Report

Project Name:	EMEC tidal renewables site observations
Reference:	
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Date:	Friday, 07 September 2007	

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The number and distribution of marine mammals in the Fall of Warness, Orkney July 2006 - July 2007

Final Report for EMEC
August 2007

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Summary

- Land-based marine mammal surveys of the Fall of Warness were carried out from 15th July 2006 to 13th July 2007, encompassing a total of 240 days, and 928 hours of observation. These are a continuation of previous surveys of the site that ran from 11th July 2005 to 14th July 2006 and encompassed 219 days and 964 hours of observations.

- Grey seals, harbour seals, harbour porpoises, minke whales, white-beaked dolphins, killer whales, Risso's dolphins and basking sharks were all seen during the study period. All species of marine mammal (and basking sharks) observed in the study area are protected under international and/ or national legislation.

- Chi-squared ($\chi 2$) tests were used to investigate the patterns underlying seal and harbour porpoise observation data. Generalised Additive Models (GAMs) were fitted to the entire two year dataset to explore these patterns further. There was insufficient information on the other species to support anything beyond descriptive statistics.

- Grey seals were the most frequently observed species, with a significant peak in occurrence during their breeding season from September and October . Sightings were concentrated close to the shore area, especially to Muckle Green Holm. The probability of sighting grey seals was greatest while the tide was ebbing, and on calm afternoons. The rate of sighting grey seals has declined over the period of the study.

- Harbour seals were rarely observed between December 2006 and February 2007, though overall the numbers of sightings have been decreasing. They were most commonly seen during high tide and at the ends of the day. The small numbers of sightings was probably responsible for the lack of any other significant factors in the data analysis.

- Harbour porpoises were mainly observed on calm days during the summer and were observed to be mainly in small groups. The small number of sightings of this species

meant that it was not possible to determine any other significant factors in the data analysis.

- Occasional sightings of minke whales, white-beaked dolphins, killer whales, Risso's dolphins, and basking sharks are consistent with existing knowledge of these species behaviour and distribution in Orkney waters.

- The potential effects of tidal stream devices on large-bodied animals in the water column are a subject of considerable concern that requires a careful approach to management and mitigation. The methodological approaches developed in this study to help assess these effects are at the leading edge of the field. We suggest that they have broad application to most circumstances in which tidal power generation is being considered.

1 Introduction

1.1 Context

SMRU Ltd has been tasked with developing providing analysis of baseline data from visual observations of marine mammals in the area surrounding the European Marine Energy Centre (EMEC) tidal turbine test facility in the Fall of Warness, Orkney. It is assisted in this by staff of the Sea Mammal Research Unit at the University of St Andrews. The Sea Mammal Research Unit (SMRU) undertakes routine surveys of harbour and grey seals around Scotland and part of England. The surveys provide the Natural Environment Research Council (NERC) with part of the information required to fulfil its statutory obligation under the Conservation of Seals Act, 1970, namely to provide the Scottish Executive, the Home Office and the Department of the Environment, Food and Rural Affairs (DEFRA) with scientific advice relating to the management of seal populations.

1.2 Existing information on marine mammals in Orkney

Past research conducted by SMRU on the numbers and distribution of harbour and grey seals in the north Orkney Islands has been summarised by Duck and Mackey (2005). Grey seals are known to haul out on Muckle and Little Green Holm, Eday, Orkney. These two islands are designated as Sites of Special Scientific Interest (SSSIs) for grey seals on account of the large number of pups born on each island during the autumn breeding season. Grey seals start to breed on Muckle Green Holm in late September and early October. On Little Green Holm breeding starts about 10 days later, and the number of grey seals observed in the surrounding area is expected to increase during this time. In 2004, an estimated 736 pups were born on Muckle Green Holm and 367 on Little Green Holm (SMRU, unpublished). Geographically, the closest grey seal Special Area of Conservation (SAC) to the test site is Faray and Holm of Faray, approximately 8km to the north (Figure 1).

