

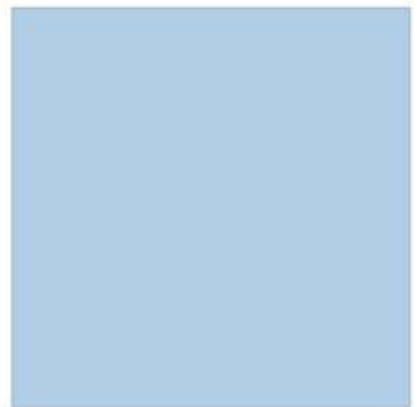


Llywodraeth Cymru  
Welsh Government

# 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

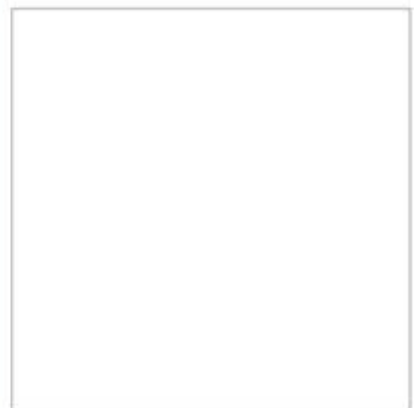
### Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy



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## Quality Management

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## Acknowledgements

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## Executive Summary

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The Marine Renewable Energy Strategic Framework for Wales (MRESF) provides for the sustainable development of marine renewable energy in Welsh waters. As one of the recommendations from the Stage 1 study, a requirement was identified for further evaluation of the occurrence and use of Welsh waters by marine mammals (cetaceans and pinnipeds), and for an initial assessment of the potential risks to these receptors from marine renewable devices. The Phase 1 report for the 'Assessment of Risk to Marine Mammals from Underwater Devices in Welsh waters' (Wilson and Gordon, 2011) is a desk based review of the potential impacts from marine renewables devices on marine mammals. The Phase 2 report (Gordon *et al.*, 2011), to which this report forms an Annex, focuses on providing additional baseline characterisation information of the occurrence and use of Welsh waters by marine mammals. The Phase 2 report covers both cetaceans (whales, dolphins, porpoises) as well as pinnipeds, in this case, grey seals (*Halichoerus grypus*). This Annex provides an assessment of the grey seal tagging study undertaken in autumn 2009 and 2010.

With the exception of a few visual sightings made during cetacean surveys, all the information on seal movements and behaviour has been collected using high resolution fastloc Global Positioning System (GPS) and depth tags which relay data back via the Global System for Mobile Communications (GSM) mobile phone network. These were attached to newly weaned grey seal pups at breeding beaches close to high tidal current sites at the Skerries, Bardsey Island and Ramsey Island in October of 2009 and October and November of 2010. Typically, pups spent the first month or so in waters close to their breeding beaches, spending most of this time in tidal rapid areas, apparently drifting with the current and repeatedly diving to the bottom in a pattern characteristic of foraging dives. With time, animals travelled more widely, one ranging as far as the west of Brittany. In several cases however, seals found other high tidal current areas and appeared to drift and forage within these in a similar way. It is therefore clear that during the first few months of life, when individuals might be expected to be most vulnerable, young seals are making extensive use of high tidal current areas.

Pups from both Ramsey and Anglesey dispersed widely by the end of the study, with seals from both sites moving to south east Ireland and Cornwall.

Dive patterns show that grey seal pups spend the majority of their time either at the surface or close to the maximum dive depth which is usually the sea bed. They swim

directly to the bottom and therefore spend relatively little time in mid water where they would be at risk from collision with tidal turbine blades risk.

Movement patterns in areas of high tidal flow close to the Skerries and in Ramsey sound show that there is wide variation in rates of transit between individuals. Most seals transited through the tidal rapids but one seal at each of the sites performed approximately 70% of the transits. This extreme variation would presumably translate into a wide variation in the likely exposure to collision risk.

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### *Appendix 1      Parameter Settings for Data Logging*

# 1 Introduction

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- 1.1.1 The Marine Renewable Energy Strategic Framework for Wales (MRESF) provides for the sustainable development of marine renewable energy in Welsh waters. As one of the recommendations from the Stage 1 study, a requirement was identified for further evaluation of the occurrence and use of Welsh waters by marine mammals (cetaceans and pinnipeds), and for an initial assessment of the potential risks to these receptors from marine renewable devices. The Phase 1 report for the 'Assessment of Risk to Marine Mammals from Underwater Devices in Welsh waters' (Wilson and Gordon, 2011) is a desk based review of the potential impacts from marine renewables devices on marine mammals. The Phase 2 report (Gordon *et al.*, 2011), to which this report forms an Annex, focuses on providing additional baseline characterisation information of the occurrence and use of Welsh waters by marine mammals. The Phase 2 report covers both cetaceans (whales, dolphins, porpoises) as well as pinnipeds, in this case, grey seals.
- 1.1.2 Given that some data on adult grey seals for Welsh waters is already available (see Gordon *et al.*, 2011), and the perception that juveniles seals are potentially at greater vulnerability to risks as a result of marine renewables devices (Wilson and Gordon, 2011), the focus of the study for grey seals has focused on collecting data on the movement and use of tidal areas by juvenile grey seal. Initial seal tagging (see Section 1.1.3 below) in autumn 2009 reported in the main report (Gordon *et al.*, 2011) was followed by additional tagging in autumn 2010, to allow for a more robust study of a number of individuals, given low numbers of juveniles available for tagging in 2009 and some tag failures.
- 1.1.3 The Sea Mammal Research Unit (SMRU) was contracted to carry out a telemetry-based study of the behaviour of grey seals at sea. The basic aims of the study were to track the movements and record the diving and swimming behaviour of individual juvenile grey seals, tagged at sites in Wales, and relate the observed behaviours to the potential for interaction with future tidal turbine installations in Welsh coastal waters. Twenty high Global System for Mobile Communications (GSM) phone tags with high resolution Global Positioning System (GPS) logging capabilities were available for the study. This allowed 10 tags to be deployed at Ramsey Island and 10 tags to be deployed in North Wales (eight at the Skerries in October/November 2009 and 2010 and two at Bardsey Island in October 2009).

## 2 Methods

### 2.1 Telemetry system

2.1.1 An investigation of the scale of possible interactions with tidal turbine devices requires information on the 3D movements of marine mammals. Seals are extremely hard to see in open water and spend the majority of their time (>85%) submerged. They are effectively silent for most of the time and therefore cannot be accurately tracked using either visual or acoustic monitoring techniques (as used for harbour porpoise discussed in the main report). In addition, grey seals are known to make wide ranging movements between distant foraging and haul-out areas making it impossible to study individuals using any boat or land based monitoring method. In order to study the movement and dive patterns of seals at an appropriately fine scale, we used recently developed GPS Phone Tags, which combine GPS quality locations with efficient data transfer using the international GSM mobile phone network (Figure A1).



**Figure A1** *GPS phone tag*

2.1.2 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, high data bandwidth and international roaming capability (including Ireland and France).

2.1.3 The tags incorporate a Fastloc GPS sensor that offers either the possibility of attempting a location at every surfacing or as frequently as required. Less than a second is needed to acquire the information required for a location. The tags also use precision wet/dry, pressure and temperature sensors to form detailed individual dive (max depth, shape, time at depth, etc.) and haul-out records along with temperature profiles and more

synoptic summary records. Both location and behavioural data are then stored in memory for transmission when within GSM coverage.

- 2.1.4 For species such as grey seals that periodically come near shore – within GSM coverage – the entire set of data records stored in the memory can be relayed via the GSM mobile phone system. Visits ashore may be infrequent, so up to six months of data can be stored on-board the tag and these data can also be downloaded directly if the tag is retrieved.
- 2.1.5 A detailed description of the parameter settings in the data handling software is attached as Appendix A1.

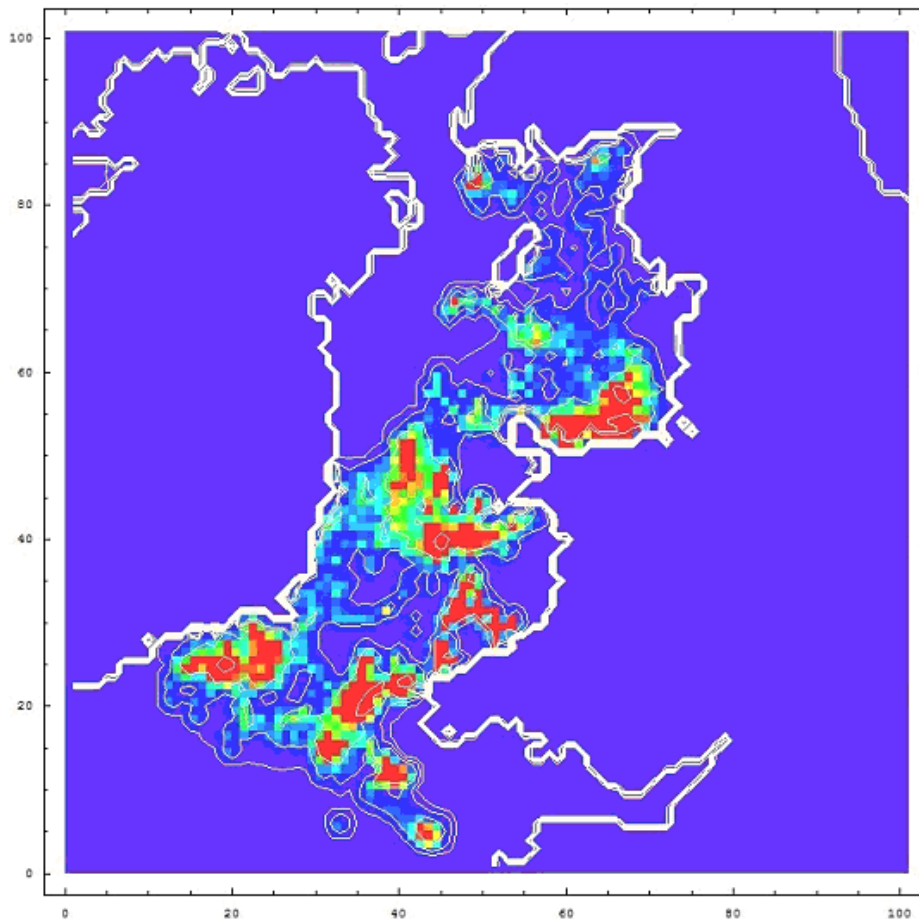
## **2.2 Timing of tagging and choice of study animals**

- 2.2.1 Two age classes of seal had been initially identified as being of prime interest, newly weaned pups and adult females. However, the project start date meant that there was no opportunity to catch adult females before September 2009. At this time of year females are generally returning to their breeding sites and do not range widely. In addition, the period of haul-out for breeding would mean that tags would not provide useful information for around a month, during which time they would be subject to additional problems of abrasion before being moulted off approximately one month later. Furthermore, a 2004 study using ARGOS satellite transmitter had already provided background data on movements and dive behaviour of adult grey seals in this region, whereas no equivalent data for pups were available.
- 2.2.2 Grey seal pups are abandoned on land and therefore enter the water as completely naïve animals with no experience of foraging and no established movement patterns. Breeding sites in North Wales are either in caves or on small islands which are often associated with strong tidal currents. Grey seal pups are therefore likely to be in areas of potential interaction with tidal generators during what is likely to be a vulnerable phase of their lives. After consultation with CCW, it was decided that the best strategy would be to concentrate the tagging effort on pups during their initial time at sea, with no tags fitted to adult females. For practical and logistical reasons, it was further decided that the tagging effort in 2009 should be concentrated in the vicinity of the Skerries, off Anglesey. In October and November 2010 additional transmitters were deployed at the Skerries and the study was extended to include a sample of pups at Ramsey Island in Pembrokeshire.

## Seal Movement Data

- 2.2.3 Seal track data can be examined in relation to locations of potential tidal turbine sites to estimate the length of time spent within specified distances of sites and in areas of strongest tidal energy. Dive behaviour data can provide a 3D picture of space use throughout the tracking periods. However, it is not possible to generate space usage maps for the grey seal pup database. There is only limited information on the size of the non breeding haul-out groups in the region and these data are not subdivided by age class. In the past we have used the non classified counts to scale up the at sea distribution information from a non age-structured sample of animals caught outside the breeding season during 2004. This relies on the simplifying assumption that the seals caught were effectively a random sample of the population and would be representative of the animals counted at haul-out sites. This assumption does not hold for the sample of pups. The seal pup data collected here represent a period of dispersal away from natal sites that is unlikely to mimic the distribution of the all age population. It would therefore be misleading to use the all age haul-out data to scale the at sea distribution of the pups. The data are therefore simply described in terms of where, when and for how long the pups were tracked.
- 2.2.4 For illustration the method for generating the space usage map for the previous all age sample is summarised below. The space usage analysis applied to the existing 'all age' tracking data set collected on 2004/05 all age sample comprised two stages, as described in Matthiopoulos (2003a, b) and Matthiopoulos *et al.* (2004), Data on the number of grey seals at haul-out sites around the Irish Sea are sparse. For the spatial analysis of the 2004 tracks data were taken from several sources:
- Scotland and Northern Ireland: data from SMRU aerial surveys in 1996-2008 (SCOS, 2009);
  - Irish Republic: data from aerial surveys and ground counts in 2003 (Cronin *et al.* 2004); and
  - Wales: ground count data (Westcott and Stringell, 2004; Keily *et al.*, 2000).
- 2.2.5 Numbers of seals associated with all known haul-out sites are grouped together, based on the telemetry data, to give a single figure for each of seven haul-out regions.
- 2.2.6 Argos location data were filtered to smooth the tracks and minimise the error associated with the locations before being included in the model. Tracks for each animal were split into individual trips, defined as beginning when an animal first dived to over 10 m after a haul-out period and ending when the animal hauled out again. Each trip was assigned to one of the seven haul-out regions.

- 2.2.7 Data on seal movement (speed, trip duration, locations of haul-outs, and obstacles to movement) were then used to calculate the accessibility of points at sea as a function of distance from the centre of a haul-out region (Matthiopoulos, 2003a). Maps of accessibility were used to inform estimation of space use by each seal. Estimates of uncertainty were calculated through combining estimates of usage for all tagged individuals. Usage maps were weighted for the number of seals within each haul-out region.
- 2.2.8 The main product from this analysis was a seal usage map, equivalent to a density contour plot for the estimated distribution of seal activity at sea. The usage map generated from deployment of 19 Argos satellite transmitters in 2004 is shown in Figure A2.



**Figure A2** The modelled at-sea usage for grey seals in the Irish Sea based on data from 19 satellite transmitters attached to adult grey seals in 2004.



