breeding (solid) and breeding (striped) seasons.

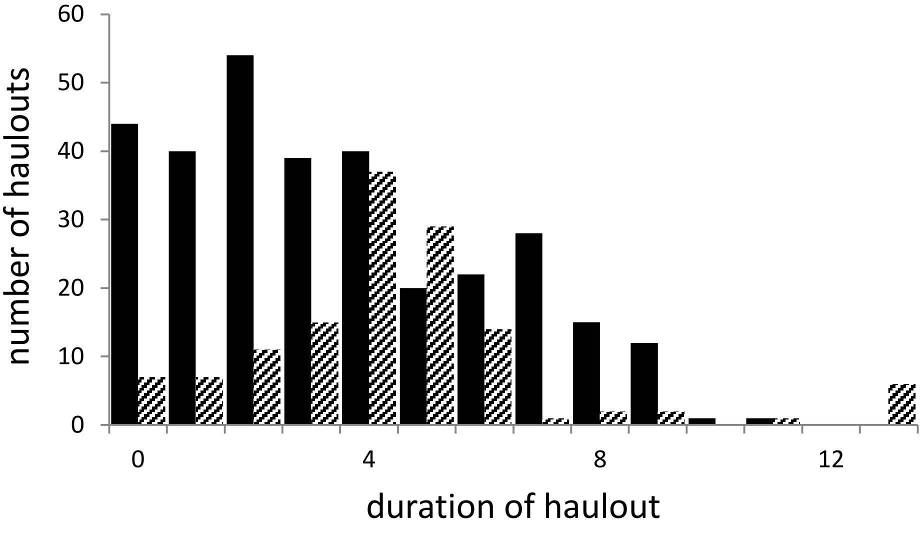


Figure 17. Frequency histogram of the durations of all haulout events within Kyle Rhea, split into pre-breeding (solid) and breeding (striped) seasons.

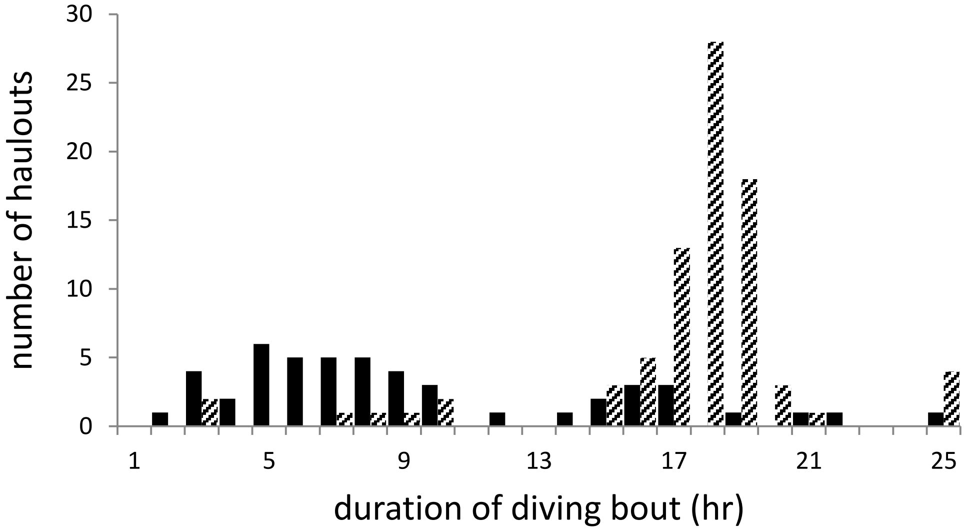


Figure 18. Frequency histogram of dive bouts/foraging trips that both started and ended in Kyle Rhea, split into pre-breeding (solid bars) and breeding (striped bars) seasons.

8 Discussion/ Conclusions

- Fine scale telemetry data have been collected from adult harbour seals during the summer period when there are significant numbers of seals in Kyle Rhea. It is not known why seals are present only in the summer months in Kyle Rhea, but the arrival of large numbers of seals and their intense diving activity within the channel suggests that they are exploiting a concentrated and valuable seasonal food resource.
- At present we have little information on fine scale re-distribution of harbour seals throughout the year and we do not know if this type of strong seasonal pattern of haulout site use is a widespread phenomenon. Clearly, the presence or absence of seals for long periods will have a major impact on collision risk.
- Only two of the tagged seals made extensive movements outside the channels between Skye and the mainland and even these two seals spent the majority of the tagging study within the channels. The remaining seven seals spent their time foraging in the tidal channels. Over half of all seal swimming activity occurred within the narrows at Kyle Rhea.
- The extensive (in some cases exclusive) use of tidal race areas, seeming to move forwards and backwards with the tide and repeatedly diving to or close to the bottom suggests that the seals were using the tidal rapids for foraging.
- Movement patterns within Kyle Rhea suggest that seals are moving in and out of the current in order to remain within the channel and the pattern of diving is highly variable within the narrows with a wide

range of dive shapes and variable maximum dive depths suggesting either extensive mid water diving or rapid changes in bottom topography as the seals move around the channel.