The closest significant harbour seal haul out sites are Seal Skerry, Eday, approximately 4km to the north of the Study Area and The Graand, Eday, approximately 3km to the east of the Study Area (Figure 2). The closest harbour seal SAC to the Fall of Warness test site is Sanday, approximately 16-20km northeast of the study site. Eynhallow is the closest SSSI, approximately 18km to the west.

In 2005-06, a study was established to monitor and evaluate the distribution and relative abundance of marine mammals and seabirds in the Fall of Warness area (Duck, Black et al.

2006). The results confirmed the presence of relatively large numbers of grey and harbour seals, and the occurrence of a number of cetacean species. This work also highlighted significant spatial and temporal patterns of use in the area and highlighted potentially sensitive periods and areas.

1.3 Aims

The principle aim of this study is to expand and develop the analyses of the observer data from the Fall of Warness (to include data from 2007-07) and provide an updated assessment of the spatial and temporal characteristics of seabird (SMRULtd 2007) and marine mammal distribution around the tidal turbine test facility.

The results and discussion presented here aim to build upon the previous set of data and provide a more robust series of predictive models to assist in the evaluation of the potential impacts on marine mammals using the area of the installation and testing of prototype tidal stream devices in a pre-defined area within the Fall of Warness.

The study also aims to provide an assessment of the observer effort and will carry out an analysis to evaluate whether reduced effort would significantly impact the power to detect changes in marine mammal use of the area (SMRULtd 2007).

2 Methods

2.1 Data collection

The survey are and data collection protocol are described in detail in the previous report (Duck, Black et al. 2006). The test sites are in the Fall of Warness, between Muckle Green Holm and Eday, as shown in Figure 3. Land based surveys were carried out from an elevated position on Eday (59°08'975, 002°47'396). The Study Area encompassing the Fall of Warness was subdivided into smaller units as described in the previous report.

Surveys were carried out between July 2006 and July 2007 during daylight hours, ranging between 05:00hrs and 21:00hrs. Surveys encompassed all states of tide, although survey effort varied between days, time of day and state of the tide. Tide state was defined in relation to total time since the previous high tides recorded at Kirkwall and were classified as "high tide", "ebb tide", "low tide", and "flood tide" as defined in the previous report.

The Study Area was continually scanned during hour-long periods. In addition to the timing and location of any marine mammal sighting, data were recorded on tidal state, sea state, speed and direction of water flow, and several weather variables (including precipitation, cloud cover, and wind speed and direction).

Marine mammals were identified to species whenever possible. Due to the difficulty in differentiating between harbour and grey seals, especially at distance, an additional category of 'unclassified seal' was included in the species list and the analyses consider each species separately as well as all seals observations together. It should also be noted harbour porpoises were generally sighted in small groups of individuals, and as such, data points in all descriptive statistics represent groups rather than individuals.

2.2 Data Analysis

2.2.1 Descriptive statistics

The total number of days and hours of observations have been summarised for the survey period (Table 1). As the probabilities of sighting marine mammals are generally affected by sea state, the survey effort in different sea states has also been summarised (Table 2). The total numbers of sightings for each species were summarised. To provide a simple evaluation of marine mammal occurrence and their patterns of use in the area, for species where sufficient data existed, simple χ^2 tests for homogeneity were used to investigate differences in the rate of sightings between each month, tide state, time of day, and each zone of the study area. These tests provide a simple arithmetical comparison between an observed frequency and an expected frequency.

2.2.2 General additive models (GAMs)

To further investigate patterns of use in the area, and to strengthen the results from the 2005-06 analysis, a series of generalised additive models were produced. This is a modern regression technique (Wood 2006) that assumes that the number of animals present changes smoothly, but not necessarily linearly, with environmental conditions. Its use is appropriate where similar numbers of animals can be expected to be present in similar conditions, on consecutive days and in nearby areas, but the patterns of change are complex or difficult to predict. By allowing the data determine these patterns, GAMs produce more precise results than could be obtained by considering each area or time period separately, while avoiding strong, and often hard-to-justify, assumptions. GAMs can also side-step some of the problems of autocorrelation associated with more traditional regression methods. However, they retain the assumption that the recorded positions of all the observations are correct. This seems a reasonable simplification for the data presented here given the relatively coarse spatial grid used in this study. A general difficulty with spline-based models is that the flexibility, which allows them to track data closely, also makes them particularly prone to over-fitting and interpreting data. Choosing appropriate locations for the "knots" that limit the complexity of splines can also be problematic.