## 3 Results

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### 3.1 Tagging

- 3.1.1 Based on observations of pup age classes during CCW field trips in early October 2009, and previous experience of the duration of lactation and post weaning fasting periods, a joint SMRU and CCW team visited the Skerries in late October 2009. Far fewer seal pups were present than had been expected, possibly as a consequence of the severe weather throughout mid and late October. Known breeding sites between Anglesey and Hells Mouth Bay were searched, including cave sites. In the event, just five pups of the correct developmental stage and condition were located, i.e. pups that were fully moulted (at least over the front half of the body), assumed to be weaned, greater than 37kg in mass and with no significant injuries. Of these five, three were found on the Skerries off Holyhead. The search area was extended and the two additional pups of suitable age and condition were found on Bardsey Island. All five pups were tagged on 22<sup>nd</sup> and 23<sup>rd</sup> October 2009.
- 3.1.2 In 2010 an additional five transmitters were deployed on weaned grey seal pups on the Skerries in early November and ten were deployed on weaned pups on the main breeding beaches on the west coast of Ramsey Island in Pembrokeshire in late October. Details of the timing, location and characteristics of the tagged animals are presented in Table A1.
- 3.1.3 All animal handling and tagging methods are approved and licensed under the Animals (Scientific Procedures) Act, under SMRU's Home Office Licence No. 60/4009. Standard transmitter attachment techniques were used. Briefly, seals were caught on land and physically restrained. In 2009 seals were physically restrained and tags were glued to cleaned, dried fur on the back of the neck using quickset Epoxy resin. No anaesthesia was required. In 2010 seals were physically restrained, given a low 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 (Loctite422). Seals were released and left at their capture site. In both 2009 at Bardsey and 2010 at Ramsey one seal went briefly into the shallows next to the beach within a few minutes of release but hauled out again within a few minutes. In general, seals moved a short distance along the beach (<100 m) after release and settled to rest.

**Table A1** *Details of tag deployments on grey seal pups in 2009 and 2010.*

Tag #	Sp.	Sex	Age Class	Mass (kg)	Tag life (days)	Tagging Date	Time	Location	Lat	Long
<b>2009</b>										
11367	Hg	F	MP	41.0	234	22/10/2009	10:55	Anglesey-Skerries	53.41791	4.60654
11160	Hg	M	MP	37.6	216	22/10/2009	10:30	Anglesey-Skerries	53.41791	4.60654
11335	Hg	M	MP	37.0	183	23/10/2009	17:00	Anglesey-Skerries	53.41791	4.60654
11368	Hg	F	MP	34.9	14	23/10/2009	13:00	Bardsey	52.75211	4.79651
11369	Hg	F	MP	32.5	63	23/10/2009	13:30	Bardsey	52.75211	4.79651
<b>2010</b>										
11751	Hg	M	MP	34.1	121	20/10/2010	12:39	Ramsey- Aber Mawr	51.86934	5.86233
11754	Hg	M	MP	36.6	152	20/10/2010	13:14	Ramsey- Aber Mawr	51.86934	5.86233
11425	Hg	M	MP	32.1	117	20/10/2010	13:03	Ramsey- Aber Mawr	51.86934	5.86233
11714	Hg	M	MP	29.1	37	20/10/2010	15:05	Ramsey- Aber Mawr	51.86934	5.86233
11002	Hg	M	MP	39.1	0	20/10/2010	15:43	Ramsey- Aber Mawr	51.86934	5.86233
11750	Hg	F	MP	39.1	234+	20/10/2010	16:01	Ramsey- Aber Mawr	51.86934	5.86233
11747	Hg	F	MP	38.6	234+	20/10/2010	14:05	Ramsey- Aber Mawr	51.86934	5.86233
11007	Hg	F	MP	36.5	0	20/10/2010	14:36	Ramsey- Aber Mawr	51.86934	5.86233
11369	Hg	F	MP	31.5	33	20/10/2010	18:58	Ramsey-Porth Lleuog	51.85874	5.34215
11335	Hg	F	MP	36.0	0	20/10/2010	18:18	Ramsey-Porth Lleuog	51.85874	5.34215
11748	Hg	F	MP	45.1	116	22/10/2010	08:03	Anglesey-Skerries	53.41791	4.60654
11599	Hg	F	MP	39.6	144	22/10/2010	09:02	Anglesey-Skerries	53.41791	4.60654
11571	Hg	F	MP	34.5	176	07/11/2010	09:20	Anglesey-Skerries	53.41791	4.60654
11752	Hg	F	MP	36.0	234+	08/11/2010	10:02	Anglesey-Skerries	53.41791	4.60654
11744	Hg	M	MP	35.0	234+	09/11/2010	10:35	Anglesey-Skerries	53.41791	4.60654

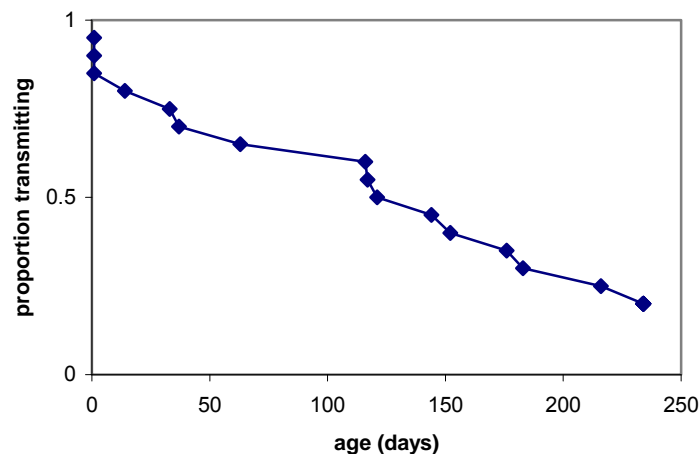
## 3.2 Tracking results

3.2.1 Seal movement data: In 2009, only five out of the eventual total of twenty seals were tagged. One seal died after 13 days at sea and one was 'rescued' after coming ashore in Cornwall after 62 days at sea. The three remaining devices continued to send location and dive data until the time at which their batteries should have been exhausted in late spring.

3.2.2 In 2009 highly detailed movement and dive behaviour records were received from all five tagged seals. Almost complete records of location, diving depths and durations were received from all five seals (Table A1). Tracking periods lasted 234, 216, 183, 63, 14 days. The two shorter deployments were terminated when one of the seals died and one was rescued. Continuous dive data were received for all five seals.

3.2.3 In 2010 highly detailed movement and dive behaviour records were received from all five seals tagged at the Skerries and seven of the ten seals tagged at Ramsey. Almost complete, continuous records of location, diving depths and durations were received from these 12 seals (Table A1). Three transmitters at Ramsey did not make contact

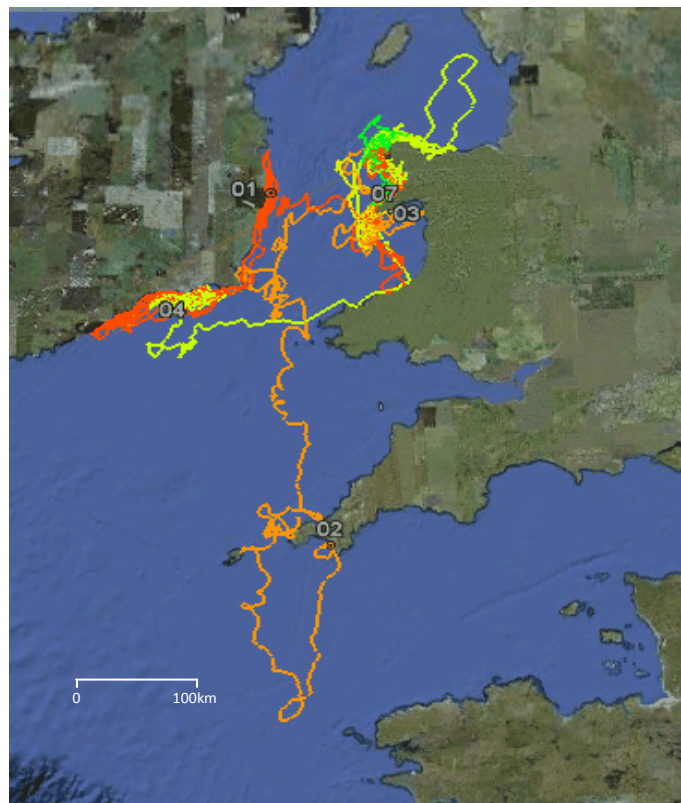
with any phone networks after release. The tagging sites on Ramsey were in radio shadow at the base of cliffs on the west side of the island. The GSM tags could not connect to any network from these beaches so no contacts were received before seals left the beach and swam to a location where phone reception was good enough for either an SMS message or a data transmission. No carcasses of tagged seals have been reported from Ramsey indicating that the seals did leave the beach. The absence of contact means that they did not come within range of a phone cell before either the tags failed or the pups died, probably during their first foraging trip. It is not possible to estimate how long these three tags continued to transmit. Several seals visited haul-out sites that did not have cell phone coverage so it is possible that the missing seals survived for several foraging trips. Figure A3 shows the proportion of animals transmitting data as a function of time since tagging. The plot shows a gradual almost linear decline similar to results from other grey seal and harbour seal (*Phoca vitulina*) pup studies (SMRU unpublished data). The decline over the first four months is most likely due to pup mortality with tag failure becoming the dominant feature during the later period. There are insufficient data to calculate the mortality rate and tag failure rates with reasonable confidence, but the plot does not indicate a greatly enhanced tag failure rate or unusual mortality pattern for weaned pups.



**Figure A3** Proportion of GSM tags still transmitting as a function of time since tagging, for all deployments in 2009 and 2010.

3.2.4 Figure A4 shows the swimming tracks of all five seals tagged in 2009, with the end points of their tracks indicated by the tag ID numbers. The three pups tagged on the Skerries spent 26-39 days foraging close inshore around Anglesey before moving away (Figure A4). Seal 01 spent 30 days foraging around Anglesey before moving to Bardsey Island. It made two short trips into Cardigan Bay before moving to Ireland where it spent

6 weeks foraging close inshore along the east coast before moving to the Saltee Islands. Seal 04 spent 10 weeks foraging in coastal waters around Anglesey, within 15 km of the coast. It then made a single round trip to an area off the Cumbrian coast approximately 105 km to the north east, close to Barrow in Furness before moving to the Saltee Islands in south east Ireland. It continued to forage along the south coast of Ireland until it was by-caught and drowned in a creel (the transmitter was recovered, refurbished and deployed in 2010). Both seals foraged primarily within 10 km of the Irish coast and generally within 30 km of their most recent haul-out site. The third Skerries pup (Seal 07) spent five weeks foraging close inshore around the north of Anglesey before moving to a haul-out site on the Llŷn Peninsula. It spent 20 weeks making short foraging trips to an area 10 to 15 km north east of its haul-out site, staying within 10 km of the coast. In all three cases foraging was mainly restricted to waters within 10 km of the shore and within 30 km of their haul-out sites.



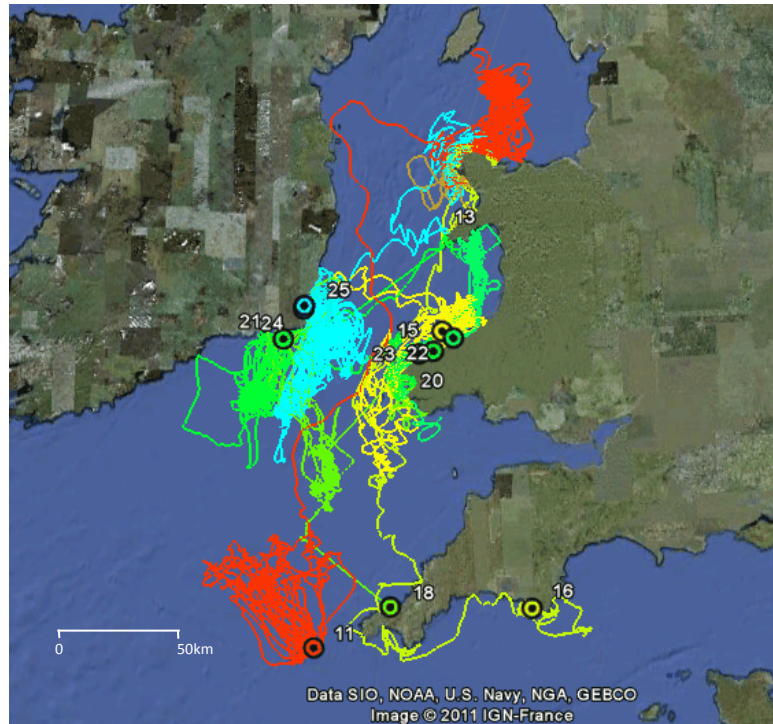
**Figure A4** *GPS tracks of three grey seal pups tagged on Skerries, Anglesey and two grey seal pups tagged on Bardsey Island in 2009. All five seals spent an initial period foraging close to their natal sites before moving away.*

3.2.5 Both Bardsey pups spent the first two to four weeks foraging close to their pupping site, again apparently in high tidal energy areas (Figure A 4). Seal 02 initially spent 28 days

foraging within 30 km of its tagging site. It then began a period of continuous movement, going to Anglesey, then to the coast near Rosslare in Ireland, west Cornwall and the Scilly Isles. It did not appear to develop a fixed foraging pattern at any site and after a final swim from the Scilly Isles to an area 40 km west of Brittany it returned to Cornwall and was caught onshore and taken to a seal sanctuary. This seal had lost approximately 30 % of its weaning mass by the time of capture. Had it not been caught, it would probably not have survived the winter.

Seal 03 made a series of foraging trips 30 to 50 km from Bardsey Island. It was subsequently found dead on shore, 13 days after leaving the pupping site. Initial inspection indicated that the seal was apparently in good condition and showed no signs of injury associated with the transmitter. Results of a formal post mortem did not ascertain the cause of death. Wounds were found on the side of the abdomen and close to the anus but these showed clear signs of damage by scavenging birds. Examination of the dive profiles during the last trip to sea did not provide any indication of the cause of death. The seal performed an apparently normal sequence of short benthic dives ending with one long (10 minute) duration dive and an apparently normal ascent to within 2 m of the surface. The transmitter's wet/dry sensors then remained wet until the seal stranded, implying that it did not surface to breathe.

3.2.6 Figure A5 shows the complete swimming tracks for all seals tagged in 2010. The movement patterns in 2010-11 were similar to 2009-10 data in that they show a high degree of variability in both the extent of movement and the timing of the long range movements.