- Despite the difficulties in assigning seabed depths to individual dive locations it seems likely that some dives at least are going to or close to the seabed. In most dives the majority of the time/effort is spent at or close to the maximum depth (>40%) or at the surface (20%), with rapid transit between the two. If these are to the bottom then the dive patterns suggest that seals will be spending little time in mid-water when foraging. Similar patterns have been recorded in juvenile grey seals exploiting tidal rapids around North Wales (Thompson 2012).

- Examination of the fine scale movements of seals in the tidal rapids in Kyle Rhea suggests that when passing through such an area seals are widely distributed in the channel with respect to both depth and distance from shore.

- All of the seals tagged in Kyle Rhea swam repeatedly through the channel in the vicinity of the proposed turbine deployments. We presented an example of how seals were distributed in the water column as they passed through one section of the channel. The filtered data shows a clear bimodal pattern in transits with respect to distance from the shore, with transits being less frequent in the central, deeper section of the channel. In addition, there appears to be a reduced density of transits in mid-water through the central deep channel. This would be an expected consequence of the dive profile patterns and has clear and important implications for estimating collision risk. However, the interpolation error due to timing of GPS fixes and the small but significant GPS position error means that the transit depth and location data will still contain substantial error. These combined errors will bias the estimates of the number of transits through specific subsections of the channel. It will lead to underestimates of the passage rates for heavily used sections and overestimates for sections that seals avoid. A higher GPS sampling rate with fixes at every surfacing will substantially improve such estimates (see below).

- Harbour seals make extensive use of the high tidal energy area in Kyle Rhea throughout the summer months. Under the simple assumption that the presence of turbines will not affect diving behaviour and movement patterns there would clearly be a potential risk of collision with tidal turbines deployed in Kyle Rhea. Some seals remained in the vicinity of the sites for many weeks and made repeated transits through the proposed tidal array area.

- One important caveat that applies to any baseline study of this type is that we do not yet know to what extent different species of marine mammal can detect and avoid tidal turbines. Such information can only come from direct observations of animals interacting with real devices. To date the only study of the movements of harbour seals in relation to a functioning tidal turbine was conducted in Strangford Narrows, Northern Ireland. In that case there was some indication that seals transited less frequently during periods of turbine operation. The spatial resolution of the data was not sufficient to determine whether seals made fine scale avoidance manoeuvres (Keenan et al. 2011). The seals tracked in the present study were not reacting to any form of device. It is therefore not known whether the observed transit rates through the channel will be indicative of their behaviour in the presence of operating devices. This study therefore does not provide any information to allow us to directly estimate the likelihood that seals will collide with devices, only the likelihood that animals might be in the vicinity of and therefore have the potential to interact with devices.

- Future work planned for summer 2013, as part of the NERC/Defra funded RESPONSE project, will include use of higher temporal resolution GPS tags on harbour seals caught at the same haulout sites in Kyle Rhea. These data should allow us to further refine the description of diving behaviour and movement patterns.

9 References

Band, W., M. Madders, and D. P. Whitfield. 2007. Developing field and analytical methods to assess avian collision risk at wind farms. Pages 259–275 in M. de Lucas, G. F. E. Janss, and M. Ferrer, editors. *Birds and wind farms: risk assessment and mitigation.* Quercus, Madrid, Spain

Gerritsen, J. and J. R. Strickler (1977). "Encounter Probabilities And Community Structure In Zooplankton - Mathematical-Model." Journal of the Fisheries Research Board of Canada **34**(1): 73-82.

Keenan, G., C. Sparling, Williams,H. and Fortune,F. (2011). SeaGen Environmental Monitoring Programme Final Report. Haskoning U.K. Ltd., Edinburgh, U.K. & Marine Current Turbines.

Linley, A., Laffont, K., Wilson, B., Elliott, M., Perez-Dominguez, R. & Burdon, D (2009). "Offshore and coastal renewable energy: Potential ecological benefits and impacts of large scale offshore and coastal renewable energy projects. ." NERC Marine Renewables Scoping Study Final Report

Thompson, D. (2012). Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh waters (on behalf of the Welsh Government). Phase 2: Studies of Marine Mammals in Welsh High Tidal Waters: Annex 1 Movements and diving behaviour of grey seals JER3688 R 120712 HT. **www.marineenergypembrokeshire.co.uk**.

Wilson, B., R. S. Batty, Daunt, F. & Carter, C.. (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.

Wilson, B. and J. Gordon (2011). Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh waters Phase 1 - Desktop Review of Marine Mammals and Risks from Underwater Marine Renewable Devices in Welsh waters On Behalf of The Welsh Assembly Government JER3688R101122 BW Phase 1