The models used here have an overdispersed Poisson error structure with a log link. This means that the effects of the various environmental factors were considered to multiply together to produce the overall results. The data appeared relatively well-behaved, with the best models generally showing limited over-dispersion and no problematic colinearity in the environmental covariates. Because the same animals could be observed in the same locations in consecutive hours, and identifying individuals is difficult, the models included a first order autocorrelation term. Such models are very computationally intensive (and can take many hours to converge), but were essential to properly investigate and represent the data. Simply ignoring temporal autocorrelation can substantially exaggerate the amount of information available and lead to overly complicated representations of the data.

One of the most difficult and least well-developed aspects of modern data analysis is model selection. More complicated models ought to be able to explain data better than simpler ones, and any comparison of the results of different models need to allow for this. Two standard approaches to model selection are significance testing, removing any parameters that cannot be shown to be essential, and likelihood based methods that attempt to assess the relative probability of different models being correct. These strategies have different goals, with the former looking for a parsimonious (simple) representation while the latter seeks the most likely solution. Akaike's Information Criterion (AIC) and its extensions (AICc, QAIC, etc) are theoretically well-founded techniques for implementing the second approach (Burnham and Anderson 2002). The previous report on this study (Duck, Black et al. 2006) used AIC for model selection, while noting that this assessment is only approximate for GAMs where automated smoothing parameter selection is used to reduce the risk of over-fitting. It has also been pointed out that using separate methods to determine which covariates to include and the complexity of their representation is unsatisfactory (Wood 2006). Here an alternative approach is utilised, where a shrinkage term is included in the spline representations of the data. The cross-validation techniques (which effectively look at how well models fitted to subsets of the data can predict the remainder) that are used to penalise complex models and reduce the effects of knot location are then able to identify where splines are better replaced by linear terms or removed entirely and so incorporate model selection into a single model fitting step (Wood, 2006). The models presented here attempt to draw out the main patterns while avoiding the overcomplicated patterns that can indicate over-fitting.

There can be difficulties with the convergence of models using Poisson error structures with low means. As the mean numbers of sightings was around 0.1 animals per grid cell per hour, this is a potential problem for this study. Models that showed symptoms of imperfect convergence were refitted using alternative optimisation techniques within the software. As further checks, the data was summed over all the grid cells and non-spatial models re-fitted to it, and also grouped by day and spatial models fitted at this coarser temporal resolution. Both these simplifications increased the expected number of sightings per unit and reduced the dimension of the data. Neither had any substantial effects on the models.

This section of the report utilises the entire dataset of observations collected between 11 July 2005 and 13 July 2007 in order to extract as much information as possible on the patterns within the data. This should improve the precision of the estimates, assuming that there have been no complex interactions between the effects. It also allows the direct assessment of any change in the overall numbers of animals using the area between the two years. It is particularly important to include inter-annual changes in this assessment because of the, recently reported, dramatic declines in the harbour seal population around Orkney (Lonergan, Duck et al. 2007). The inclusion of such trends in the surrounding population would be essential for the proper evaluation of the impacts of any devices installed in this location.

Model covariates

A range of environmental information were recorded along with the location and timing of sightings. These have different characteristics and were represented in various ways.

Categorical

These variables have no obvious natural ordering for their effects, so they are simply treated as taking several separate values.