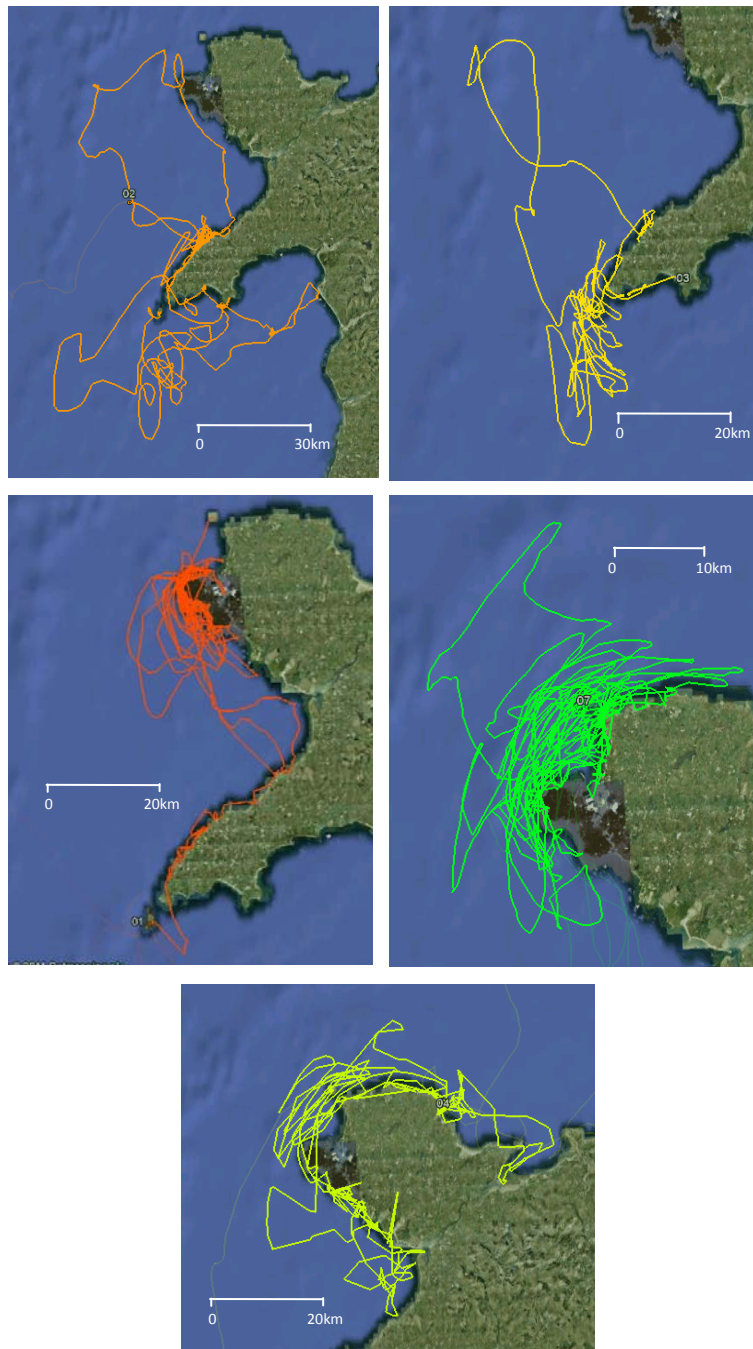


**Figure A5** GPS tracks of five grey seal pups tagged on Skerries, Anglesey and seven grey seal pups tagged on Ramsey Island in 2010 (three seals that did not make phone contact have been omitted). All five seals in Anglesey spent an initial period foraging close to their natal sites before moving away, the pattern at Ramsey was less clear.



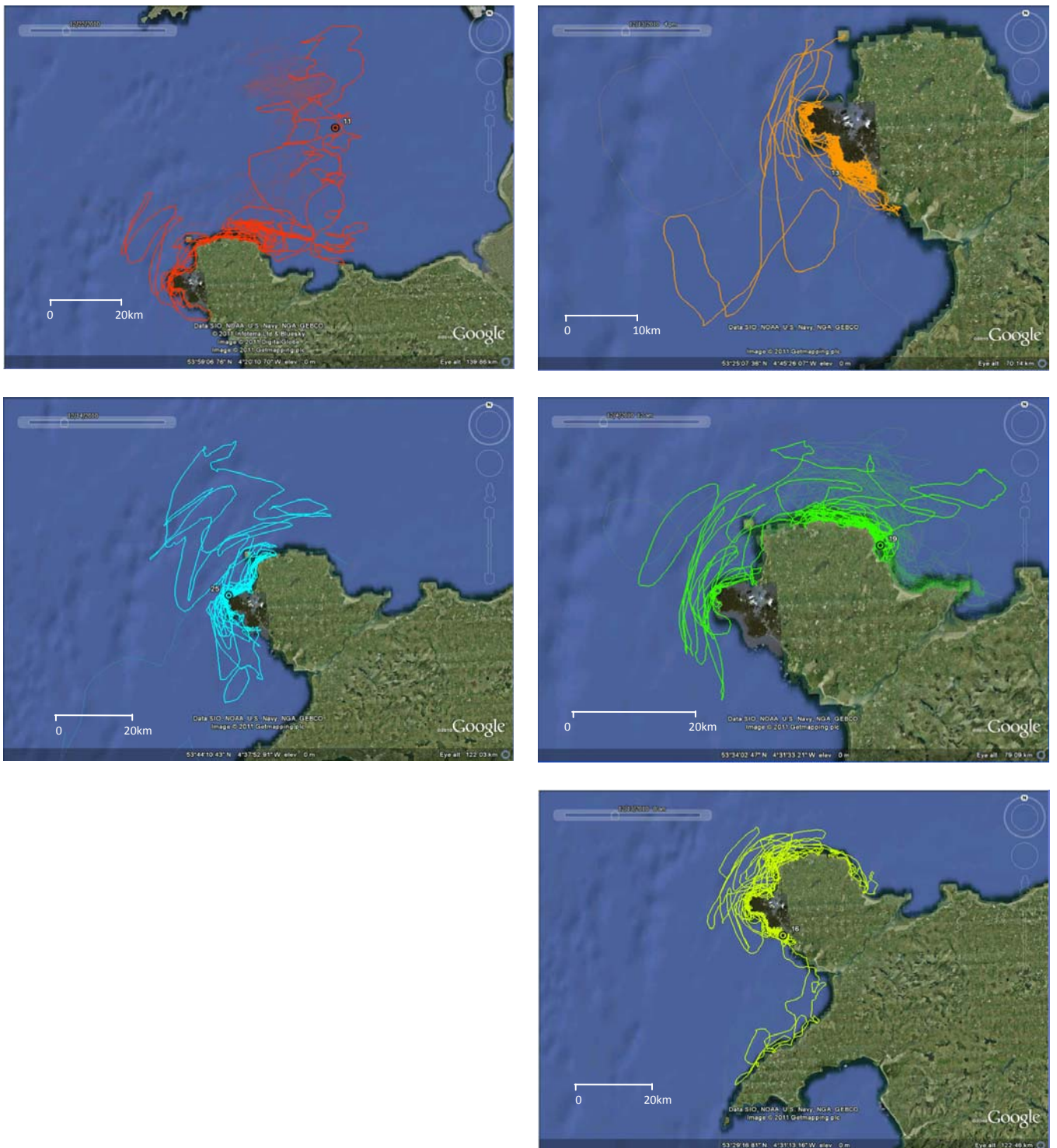
### 3.3 Initial naïve movement patterns

3.3.1 The primary reason for this research into the movements of grey seal pups is that two of their main breeding sites in Wales are adjacent to prospective tidal turbine development sites. As grey seal pups are weaned and abandoned on land it is clear that naïve pups will enter the water near these devices. The likelihood of interactions between these inexperienced animals and tidal devices is not known, but clearly the probability of interaction will be related to the amount of activity in the vicinity of the pupping sites. Figure A6, A7 and A8 show the movement patterns of eight juvenile seals from the Skerries, two from Bardsey Island and seven from Ramsey Island during the initial five weeks of tracking data, representing their initial naïve foraging movements. As with the long-term movements there is a high degree of variation and no clear pattern from any of the locations. Most but not all seals spent a period of time swimming and presumably foraging in the vicinity of their natal sites (Figure A6 to A11). Seals tagged at the Skerries spent longer periods foraging in the vicinity of the sites and showed a greater tendency to forage close to shore. All but eight remained within 50 km of the site during the first five weeks of foraging. At Ramsey the pattern was less obvious. Several seals moved directly away from the site, to locations along the west coast or to remote sites in south east Ireland and none of the animals was resident at Ramsey Island by the end of the first five weeks. Five weeks after tagging, no seals were found within 30 km of Ramsey Island, whereas four seals were still foraging within 30 km of the Skerries in the combined 2009-10 and 2010-11 samples.

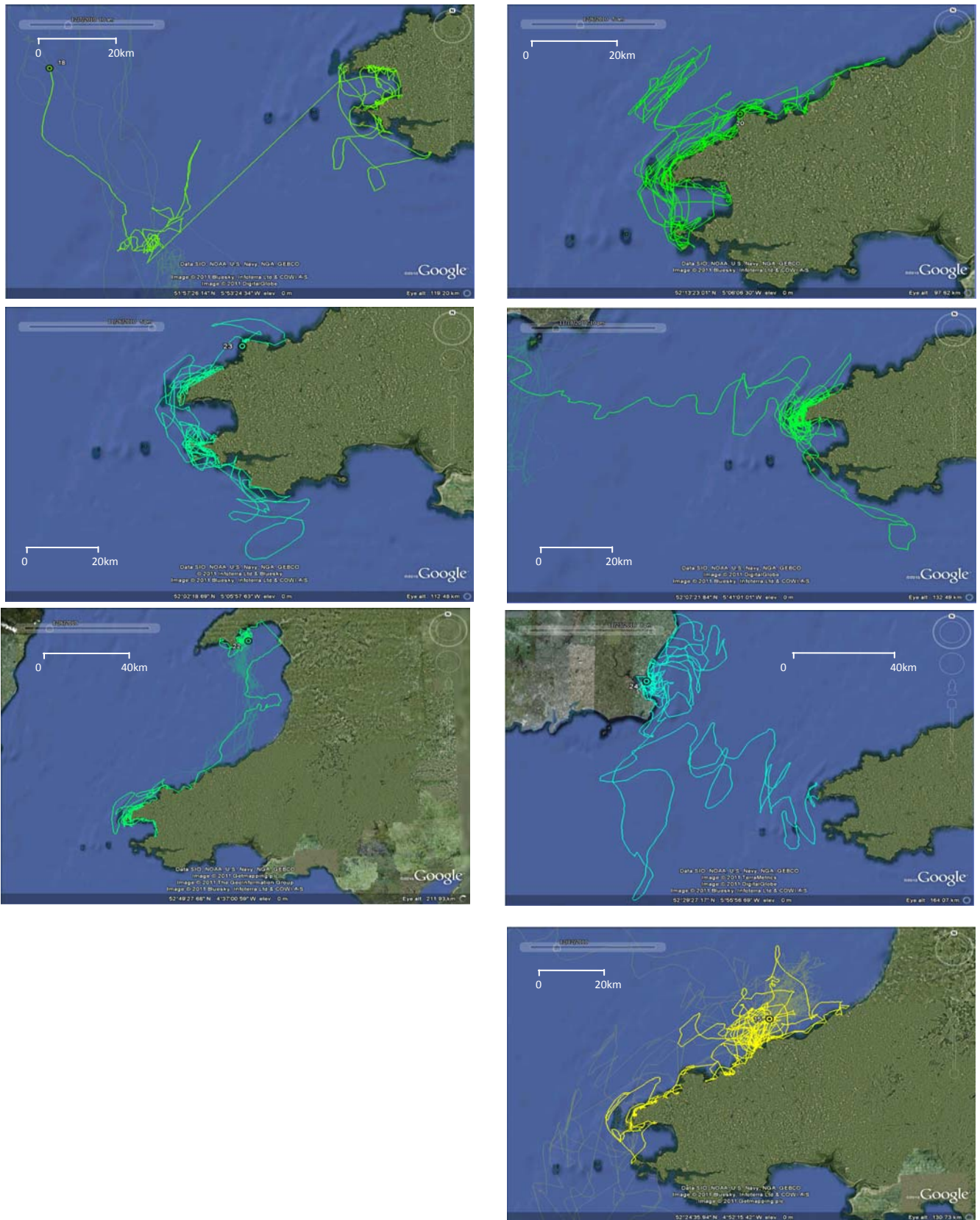


**Figure A6** GPS tracks of grey seal pups tagged on Bardsey Island (a & b) and on the Skerries (c, d, e) during the first 5 weeks after tagging in October 2009

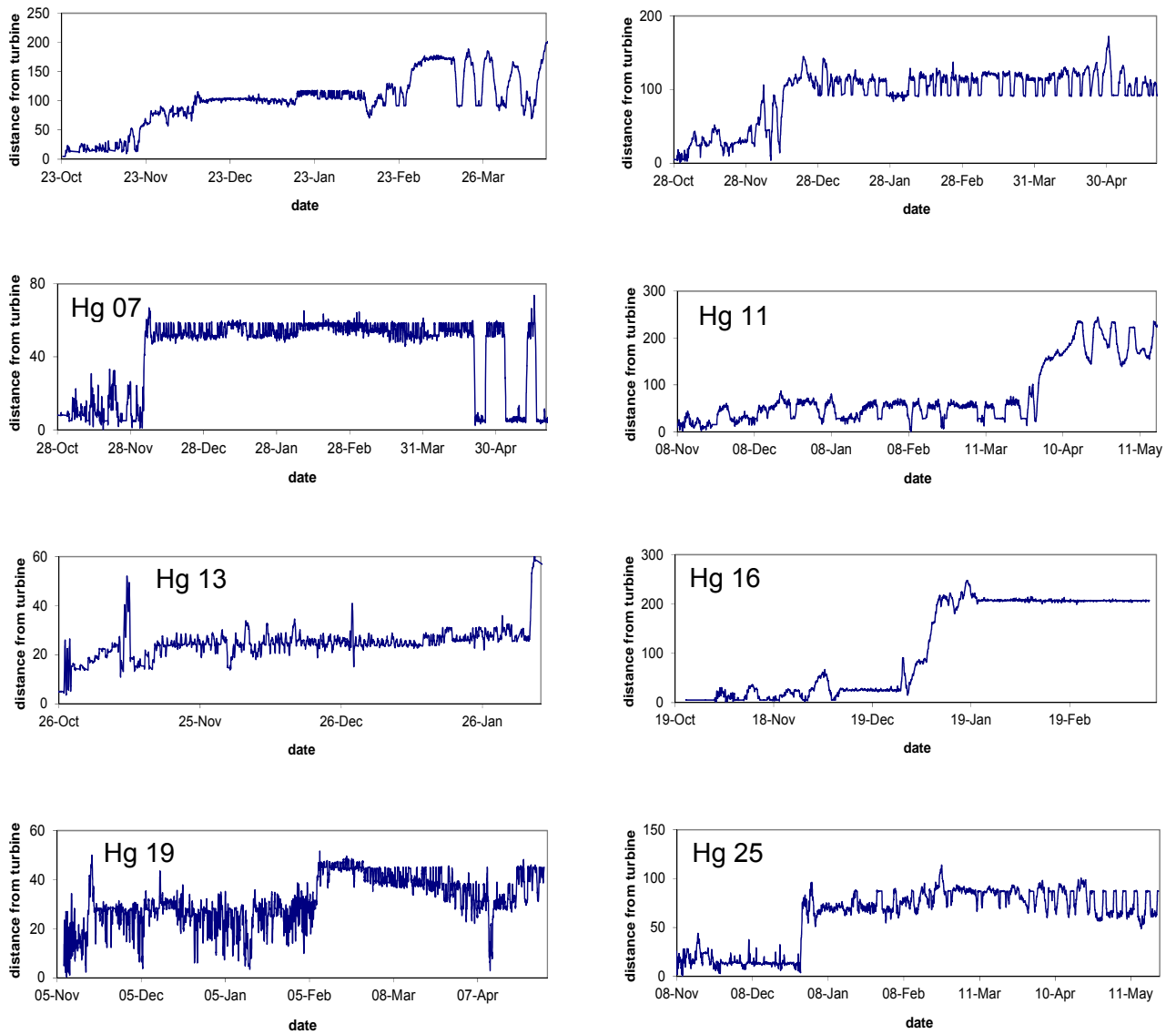




**Figure A7** GPS tracks during the first 5 weeks after tagging of five grey seal pups tagged on the Skerries off Anglesey, November 2010.

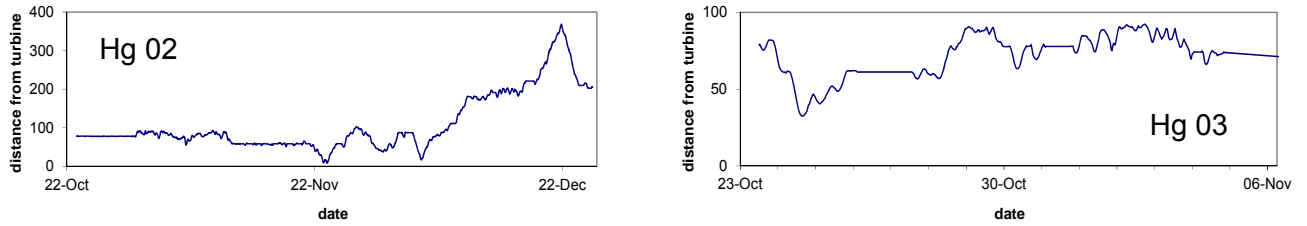


**Figure A8** GPS tracks during the first 5 weeks after tagging, of seven grey seal pups tagged on Ramsey Island, October 2010.

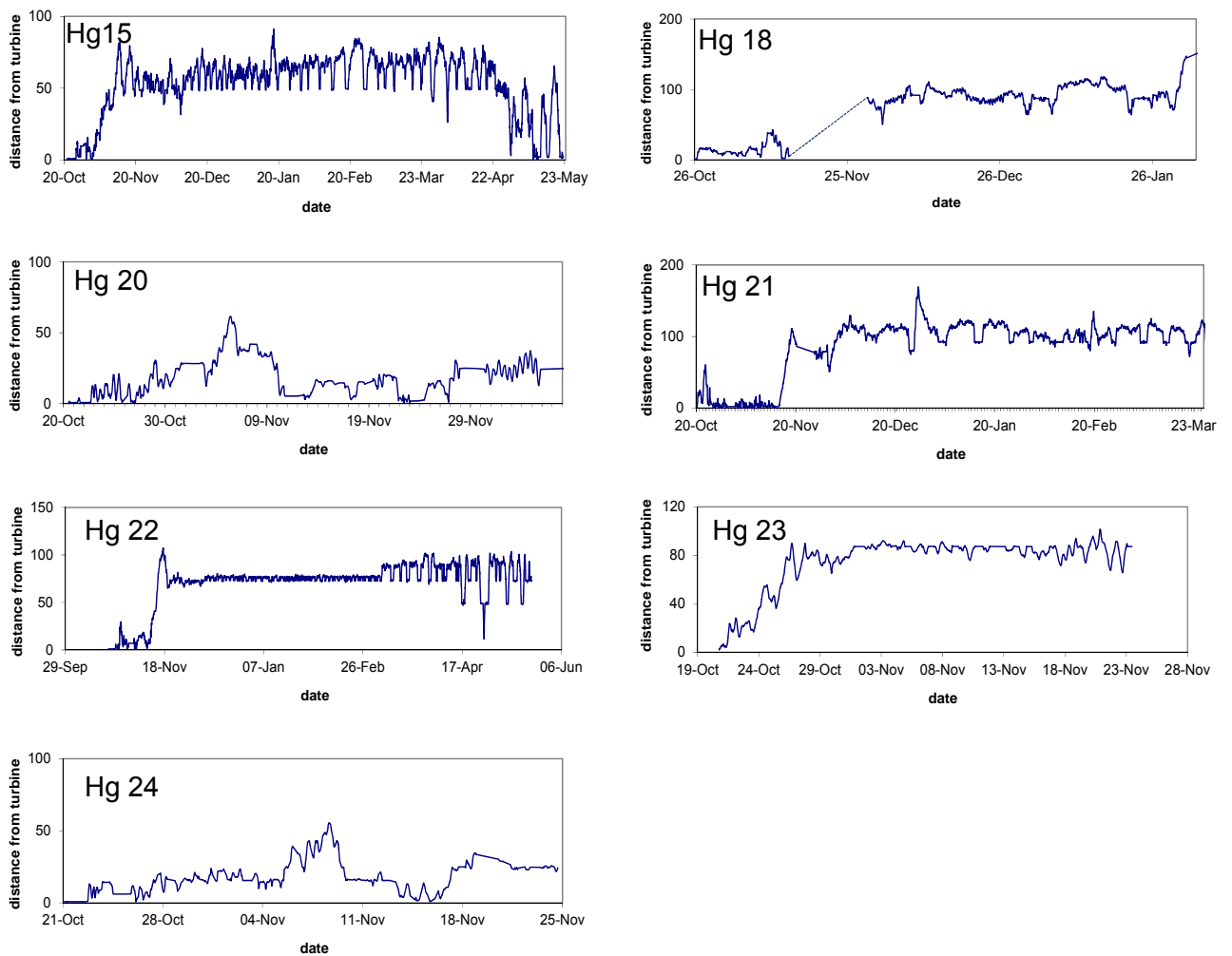


**Figure A9** Distance from nearest tidal turbine site (either Skerries or Ramsey Sound) of all location fixes for eight seals tagged at the Skerries off Anglesey. Tags 1, 4, 7 in 2009-10; 11, 13, 16, 19, 25 in 2010-11.



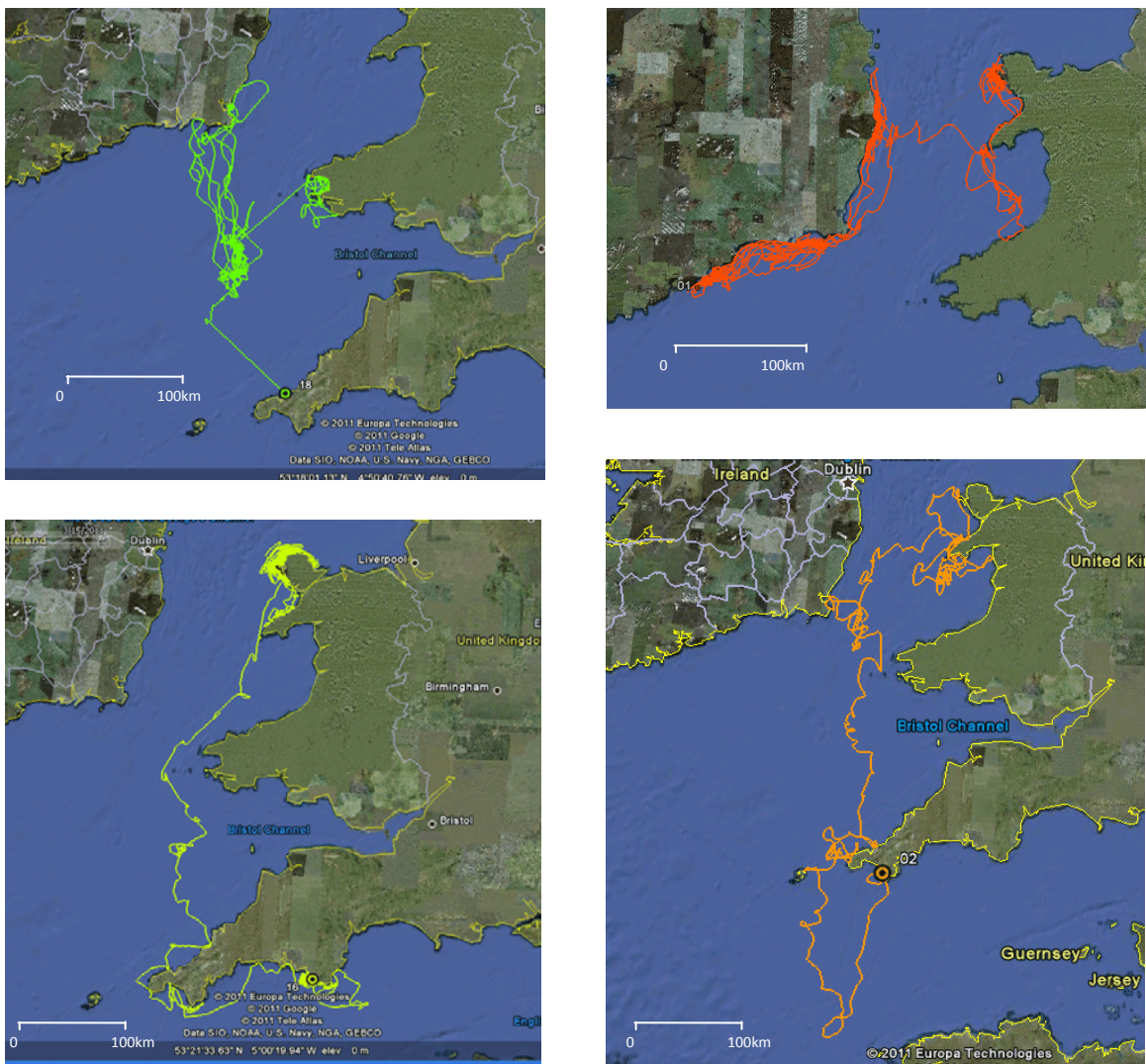


**Figure A10** Distance from nearest tidal turbine site (either Skerries or Ramsey Sound) of all location fixes for two seals tagged at Bardsey Island (2009-10).



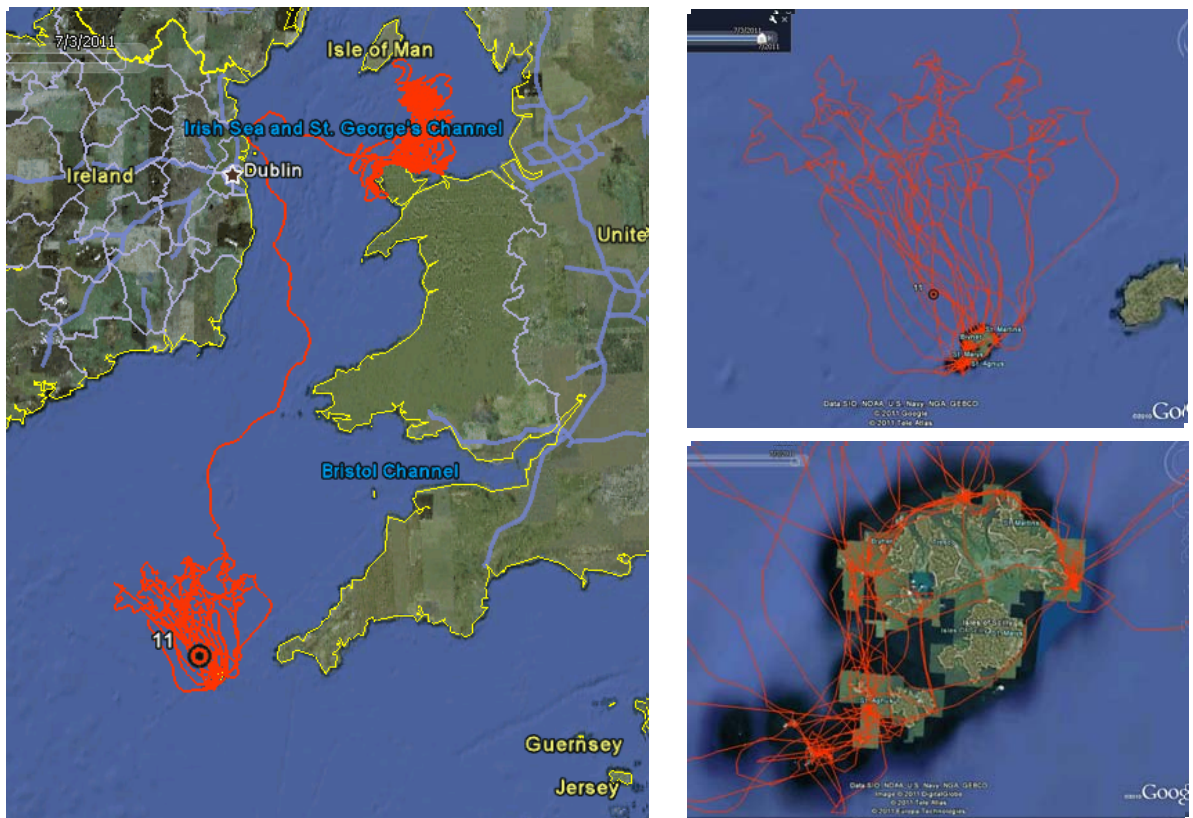
**Figure A11** Distance from nearest tidal turbine site (either Skerries or Ramsey Sound) of all location fixes for seven seals tagged on Ramsey Island (2010-11). Three seals that did not communicate with the cell phone network after tagging have been omitted.

3.3.2 Many of the seal pups performed wide ranging movements at irregular stages in their early months. Figure A12 shows movements by four pups, two from Anglesey and one each from Bardsey and Ramsey. Each shows a long range movement away from the natal site. This has been seen in studies of juvenile grey and harbour seals in the past (Bennett *et al.*, 2010) but has usually been assumed to represent an initial period of dispersal away from the natal area. Although such early movements did occur in our sample, a striking occurrence was the frequency with which seals moved long distances away from areas where they appeared to have settled into established, regular patterns of foraging trips to specific areas.



**Figure A12 Complete GPS tracks of a selection of four seals tagged at Ramsey, Bardsey and Anglesey showing wide ranging movements. Contrary to assumptions of initial dispersal followed by settled foraging, many of the Welsh pups showed wide ranging movements throughout the tracking period, sometimes after long periods of apparently settled foraging behaviour.**

3.3.3 Figure A13 shows the complete GPS tracks of a grey seal pup tagged at the Skerries off Anglesey in 2010. The seal showed an apparently settled foraging pattern spending the first three months making repeated trips between haul-out sites in North Anglesey (at the Skerries and Carmel Head) and a foraging area to the north, approximately half way between Anglesey and the Isle of Man. It then moved in one continuous trip from Anglesey to the Isles of Scilly from where it performed a regular pattern of foraging trips to an area approximately 60 km to the north of the Isles of Scilly. Within the Isles of Scilly the seal visited all known haul-out sites.

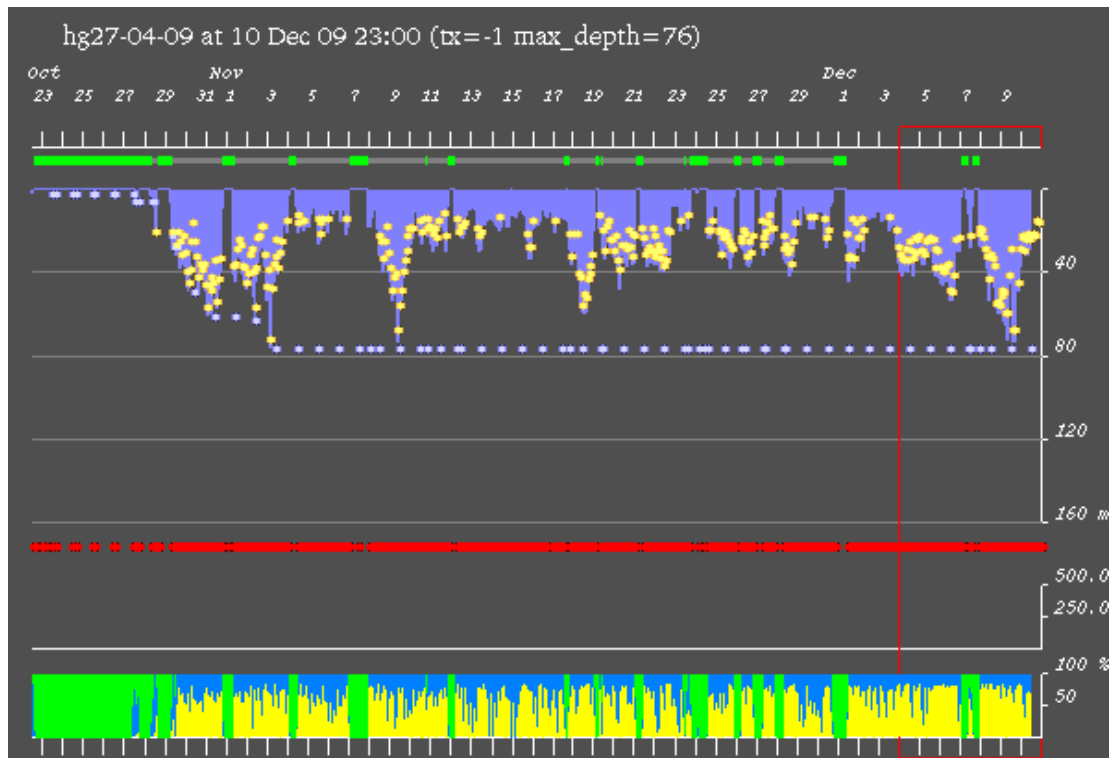


**Figure A13 Complete GPS tracks of a grey seal pup tagged at the Skerries off Anglesey showing wide ranging movements and two widely separated foraging areas one between Anglesey and the Isle of Man and the other to the north of the Isles of Scilly. Within the Isles of Scilly the seal visited all known haul-out sites.**

3.3.4 Such wide ranging and apparently unpredictable movements between distant haul-out sites and the use of widely separated foraging areas at different times has major implications for the management of seal populations in the south west of the UK and southern Ireland. The tracking data generated here has implications for seal management strategies at both national and local levels.