WIND DIRECTION	This was considered as taking six distinct values: "NORTH", "SOUTH", "EAST", "WEST", "VARIABLE" or "NONE".
TIDE STATE	The classification is described in the text above.
PRECIPITATION	Descriptions rather than numeric values were recorded during data collection. This was considered for inclusion in the models previously made of the 2005-2006 data, but, perhaps unsurprisingly given the 21 distinct values recorded, did not remain in the final model. The 71 distinct values that have now been recorded made it impractical to include this parameter in full. It was therefore reduced a binary, classification, with 1202 of the 1551 observation hours included in the final dataset being labelled "dry". An intermediate classification that produces a numeric result or a manageable number of categories would have been preferable.
OBSERVER.ID	An abrupt change in observer in August 2005 prevented its modelling. Either a much longer study (over several years) or a gradual handover would help in assessing this effect. Although competent substitutes standing in for the main observer is not necessarily a problem in a study like this, information on which observations were made by whom was not available for this analysis.

Numerical

These covariates had an effect that was considered to be (at least approximately) linear.

WIND STRENGTH	Only observations made at Beaufort 3 or below were included. (The models were not improved by considering this as a categorical variable.)
CLOUD COVER	
DISTANCE	As it is inherently easier to see nearby objects, lower proportions of animals therefore tend to be seen at greater

distances. It is impossible to fully compensate for this effect in observational data collected from a single location, and surveys such as this one can only really extract patterns within the sightings rather than those in the actual population of animals. An additional "distance" covariate was used, measuring the distance from the observation point to the centre of each cell, in order to investigate the effects of declining observability with distance. It cannot be used to fully compensate for these effects, but does at least allow situations where they have a substantial effect to be identified.

Smooths

The effects of some numeric covariates were believed to change gradually, but not necessarily in a straightforward manner, so they were represented by smooth functions. These are a compromise between assuming that usage is the same everywhere and producing separate estimates for each cell. In this case this approach seemed to produce a better result than either of the two extremes. In each case smooths that appeared to represent effectively linear relationships were reduced to linear terms.

LOCATION	Row & column coordinates of the grid cells were smoothed across to attempt to determine some of the patterns between them.
JULIAN DAY	Days were counted from 1 January each year and a cyclic smooth function used to represent the corresponding change in observations. This explicitly models the seasonal pattern in animal abundance.
TIME OF DAY	The daily pattern of observation numbers was also represented by a smooth.
YEAR/ELAPSED TIME	If there were a clear population trajectory, year would simply be a numeric covariate. However, if the population size changed at a fixed time each year it could be a categorical covariate. Without this prior information, the most appropriate representation was as a low dimensional smooth.

The three temporal smooths directly and explicitly model the changes in animal abundances over time, and allow the separation of patterns at different timescales.

3. Results

Surveys were carried out between July 2006 and July 2007 and encompassed a total of 928 observation hours over 240 days. Table 1 provides a summary of the dates on which surveys were made.

Table 1: Detail of survey dates each month

Month	Dates surveyed
July 2006	15th – 18th, 21st – 25th
August 2006	4th – 8th, 12th – 18th, 20th – 25th, 27th & 31st
September 2006	1st – 3rd, 5th, 7th – 13th, 15th, 17th – 18th, 21st – 23rd, 26th – 28th
October 2006	2nd – 6th, 8th, 10th, 12th – 17th, 22nd – 28th
November 2006	1st – 2nd, 7th – 9th, 12th – 23rd, 25th – 28th
December 2006	1st – 2nd, 4th – 9th, 11th, 13th, 17th – 23rd, 27th – 28th
January 2007	2nd, 5th – 8th, 10th, 13th, 15th – 18th, 20th, 23rd, 25th – 28th, 30 –31st
February 2007	1st, 3rd, 6th – 8th, 10th, 16th – 21st, 23rd, 25th – 26th, 28th
March 2007	1st – 8th, 11th – 13th, 17th, 19th – 24th, 26th, 29th – 30th
April 2007	1st – 5th, 8th – 9th, 11th – 24th, 26th, 28th
May 2007	1st – 5th, 7th – 9th, 11th, 13th – 18th, 21st, 24th – 28th
June 2007	1st, 4th – 7th, 9th – 15th, 17th – 23rd, 27th – 30th
July 2007	4th – 6th, 8th – 13th

The total numbers of sightings of each species in all weather conditions throughout the study period (July 2006 to July 2007) are given in Figure 4 and 5. The probabilities of sighting marine mammals are significantly affected by the sea state, general visibility and distance with sea state having the greatest potential impact. Therefore, in all subsequent analyses only observation periods where the sea state was 3 or less were used. This resulted in a reduction of 8 % in total observation time during the winter months (November 2006 to February 2007). The largest reduction in suitable observation periods was in November 2006 (11.3%; Table 2). By minimising the observation periods in this way 906 survey hours were used in the analysis. During this time a total of 1434 observations were made of (one or more) marine mammals.