### 3.4 Dive behaviour

3.4.1 Figure A14 shows an example of the summary data from the dive depth and haul-out sensors. The data presented are simple two hour summaries of maximum depth and time spent dry at the surface or on land. Similar data are available for all five pups for which records have been received so far. The raw dive data, i.e. detailed depth time profiles and accurate surface times are available for all animals.

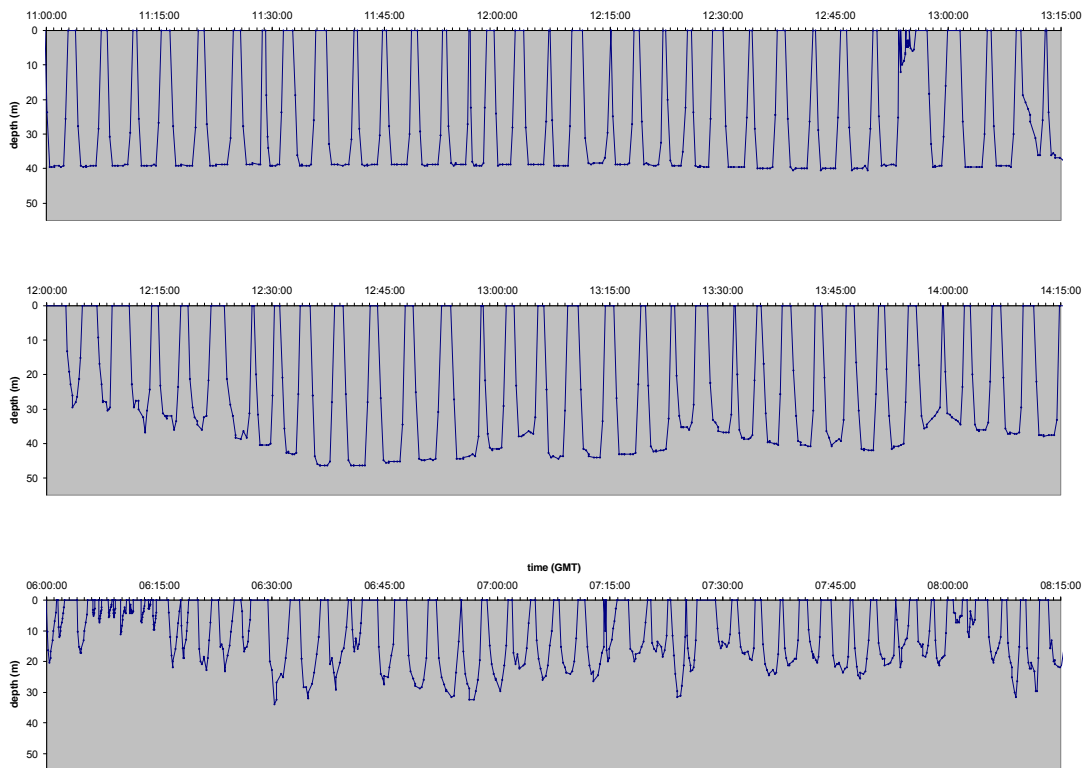


**Figure A14** Example of the summary data transmitted by one of the grey seal pups tagged on the Skerries. Blue bar graph at the top represents the summary dive behaviour showing maximum dive depth in two hour bins. Yellow dots indicate where full depth temperature profiles were recorded. Depth profiles of all individual dives are transmitted and will be used in analysis of 3D space usage.

3.4.2 Figure A15 shows dive profiles of a seal swimming in the high tidal current area around the Skerries. Depth records indicated typical patterns of diving behaviour for grey seals in both datasets. While at sea, the pups spent the majority of their time diving, spending 76% of their time submerged similar to the adults 75%. Figure A15 (a and b) show typical flat bottomed foraging dives (Thompson *et al.*, 1991; 1993) in areas with relatively flat sea bed, where the maximum depth is close to the estimated water depth. Figure A15 (c) shows an example of typical travelling dives with more variable profiles. The complexity of the bottom topography in this area and the error inherent in the interpolating between GPS fixes makes it impossible to accurately assign an estimate of



the depth of the water column to each dive. However, in previous studies, dive patterns suggest that the seals swam down to or close to the seabed on the majority of dives during travel phases (McConnell *et al.*, 1992, 1999; Thompson *et al.*, 1991; 1993).

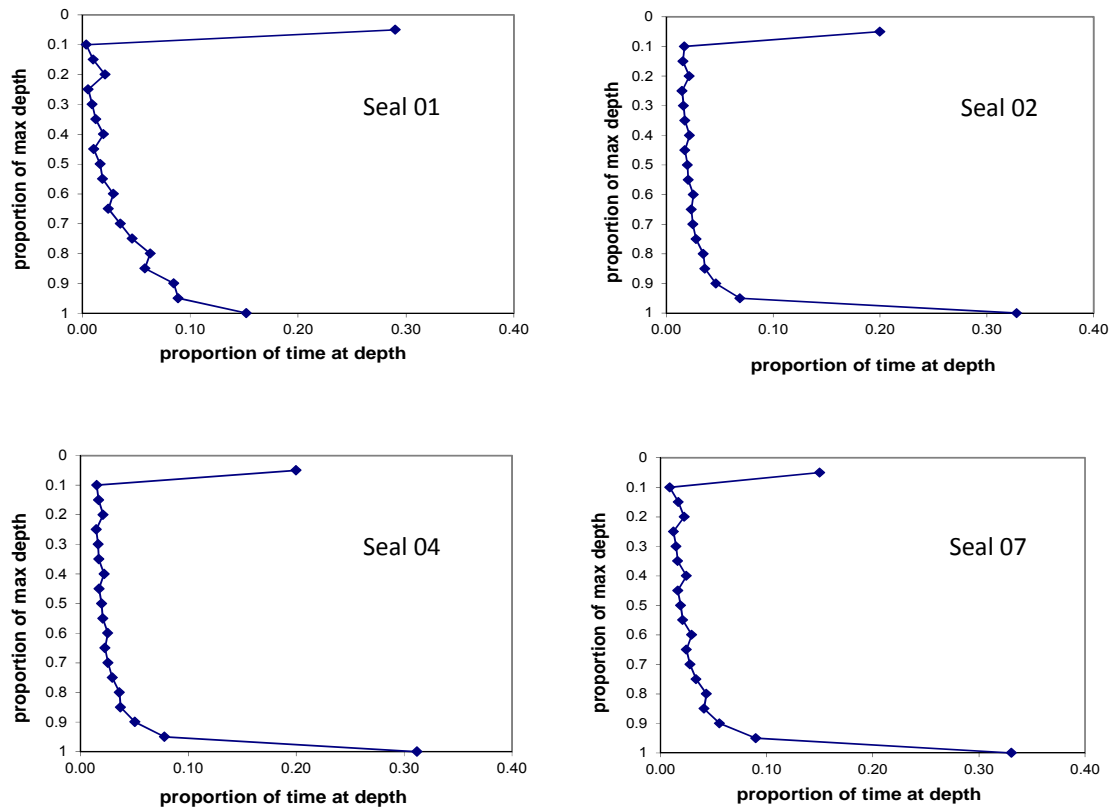


**Figure A15** Dive profiles of a juvenile grey seal swimming in high tidal current areas around the Skerries off Anglesey, North Wales. Periods of typical flat bottomed foraging dives to the sea bed (a and b) were interspersed with typical travelling dives (c).

3.4.3 As with all previous grey seal studies, the dives comprised a rapid descent phase followed by either a rapid ascent or a protracted bottom phase followed by a rapid ascent. While at the surface grey seals typically do not swim actively (Thompson *et al.*, 1993), simply resting at the surface for short periods to load oxygen and dump carbon dioxide before diving again. The seals therefore spent a limited amount of time in mid water depths.

3.4.4 Figure A16 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 or 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 A 16** Proportion of time spent at different depths, expressed as a proportion of the maximum depth, within individual dives. Data from four seals are presented for illustration. These patterns were typical of all seals tracked in this study.

3.4.5 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 GPS position fixes accurately indicate the seals' XY positions at approximately 15 minute intervals. The pressure sensor data provide a 10 point depth profile for each dive. 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.

3.4.6 Fifteen seals tagged adjacent to potential tidal turbine sites at Ramsey Island and at the Skerries provided locations at sea (eight Skerries and seven Ramsey Sound). There are proposed turbine deployment sites in Ramsey Sound and in the channel between the Skerries and Anglesey. Eleven of the pups passed through these channels at least once during the tracking period. Table A2 shows the distribution of these passes. None of the Ramsey seals went to the Anglesey site and none of the Anglesey seals went to the Ramsey site. In total there were 278 crossings at the Skerries and 44 at Ramsey. However, the distribution was uneven, with 75 % of the crossings at the Skerries being

due to one seal that used haul-out sites on both sides of the channel throughout its tracking period.

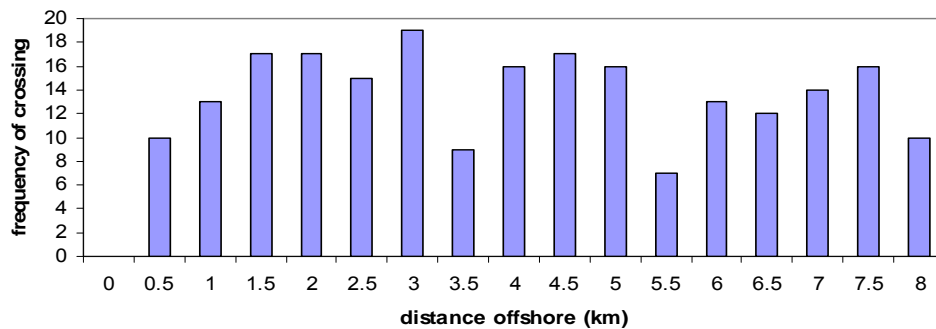
**Table A2** *Numbers of times seals passed through potential tidal turbine sites at the Skerries off Anglesey and in Ramsey Sound.*

Anglesey				Ramsey Sound			
seal id	year	hypothetical turbine site	crossings	seal id	year	hypothetical turbine site	crossings
1	2009	Skerries	0	15	2010	Ramsey Sound	3
4	2009	Skerries	11	18	2010	Ramsey Sound	0
7	2009	Skerries	210	20	2010	Ramsey Sound	5
11	2010	Skerries	10	21	2010	Ramsey Sound	30
13	2010	Skerries	0	22	2010	Ramsey Sound	5
16	2010	Skerries	15	23	2010	Ramsey Sound	1
19	2010	Skerries	13	24	2010	Ramsey Sound	0
25	2010	Skerries	20				

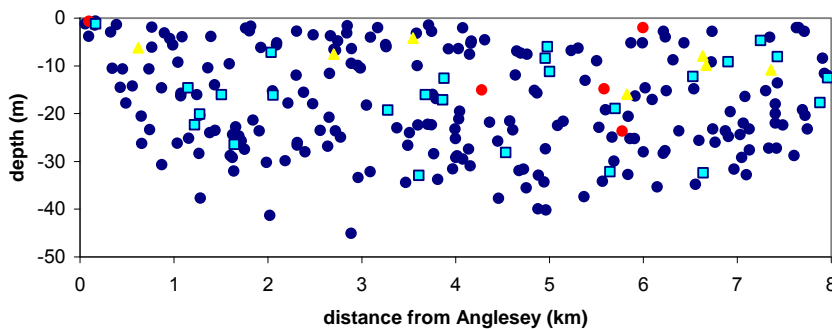
3.4.7 As an example of the type of data available we estimated the number of times and the depths at which the tagged seals crossed an arbitrary 8 km long line drawn from Carmel Head to the Skerries and extending approximately 4 km further offshore and for a line across the northern end of Ramsey Sound. Pairs of consecutive locations were used to estimate the seal's swimming track assuming that it swam in a straight line between the location fixes. The time at which the seal crossed the line was estimated assuming constant swimming speed between locations. Swimming depth at that point was estimated by linearly interpolating between the pair of depth estimates immediately before and after the crossing point.

3.4.8 This study is based on an analysis of a relatively small sample of seals in both areas. At both the Skerries and Ramsey it appears that the crossing points are approximately uniformly distributed across the area both in terms of distance from shore. (Figures A17 and A19) and swimming depth (Figures A18 and A20). The difference between the proportion of time spent in the mid water depth shown in Figure A16 and the more even spread of depth usage implied by Figures A18 and A20 is problematical. It may simply be the result of increased horizontal movement between locations due to tidal currents and the fact that a higher proportion of dives crossing the arbitrary line were V shaped transit dives. Figure A21 shows a random sample of the dives identified as having crossed the arbitrary line in Ramsey Sound. The dives were very variable in shape and

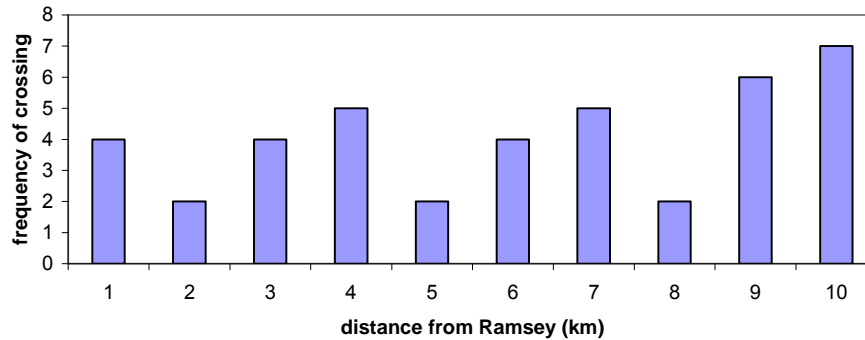
in dive depth and showed a high proportion of V and U shapes compared to typical foraging behaviour where dives are generally more square wave in profile.



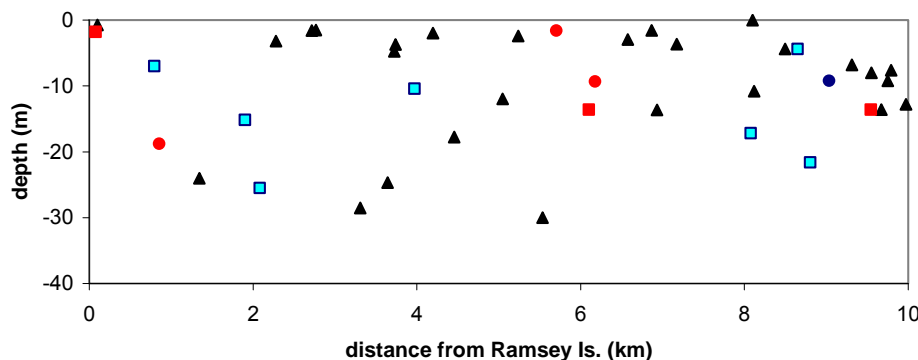
**Figure A17** Distribution of distances from shore at which seals crossed an arbitrarily defined line stretching 8 km from Carmel Head passing through the Skerries.



**Figure A18** Depth and distance from shore of seals crossing an arbitrarily defined line stretching 8 km from Carmel Head passing through the Skerries. Different seals are represented by different symbols.



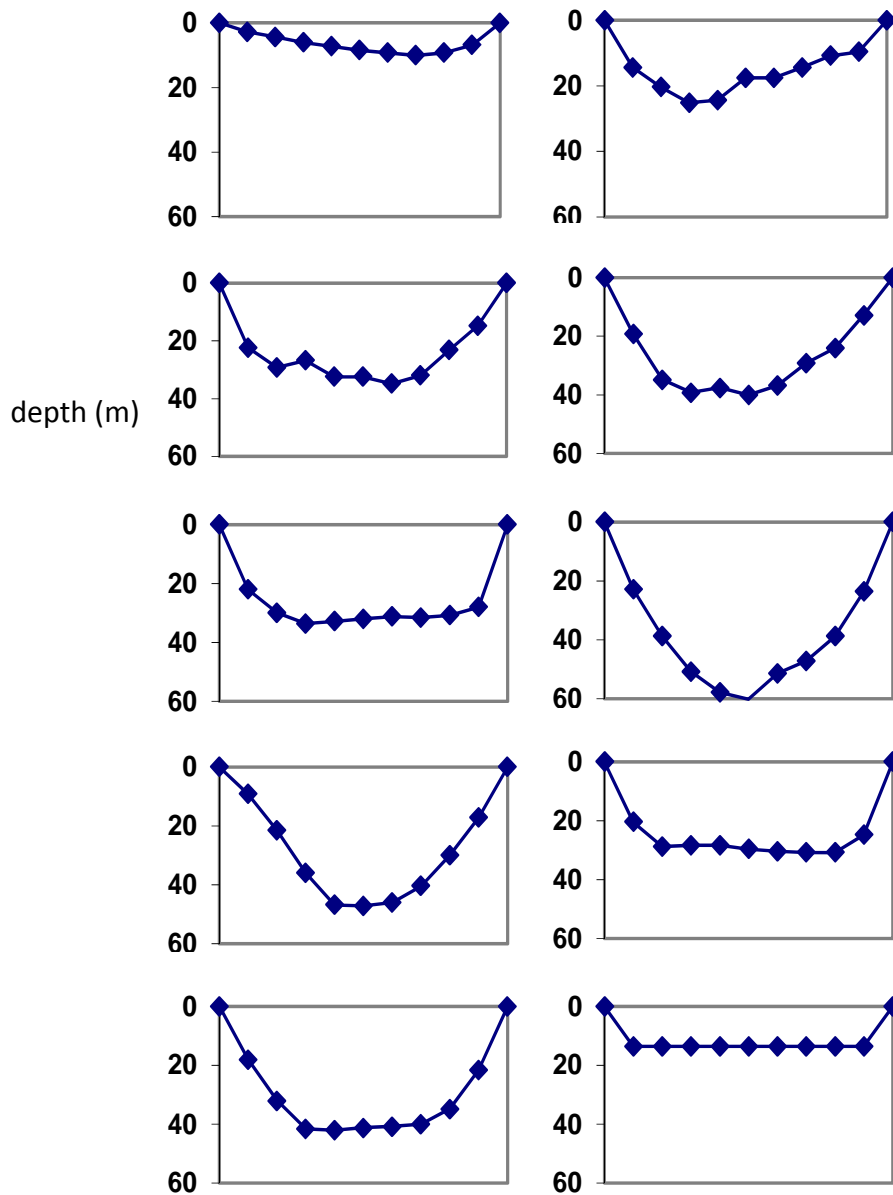
**Figure A19** Distribution of distances from shore at which seals crossed an arbitrary defined line stretching across the northern part of Ramsey Sound passing approximately through a proposed tidal turbine site.



**Figure A20** Depth and distance from shore of seals crossing an arbitrary defined line stretching across Ramsey Sound passing approximately through the centre of the proposed tidal turbine site. Different seals are represented by different symbols.

3.4.9 The estimated positions of the crossings have some error due to the period between successive GPS locations. Seals that transited close to shore at both sites often produce consecutive points that produced interpolated paths crossing over land. These were excluded from the plots. It is therefore likely that even higher resolution tracking data may show a higher proportion of seal transits along the edges of channels with high tidal flow rates.

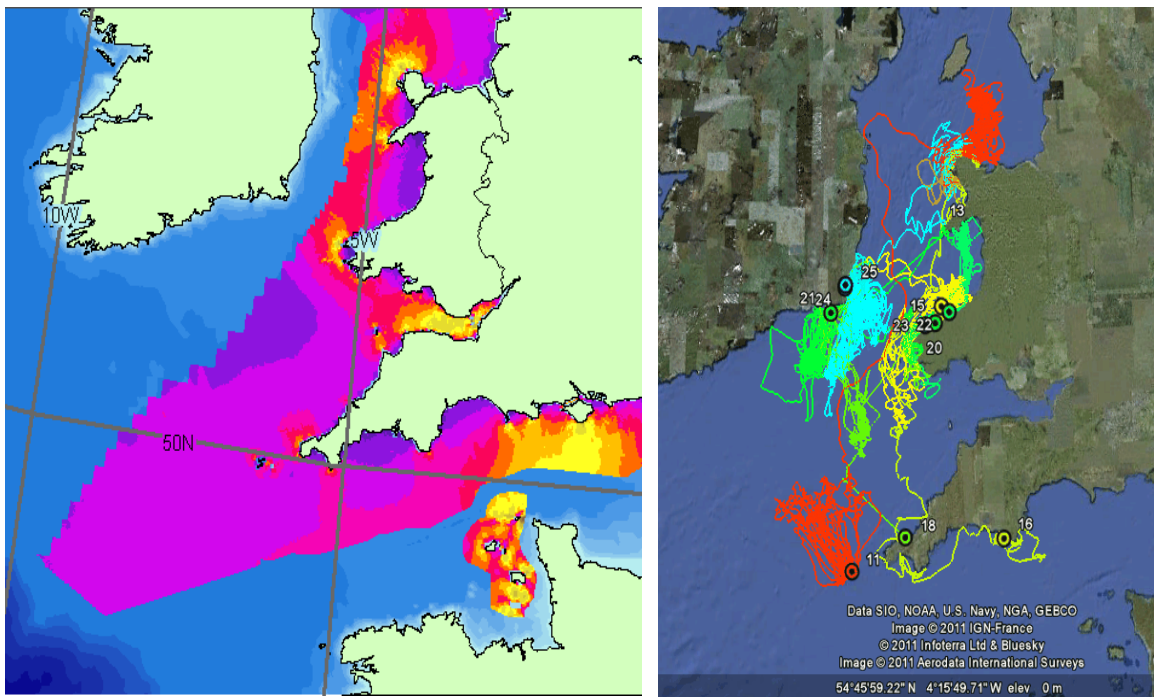
3.4.10 In total 11 of the 15 seals tagged passed through the channels where turbine developments are proposed. The tracks are not accurate enough to say what proportion of the transits would coincide in space with turbine blades, but the data do suggest that seals may travel at any depth when passing through these sites.



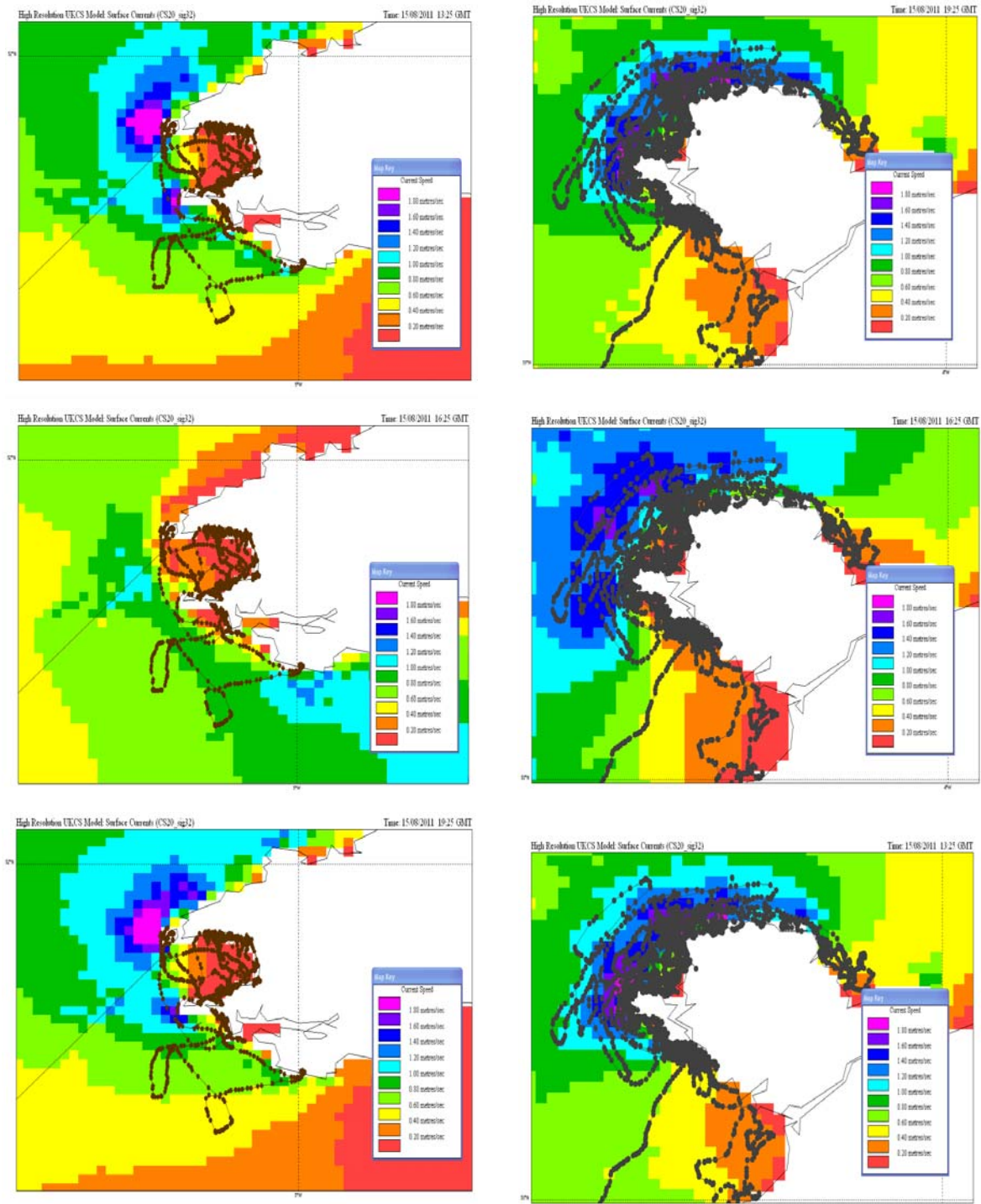
**Figure A21** Examples of dive profiles for dives identified as having crossed an arbitrary defined line stretching across the northern end of Ramsey Sound. Dive profiles varied from shallow flat bottomed dives to deep V and U shaped dives.

### 3.5 Seal activity in relation to tidal energy

3.5.1 Figure A22 shows the distribution of at sea locations for the grey seal pups tagged at Anglesey and Ramsey Island with a tidal energy distribution map for comparison. There is no clear association between foraging locations and tidal energy levels. Seals foraged, apparently successfully in areas of high tidal energy, around Anglesey in particular, but also in areas of very low tidal flow energy both offshore and close to shore (Figure A23).



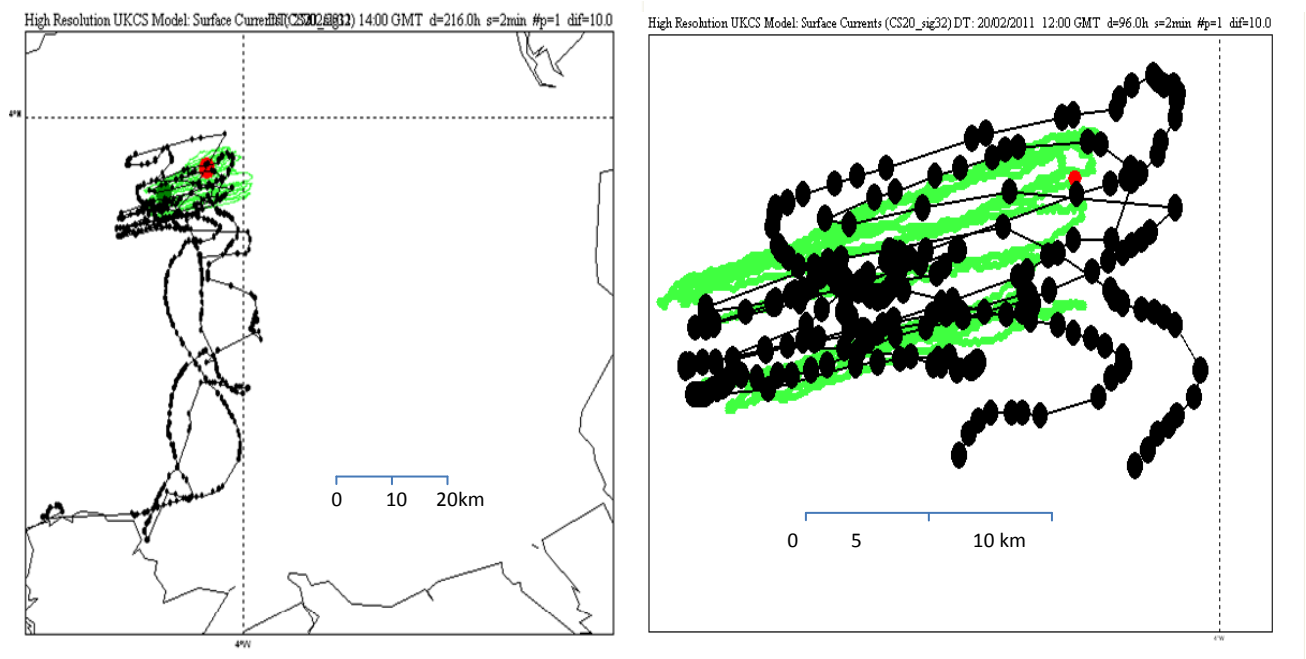
**Figure A22** Tidal energy map of SW UK waters compared to at sea distribution of seal pups tagged at Anglesey and Ramsey.