Table 2: Total survey time (hours) in each month in sea state 0-3 and sea state 4 or greater. Figures in bold shows the total number of survey hours used in analysis.

Month	Total survey hrs	Total survey hrs with sea state 0-3	Total survey hrs with sea state ≥4
July 2006	**45**	45	0
August 2006	**80**	80	0
September 2006	**80**	80	0
October 2006	**76**	76	0
November 2006	**80**	71	9
December 2006	**70**	66	4
January 2007	**71**	64	7
February 2007	**71**	69	2
March 2007	**80**	80	0
April 2007	**80**	80	0
May 2007	**78**	78	0
June 2007	**80**	80	0
July 2007	**37**	37	0

3.1 Descriptive statistics

3.1.1 Grey seals

Overall, grey seals were observed in the study area on 154 of 240 observation days during 2006-07. Only the sightings made during sea state 0-3 have been used to calculate mean hourly sighting rates for this species on a month by month basis (Figure 6a). Grey seals had the highest hourly sighting rates of all species in each survey month, except July 2006, May 2007 and June 2007, when harbour seal sighting rates were higher, and July 2006, May, June and July 2007 when unclassified seal sighting rates were higher. The peak mean sighting rate in this species was 5.71 individuals per hour during October 2006 closely followed by September 2006 (5.03 per hour). The sighting rates of grey seals were less than 1hr^{-1} between December 2006 and July 2007. Results of χ^2 test for homogeneity in the frequency of sightings between all months show that there was significant difference in the sighting rates of grey seals between months (χ^2 =2088, df = 12, p<0.001[1]).

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[1] The null hypothesis in all these tests was that the expected numbers of sightings were proportional to the time spent looking.

The mean hourly sighting rates of grey seal at each state of tide are shown in Figure 7a. Grey seals were sighted at all tide states, although the highest sighting rate was at ebb tide (1.83 individual hr^{-1}), and sightings were least frequent at low tide. Results of χ^2 test for homogeneity show that there was a significant difference in the sighting rates between the states of tide ($\chi^2 = 88.3$, df = 3, $p<0.001$).

Grey seals were sighted throughout the day between 05:00 and 21:00 (Figure 8a) with the peak in sighting rates around 17:00. In general, sighting rates were lowest in both early morning and late evening. Grey seals were sighted in all zones of the study area (Figure 9). However, most of the sightings (74%) were in zone A, the area of water closest to Muckle and Little Green Holm. Only 29 sightings (2.2% of all grey seal sightings) were in zone B. Results of χ^2 test for homogeneity showed that there was a significant difference in the frequency of sightings between each zone ($\chi^2 = 2477$, df = 4, $p<0.001$).

3.1.2 Harbour seals

In all months, except July 2006, May 2007 and June 2007 harbour seals were reported less frequently than grey seals (Figures 4 and 6b). Mean hourly sighting rates of harbour seals were highest in July to October 2006 and June 2007, at a rate of one or more per hour. There was marked variability in the observation rate throughout the whole survey period (Figure 6b). Only two harbour seals were seen during January 2006. During November 2006, December 2006 and from February to April 2007 sighting rates were very low. Results of χ^2 test for homogeneity showed that there was a significant difference in sighting rates between the months when sightings occurred ($\chi^2 = 431$, df = 12, $p<0.001$).