**Figure A23** Examples of swimming tracks of seals at Anglesey and Ramsey superimposed on maps of tidal flow rates over a tidal cycle. The Anglesey seals remained within high flow rates throughout, the Ramsey seal remained in areas of low flow rates throughout.



3.5.2 Seal swimming behaviour or movements across the ground were often heavily influenced by tidal flows. For example, Figure A24 shows the swimming tracks of a pup foraging in the tidal rapids north of Anglesey and in an area 60 km offshore. In both areas the apparent swimming tracks of the seal were very similar to the tracks of passively floating objects moving with the tide as predicted by a tidal flow model (POLPRED Offshore Tidal Computation Software, Proudman Oceanographic Lab, Liverpool). In the open sea this may simply indicate that seals either ignore or perhaps capitalise on the tidal flows to facilitate horizontal movements around their chosen foraging sites.

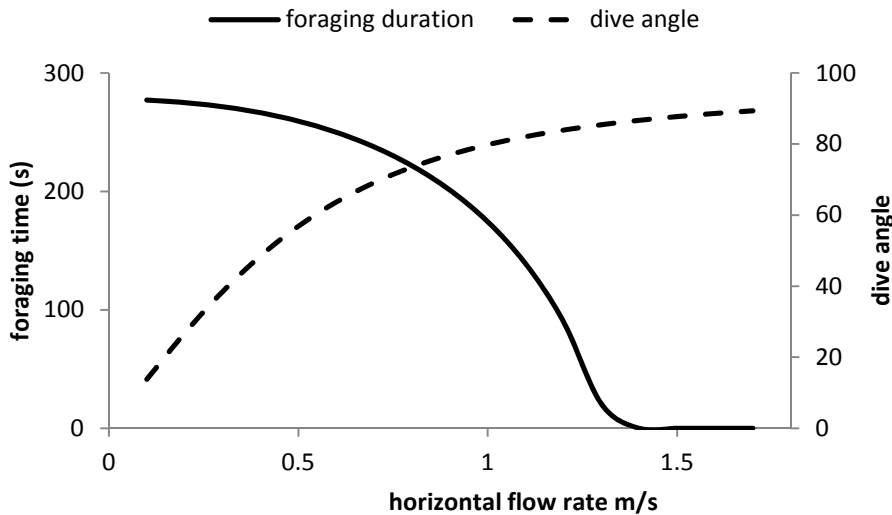


**Figure A24** The foraging tracks of a pup foraging in the tidal rapids north of Anglesey and in an area 60km offshore. Black lines and dots show GPS locations and green represents tracks of free floating objects predicted by the POLPRED tidal flow model.

3.5.3 Grey seals are generally benthic foragers, preying mainly on small demersal fish (Thompson *et al.*, 1991, 1993; McConnell *et al.*, 1999, Hammond *et al.*, 1994). Their prey is patchily distributed and a foraging seal would be expected to make repeated dives to any profitable patches it encounters. In areas of high tidal flow it is likely to be both difficult and energetically expensive to return repeatedly to a fixed spot on the sea bed. Grey seals spend approximately 15 to 20 % of each dive cycle at the surface where they remain stationary while breathing and they must also descend to the seabed and ascend to the surface on each dive. During these periods they will be transported horizontally by the tidal flow. In the limit it is obvious that a seal will not be able to maintain station or return to the same foraging patch if the flow exceeds its maximum



sustainable swim speed. In fact grey seals usually swim at around their minimum cost of transport speed of  $1.8 \text{ m.s.}^{-1}$  (Thompson *et al.*, 1993, Gallon *et al.*, 2007) while foraging and even at relatively low flow rates they will have to expend energy and time overcoming the drift and will experience a major reduction in foraging efficiency if attempting to return to the same fixed point on the sea bed (Figure A25).



**Figure A25** The effects of horizontal flow on the dive angles (where  $90^\circ$  represents vertical ascent/descent) and available foraging times for a seal trying to maintain station over a particular patch on the sea bed. In this example dive depth is 20m; dive duration 5 minutes and seal swim speed is  $1.8 \text{ m.s.}^{-1}$

3.5.4 The implication is that seals foraging in high flow regimes are unlikely to be able to exploit prey patches efficiently. Each dive will be to a different place and seals will generally be unable to return to a site or will have to expend significant amounts of extra time and energy swimming against currents in order to maintain station. Unfortunately we do not have information on the prey of seals at these sites or on the distribution of those prey species at fine resolution.

## 4 Discussion, Conclusions and Recommendations

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### 4.1 Tidal rapids as habitats for marine mammals

#### Densities and distributions

- 4.1.1 Fine scale telemetry data has been collected from newly weaned grey seals during the critical period after they leave their natal beaches. This is a period when they are completely naïve and must independently establish a successful foraging pattern that enables them to survive and grow. They are probably at the most vulnerable stage of their lives, with no experience of prey capture, no knowledge of prey distributions and because of their small size and the need to grow they have elevated metabolic requirements.
- 4.1.2 A proportion of these animals made extensive (in some cases almost exclusive) use of tidal race areas, seeming to move forwards and backwards with the tide and repeatedly diving to the bottom. These dive patterns and the extended periods spent in these areas suggest that the pups were foraging. It is interesting that in some cases, after animals left the tidal rapid area next to their natal beaches that they subsequently seemed to preferentially use other high tidal current areas. The simple diving model presented above suggests that the benthic foraging behaviour typical of grey seals would be relatively inefficient in strong tidal flows. It is not known whether seals using these sites are preying on different species or simply exploiting the habitats in a slightly different way. Other individuals foraged almost exclusively in areas of low tidal energy both offshore and close to shore, in some cases close to but apparently not in areas of high tidal energy. The variable patterns of activity relative to tidal rapids do not suggest that high tidal flow regimes are particularly attractive to grey seal juveniles, but conversely the data indicate that some individuals can clearly exploit them successfully.
- 4.1.3 This variation in use of tidal flow areas is also seen in variability in terms of total distance moved between natal sites and eventual foraging locations. Some individuals remained relatively close to natal sites, others moved >300 km away. Such long range movements by grey seal pups have been noted in other studies. In this study seals from North Wales and Pembrokeshire moved to foraged in waters along the west coast of Wales, on the south east coast of Ireland and in Cornwall and the Isles of Scilly. Assessing the likely impacts of any developments or activities is currently undertaken at a relatively small scale compared to these movement scales. These wide ranging

movements by a large proportion of the seals suggest that a more co-ordinated management regime may be required.

- 4.1.4 The extent to which these animals continue to use these areas in later life is not yet clear but additional information will be collected as the current tag deployments continues and new ones are added. Preliminary analysis of dive data suggests that seals generally dive directly to the seabed and are therefore spending little time in mid-water when foraging, but that the pattern of diving may be more variable in tidal streams, with a wide range of dive shapes. Examination of the fine scale movements of seals in the tidal rapids in Ramsey Sound and between the Skerries and Anglesey suggests that when passing through such an area seals are roughly evenly distributed with respect to both depth and distance from shore. In terms of the depth distribution this may to some extent be a consequence of errors in the interpolated locations of individual dives and may present a misleading impression of distribution in the water column. An examination of the proportions of time spent at different depths during diving showed that seals spent around 20 % of their time at or close to the surface and around 40 to 45 % of their time close to the bottom (at >90 % of the maximum dive depth). The remainder of the time was evenly distributed through the water column.
- 4.1.5 A large proportion of the seals tagged at the Skerries and Ramsey Island swam through the channels where proposed tidal turbine developments are likely to be deployed. However, the pattern of use was highly skewed, with one seal at Anglesey performing 75 % of the transits and one individual at Ramsey performing 70 % of the transits. It is not known how seals will react to operating turbines, but it can be assumed that risk of collision may be related to number of transits past the devices. The observed passage rates suggest that different individuals will be exposed to very different levels of collision risk.

#### **Significance for marine mammals**

- 4.1.6 Although the associated porpoise study indicated that tidal rapid areas are favoured foraging sites for marine mammals, there is no clear evidence that this is the case for grey seal pups during their first year. Seals clearly do not avoid such areas, and some seals spent the majority of their time in them, but other similar aged seals from the same natal sites did not.

### **Implications for encounter and other risks from tidal turbines**

- 4.1.7 There is potentially a risk of collision for naive newly weaned pups that appear to make extensive use of these areas after they leave the breeding beaches. The risk is not evenly spread, some seals remained in the vicinity of the sites for many weeks and made repeated transits, others moved rapidly away and made no or very few transits.
- 4.1.8 Understanding the high level of spatial and temporal variability that was evident in both study sites is particularly relevant in the context of a tidal turbine development for several reasons. In the first case because it will affect the likelihood of encounters between seals and turbines. Secondly, this information could be used to determine the fine scale location of turbines to reduce encounter probability. In addition, the way that marine mammals use this habitat will have implications for the significance of disturbance, habitat exclusion and any barrier effects. While the data indicates that heterogeneity exists, further work would need to be done to quantify it and determine if this is predictable in the longer term.
- 4.1.9 Future work will include combining these data with results from similar deployments on grey seal pups in Orkney in 2010. These will where possible be compared to earlier deployments of older, lower resolution ARGOS satellite tags on seal pups in the central North Sea. The primary aim will be to describe the development of foraging behaviour in grey seal juveniles in a range of foraging habitats. This analysis will be completed in early 2012.
- 4.1.10 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 only the movements of harbour seals have been studied in relation to a functioning tidal turbine, 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 (MCT, 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 particular channels will be indicative of their behaviour when devices are operating. 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 interact with the device.

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## Appendices

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## Appendix 1

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### Parameter Settings for Data Logging

The following pages give a detailed description of the parameter settings for data logging and data summarising sections of the transmitters on board software. Stored Pages are sent only when a transmitter makes a good contact with a cell phone transmitter mast. In lower quality contacts, only a single (most recent) GPS location point is sent, together with some diagnostic data.

**Software specification for GSM\_08A deployment  
(Generic GPS/GSM)**

Valid for dates in years 2008 to 2011

Transmitting via GSM

Page transmission sequences:

Until day 1464: 0 1 2 3 0 1 using 1 PTT numbers

Airtest for first 12 hours:

Attempt a call every 1 hour

GSM call settings:

Transfer messages to postbox every 1 hour 30 mins

Call every 6 hours

Abort call if submerged for 8 secs or connected for 10 mins

Service provider is 'auto'

Check sensors every 4 secs

When near surface (shallower than 4m), check wet/dry every 2/4 secs

Consider wet/dry sensor failed if wet for 2 days or dry for 99 days

Dives start when wet and below 1.5m for 8 secs

and end when above 1.5m for 0, or dry at any time

No separation of 'Deep' dives

No cruises

A haul-out begins when dry for 10 mins

and ends when wet for 40 secs

Dive shape (normal dives):

9 equally-spaced points (no characterisation) per dive

Dive shape (deep dives):

none

CTD profiles: max 500 dbar up to 4 dbar in 1 dbar bins.

Temperature: Collected, Stored.

Conductivity: Not collected.

Salinity: Not collected.

Fluorescence: Not collected.

Send the deepest 1 upcasts in each 2-hour period.

Minimum depth to trigger collection of cast:

20m in hour 1

20m in hour 2

or 20% greater than current maximum.

Sample CTD sensor every 4 seconds.

Each profile contains 12 cut points

consisting of 0 fixed points, minimum depth, maximum depth, 10 broken-stick

points

GPS fix: attempt a fix every 30 mins

Discard results with fewer than 5 satellites

Make a single attempt each time

Processing timeout: 32 secs

Inhibit GPS after first success in haul-out

TRANSMISSION BUFFERS (in RAM):

Dive in groups of 8 (77.7778 days @ 10mins/dive): 1400 = 5600 bytes

No 'deep' dives

Haul-out: 50 = 200 bytes

2-hour summaries in groups of 12 (60 days): 60 = 240 bytes

No berniegrams

No timelines

No cruises

No diving periods

No spot depths

No emergence records

No Duration histograms

No Max depth histograms

CTD casts (25 days): 300 = 1200 bytes

GPS fixes (62.5 days): 3000 = 12000 bytes

No spot CTD's

TOTAL 19240 bytes (of about 21000 available)

## Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy

MAIN BUFFERS (in 8 Mb Flash):  
Dive in groups of 8 (500 days @ 10mins/dive): 9000 x 408 bytes = 3672000 bytes  
No 'deep' dives  
Haul-out: 2000 x 16 bytes = 32000 bytes  
2-hour summaries in groups of 12 (360 days): 360 x 248 bytes = 89280 bytes  
No Berniegrams  
No timelines  
No cruises  
No diving periods  
No spot depths  
No emergence records  
No Duration histograms  
No Max depth histograms  
CTD casts (166.667 days): 2000 x 68 bytes = 136000 bytes  
GPS fixes (416.667 days): 20000 x 120 bytes = 2400000 bytes  
No spot CTD's  
TOTAL 6180 kb (from 8445 kb available)

PAGE CONTENTS (1024 bits - 40 overhead):  
PAGE 0:

```
PTT NUMBER OVERHEAD (32-bit code) -----[32 bits: 0 - 31]
PAGE NUMBER -----[3 bits: 32 - 34]

GPS in format 0:
Record could be in buffer for 62 days 12 hours
Timestamp: max 90 days 12 hours @ 1 sec= 7819200
           tx as raw 23 bits in units of 1 (range: 0 to 8.38861e+06 )
           (recommended sell-by 90 days 11 hours)
Sell-by range: 90 days
n_sats: raw 3 bits in units of 1 (range: 5 to 12 )
GPS mode: -- not transmitted --
Best 8 satellites:
           Sat ID's: raw 5 bits in units of 1 (range: 0 to 31 )
           Pseudorange: raw 15 bits in units of 1 (range: 0 to 32767 )
           Signal strength: -- not transmitted --
           Doppler: -- not transmitted --
Max signal strength: -- not transmitted --
Noisefloor: -- not transmitted --
Max CSN (x10): raw 3 bits in units of 20 (range: 350 to 490 )
-----[189 bits: 35 - 223]

GPS in format 0:
Record could be in buffer for 62 days 12 hours
Timestamp: max 90 days 12 hours @ 1 sec= 7819200
           tx as raw 23 bits in units of 1 (range: 0 to 8.38861e+06 )
           (recommended sell-by 90 days 11 hours)
Sell-by range: 90 days
n_sats: raw 3 bits in units of 1 (range: 5 to 12 )
GPS mode: -- not transmitted --
Best 8 satellites:
           Sat ID's: raw 5 bits in units of 1 (range: 0 to 31 )
           Pseudorange: raw 15 bits in units of 1 (range: 0 to 32767 )
           Signal strength: -- not transmitted --
           Doppler: -- not transmitted --
Max signal strength: -- not transmitted --
Noisefloor: -- not transmitted --
Max CSN (x10): raw 3 bits in units of 20 (range: 350 to 490 )
-----[189 bits: 224 - 412]

GPS in format 0:
Record could be in buffer for 62 days 12 hours
Timestamp: max 90 days 12 hours @ 1 sec= 7819200
           tx as raw 23 bits in units of 1 (range: 0 to 8.38861e+06 )
           (recommended sell-by 90 days 11 hours)
Sell-by range: 90 days
n_sats: raw 3 bits in units of 1 (range: 5 to 12 )
GPS mode: -- not transmitted --
Best 8 satellites:
           Sat ID's: raw 5 bits in units of 1 (range: 0 to 31 )
           Pseudorange: raw 15 bits in units of 1 (range: 0 to 32767 )
           Signal strength: -- not transmitted --
           Doppler: -- not transmitted --
Max signal strength: -- not transmitted --
Noisefloor: -- not transmitted --
Max CSN (x10): raw 3 bits in units of 20 (range: 350 to 490 )
-----[189 bits: 413 - 601]
```

## Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy

```
GPS in format 0:
Record could be in buffer for 62 days 12 hours
Timestamp: max 90 days 12 hours @ 1 sec= 7819200
           tx as raw 23 bits in units of 1 (range: 0 to 8.38861e+06 )
           (recommended sell-by 90 days 11 hours)
Sell-by range: 90 days
n_sats: raw 3 bits in units of 1 (range: 5 to 12 )
GPS mode: -- not transmitted --
Best 8 satellites:
           Sat ID's: raw 5 bits in units of 1 (range: 0 to 31 )
           Pseudorange: raw 15 bits in units of 1 (range: 0 to 32767 )
           Signal strength: -- not transmitted --
           Doppler: -- not transmitted --
Max signal strength: -- not transmitted --
Noisefloor: -- not transmitted --
Max CSN (x10): raw 3 bits in units of 20 (range: 350 to 490 )
-----[189 bits: 602 - 790]

GPS in format 0:
Record could be in buffer for 62 days 12 hours
Timestamp: max 90 days 12 hours @ 1 sec= 7819200
           tx as raw 23 bits in units of 1 (range: 0 to 8.38861e+06 )
           (recommended sell-by 90 days 11 hours)
Sell-by range: 90 days
n_sats: raw 3 bits in units of 1 (range: 5 to 12 )
GPS mode: -- not transmitted --
Best 8 satellites:
           Sat ID's: raw 5 bits in units of 1 (range: 0 to 31 )
           Pseudorange: raw 15 bits in units of 1 (range: 0 to 32767 )
           Signal strength: -- not transmitted --
           Doppler: -- not transmitted --
Max signal strength: -- not transmitted --
Noisefloor: -- not transmitted --
Max CSN (x10): raw 3 bits in units of 20 (range: 350 to 490 )
-----[189 bits: 791 - 979]

DIAGNOSTICS in format 0:

Wet/dry status: raw 2 bits in units of 1 (range: 0 to 3 )
Number of resets: wraparound 2 bits in units of 1 (range: 0 to 3 )
-----[4 bits: 980 - 983]

Available bits used exactly
=== End of page 0 ===

PAGE 1:
PTT NUMBER OVERHEAD (32-bit code) -----[32 bits: 0 - 31]
PAGE NUMBER -----[3 bits: 32 - 34]
DIVE group in format 0:
Normal dives transmitted in groups of 8
Time of start of last dive: max 91 days @ 4 secs= 1965600
           tx as raw 21 bits in units of 1 (range: 0 to 2.09715e+06 )
           (recommended sell-by 90 days 23 hours)
Sell-by range: 90 days
Number of records: raw 4 bits in units of 1 (range: 0 to 15 )
Reason for end: -- not transmitted --
Group number: wraparound 7 bits in units of 1 (range: 0 to 127 )
Max depth: odlog 2/7 in units of 4 dm (range: 0 to 7662 dm)
Dive duration: odlog 1/7 in units of 4 s (range: 0 to 1530 s)
Mean speed: -- not transmitted --
           Profile data (9 depths/times, 0 speeds):
           Depth profile: odlog 2/7 in units of 4 dm (range: 0 to 7662 dm)
           Profile times: -- not transmitted --
           Speed profile: -- not transmitted --
           Residual: -- not transmitted --
           Calculation time: -- not transmitted --
Surface duration: odlog 2/7 in units of 4 s (range: 0 to 7662 s)
Dive area: raw 7 bits in units of 7.87402 permille (range: 0 to 1000 permille)
-----[944 bits: 35 - 978]

DIAGNOSTICS in format 1:
Wet/dry status: raw 2 bits in units of 1 (range: 0 to 3 )
Wet/dry fail count: wraparound 3 bits in units of 1 (range: 0 to 7 )
-----[5 bits: 979 - 983]

Available bits used exactly
```

=== End of page 1 ===

PAGE 2:

```

PTT NUMBER OVERHEAD (32-bit code)
-----[32 bits: 0 - 31]

PAGE NUMBER
-----[3 bits: 32 - 34]

SUMMARY group in format 0:
Transmitted in groups of 12
Record could be in buffer for 60 days
  End time: max 60 days 8 hours @ 2 hours= 724
            tx as raw 10 bits in units of 1 (range: 0 to 1023 )
            (recommended sell-by 60 days 5 hours)
  Sell-by range: 60 days
  Number of records: raw 1 bits in units of 1 (range: 0 to 1 )
  Cruising time: -- not transmitted --
  Haul-out time: raw 6 bits in units of 15.873 permille (range: 0 to 1000 permille)
  Dive time: raw 6 bits in units of 15.873 permille (range: 0 to 1000 permille)
  Deep Dive time: -- not transmitted --
Normal dives:
Avg max dive depth: odlog 2/7 in units of 4 dm (range: 0 to 7662 dm)
SD max dive depth: odlog 2/7 in units of 4 dm (range: 0 to 7662 dm)
Max max dive depth: odlog 2/7 in units of 4 dm (range: 0 to 7662 dm)
Avg dive duration: raw 5 bits in units of 30 s (range: 0 to 930 s)
SD dive duration: raw 5 bits in units of 10 s (range: 0 to 310 s)
Max dive duration: raw 5 bits in units of 30 s (range: 0 to 930 s)
  Avg speed in dive: -- not transmitted --
  Number of dives: raw 7 bits in units of 1 (range: 0 to 127 )
Deep dives:
  Avg max dive depth: -- not transmitted --
  SD max dive depth: -- not transmitted --
  Max max dive depth: -- not transmitted --
  Avg dive duration: -- not transmitted --
  SD dive duration: -- not transmitted --
  Max dive duration: -- not transmitted --
  Avg speed in dive: -- not transmitted --
  Number of dives: -- not transmitted --
  Avg SST: -- not transmitted --
-----[743 bits: 35 - 777]

HAUL-OUT in format 0:
  Number of records: raw 1 bits in units of 1 (range: 0 to 1 )
  Haul-out number: wraparound 8 bits in units of 1 (range: 0 to 255 )
  Start time: -- not transmitted --
  End time: max 91 days @ 1 min= 131040
            tx as raw 17 bits in units of 1 (range: 0 to 131071 )
            (recommended sell-by 90 days 23 hours)
  Sell-by range: 90 days
  Duration: odlog 2/6 in units of 90 s (range: 0 to 85995 s)
            cf. Max duration is 1 day
  Reason for end: -- not transmitted --
  Contiguous: -- not transmitted --
-----[34 bits: 778 - 811]

HAUL-OUT in format 0:
  Number of records: raw 1 bits in units of 1 (range: 0 to 1 )
  Haul-out number: wraparound 8 bits in units of 1 (range: 0 to 255 )
  Start time: -- not transmitted --
  End time: max 91 days @ 1 min= 131040
            tx as raw 17 bits in units of 1 (range: 0 to 131071 )
            (recommended sell-by 90 days 23 hours)
  Sell-by range: 90 days
  Duration: odlog 2/6 in units of 90 s (range: 0 to 85995 s)
            cf. Max duration is 1 day
  Reason for end: -- not transmitted --
  Contiguous: -- not transmitted -- -----[34 bits: 812 - 845]
HAUL-OUT in format 0:
  Number of records: raw 1 bits in units of 1 (range: 0 to 1 )
  Haul-out number: wraparound 8 bits in units of 1 (range: 0 to 255 )
  Start time: -- not transmitted --
  End time: max 91 days @ 1 min= 131040
            tx as raw 17 bits in units of 1 (range: 0 to 131071 )
            (recommended sell-by 90 days 23 hours)
  Sell-by range: 90 days
  Duration: odlog 2/6 in units of 90 s (range: 0 to 85995 s)

```



## Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy

```
        cf. Max duration is 1 day
Reason for end: -- not transmitted --
Contiguous: -- not transmitted --
-----[34 bits: 846 - 879]

HAUL-OUT in format 0:
Number of records: raw 1 bits in units of 1 (range: 0 to 1 )
Haul-out number: wraparound 8 bits in units of 1 (range: 0 to 255 )
Start time: -- not transmitted --
End time: max 91 days @ 1 min= 131040
        tx as raw 17 bits in units of 1 (range: 0 to 131071 )
        (recommended sell-by 90 days 23 hours)
Sell-by range: 90 days
Duration: odlog 2/6 in units of 90 s (range: 0 to 85995 s)
        cf. Max duration is 1 day
Reason for end: -- not transmitted --
Contiguous: -- not transmitted --
-----[34 bits: 880 - 913]

DIAGNOSTICS in format 2:

ADC offset: raw 11 bits in units of 1 A/D units (range: 0 to 2047 A/D units)
Wet/dry fail count: wraparound 3 bits in units of 1 (range: 0 to 7 )
Max depth ever: raw 9 bits in units of 10 dm (range: 0 to 5110 dm)
Number of resets: wraparound 2 bits in units of 1 (range: 0 to 3 )
GPS no satellites: raw 14 bits in units of 1 (range: 0 to 16383 )
GPS <5 satellites: raw 14 bits in units of 1 (range: 0 to 16383 )
GPS >= 5 satellites: raw 14 bits in units of 1 (range: 0 to 16383 )
GPS reboots: wraparound 3 bits in units of 1 (range: 0 to 7 )
-----[70 bits: 914 - 983]

Available bits used exactly
=== End of page 2 ===

PAGE 3:
PTT NUMBER OVERHEAD (32-bit code) -----[32 bits: 0 - 31]
PAGE NUMBER -----[3 bits: 32 - 34]

CTD profile in format 0:
End time: max 81 days @ 2 hours= 972
        tx as raw 10 bits in units of 1 (range: 0 to 1023 )
        (recommended sell-by 80 days 21 hours)
Sell-by range: 80 days
CTD cast number: wraparound 7 bits in units of 1 (range: 0 to 127 )
Min pressure: raw 6 bits in units of 1 dbar (range: 4 to 67 dbar)
Max pressure: raw 9 bits in units of 1 dbar (range: 4 to 515 dbar)
Min temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Max temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Number of samples: -- not transmitted --
12 profile points 0 to 11 (from total of 12 cut points):
        Pressures 0 to 0 are fixed
        Min pressure is fixed
        Max pressure is sent separately
        10 broken stick pressure bins: raw 8 bits in units of 1 bin (range: 0 to 255
bin)
        12 x Temperature: raw 8 bits in units of 3.92157 permille (range: 0 to 1000
permille)
Temperature residual: -- not transmitted --
Temperature bounds : -- not transmitted --
Conductivity bounds : -- not transmitted --
Salinity bounds : -- not transmitted --
Min fluoro: -- not transmitted --
Max fluoro: -- not transmitted --
-----[232 bits: 35 - 266]

CTD profile in format 0:

End time: max 81 days @ 2 hours= 972
        tx as raw 10 bits in units of 1 (range: 0 to 1023 )
        (recommended sell-by 80 days 21 hours)
Sell-by range: 80 days
CTD cast number: wraparound 7 bits in units of 1 (range: 0 to 127 )
Min pressure: raw 6 bits in units of 1 dbar (range: 4 to 67 dbar)
Max pressure: raw 9 bits in units of 1 dbar (range: 4 to 515 dbar)
```

## Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy

```
Min temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Max temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Number of samples: -- not transmitted --
12 profile points 0 to 11 (from total of 12 cut points):
    Pressures 0 to 0 are fixed
    Min pressure is fixed
    Max pressure is sent separately
    10 broken stick pressure bins: raw 8 bits in units of 1 bin (range: 0 to 255
bin)
    12 x Temperature: raw 8 bits in units of 3.92157 permille (range: 0 to 1000
permille)
Temperature residual: -- not transmitted --
Temperature bounds : -- not transmitted --
Conductivity bounds : -- not transmitted --
Salinity bounds : -- not transmitted --
Min fluoro: -- not transmitted --
Max fluoro: -- not transmitted --
-----[232 bits: 267 - 498]

CTD profile in format 0:

End time: max 81 days @ 2 hours= 972
    tx as raw 10 bits in units of 1 (range: 0 to 1023 )
    (recommended sell-by 80 days 21 hours)
Sell-by range: 80 days
CTD cast number: wraparound 7 bits in units of 1 (range: 0 to 127 )
Min pressure: raw 6 bits in units of 1 dbar (range: 4 to 67 dbar)
Max pressure: raw 9 bits in units of 1 dbar (range: 4 to 515 dbar)
Min temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Max temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Number of samples: -- not transmitted --
12 profile points 0 to 11 (from total of 12 cut points):
    Pressures 0 to 0 are fixed
    Min pressure is fixed
    Max pressure is sent separately
    10 broken stick pressure bins: raw 8 bits in units of 1 bin (range: 0 to 255
bin)
    12 x Temperature: raw 8 bits in units of 3.92157 permille (range: 0 to 1000
permille)
Temperature residual: -- not transmitted --
Temperature bounds : -- not transmitted --
Conductivity bounds : -- not transmitted --
Salinity bounds : -- not transmitted --
Min fluoro: -- not transmitted --
Max fluoro: -- not transmitted --
-----[232 bits: 499 - 730]

CTD profile in format 0:

End time: max 81 days @ 2 hours= 972
    tx as raw 10 bits in units of 1 (range: 0 to 1023 )
    (recommended sell-by 80 days 21 hours)
Sell-by range: 80 days
CTD cast number: wraparound 7 bits in units of 1 (range: 0 to 127 )
Min pressure: raw 6 bits in units of 1 dbar (range: 4 to 67 dbar)
Max pressure: raw 9 bits in units of 1 dbar (range: 4 to 515 dbar)
Min temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Max temperature: raw 12 bits in units of 10 (range: 0 to 40950 = -5 to 35.95 °C in
steps of 0.01 °C)
Number of samples: -- not transmitted --
12 profile points 0 to 11 (from total of 12 cut points):
    Pressures 0 to 0 are fixed
    Min pressure is fixed
    Max pressure is sent separately
    10 broken stick pressure bins: raw 8 bits in units of 1 bin (range: 0 to 255
bin)
    12 x Temperature: raw 8 bits in units of 3.92157 permille (range: 0 to 1000
permille)
Temperature residual: -- not transmitted --
Temperature bounds : -- not transmitted --
Conductivity bounds : -- not transmitted --
Salinity bounds : -- not transmitted --
```

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Min fluoro: -- not transmitted --  
Max fluoro: -- not transmitted --  
-----[232 bits: 731 - 962]

DIAGNOSTICS in format 3:

Number of resets: wraparound 2 bits in units of 1 (range: 0 to 3 )  
Wet conductivity: raw 8 bits in units of 1 (range: 0 to 255 )  
Dry conductivity: raw 8 bits in units of 1 (range: 0 to 255 )  
GPS reboots: wraparound 3 bits in units of 1 (range: 0 to 7 )  
-----[21 bits: 963 - 983]

Available bits used exactly  
=== End of page 3 ===