Harbour seals were sighted at all tide states (Figure 7a). The highest sighting rate was at high tide (a mean of 0.81 per hour) though the sighting rates only varied between 0.44 and 0.81 per hour across all tide states. However, results of χ^2 test for homogeneity confirmed that there was a significant difference in the sighting rates between the different states of tide ($\chi^2 = 25.7$, df = 3, $p<0.001$). Harbour seals were sighted more frequently during early morning and late afternoon/evening (Figure 8b). During the middle portion of the day, between 09:00 and 15:30, sighting rates remained very low (below 1 per hour) with the exception of 11:15. The mean sighting rate during this middle portion of the day was 0.42 per hour, compared with 1.24 per hour out-with these times.

Harbour seals were sighted in all zones of the study area (Figure 9). Most of the sightings were closest to the shores of zone E (78.7%). Only 0.34% of the harbour seal sightings were in zone B and only a further 0.34% of sightings were in zone C. Results of χ^2 test for homogeneity showed there was a significant difference in the sighting rates between each zone (χ^2 =1298, df = 4, p<0.001).

3.1.3 Seals (unclassified to species)

Seals which could not be identified to species were named 'unclassified seals'. The sightings rate of unclassified seals was low between July 2006 and April 2007 but greater between May and July 2007 (peaking at 1.95 sightings per hour for July 2007, Figure 6c). In November 2006, January, February and April 2007, the sightings rates of unclassified seals was as great or greater than the sightings rates for harbour seals. In June 2006, the sightings rate of unclassified seals was greater than the sightings rate for grey seals. In December 2006, May and July 2007, the sightings rates of unclassified seals was greater than the sightings rates for both harbour and grey seals. Results of χ^2 test for homogeneity in the frequency of sightings between all months show that there was a significant difference in the sighting rates between months when sightings occurred (χ^2 =426, df = 12, p<0.001).

Unclassified seals were sighted at all tide states (Figure 7a). The highest sighting rate was during high tide (a mean of 0.48 per hour) though sightings rates only varied between 0.18 and 0.48 per hours over the whole tidal cycle. Results of χ^2 test for homogeneity in the frequency of sightings between all states of tide confirmed that there was a significant difference in the sighting rates (χ^2 = 29.7, df = 3, p<0.001). Unclassified seals were observed relatively consistently throughout the day, although there was a slight increase in late evening (Figure 8c).

Unclassified seals were sighted in all zones of the study area (Figure 9). Most sightings (59.0%) were in zone A (closest to Muckle and Little Green Holm and furthest from the observation point). Only 2.3% and 3.5% of sightings were in zones B and C, respectively. Results of χ^2 test for homogeneity showed that there was significant difference in the sighting rates between each zone (χ^2 =394, df = 4, p<0.001).

3.1.4 Harbour porpoises

Groups of harbour porpoises were seen in the study in all months except January and February 2007 (Figures 4 and 6d). The majority of the sightings (73%) were of groups of two or more individuals. A maximum group size of eight was observed during September 2006). Highest sighting rate of harbour porpoise groups was in July 2006 (a mean of 1.24 per hour), with a reduced sighting rate for August and September 2006 (means of 0.58 and 0.55 per hour, respectively) and much lower rates (<0.25 per hour) during October 2006 to July 2007. Results of χ^2 test for homogeneity show that there was a significant difference in sighting rates between months where sightings occurred (χ^2 =476, df = 12, p<<0.001).

Harbour porpoises were sighted during all tide states (Figure 7a). The highest mean sighting rate was during the flood tide (0.32 individuals per hour), with reduced rates for high, low and ebb tides of 0.26, 0.15 and 0.08 individuals per hour, respectively. Results of χ^2 test for homogeneity showed significant differences in the sighting rates between the different states of tide (χ^2 =37.5, df=3, p<0.001). Harbour porpoise sighting rates were lower during the middle of the day than early morning or late evening; the peak in sighting rates was around 19:00 (Figure 8d). The sighting rate at 11:50 (4 per hour) is an outlier that reflects only a single observation at this time of day during the study period.

Harbour porpoises were seen in all zones of the study area (Figure 9). Sightings were most frequently made in zone E (35.8%) and least frequently in zone A (8.6 %). Results of χ^2 test for homogeneity show that there was a significant difference in the sighting rates between each zone (χ^2 =40.7, df = 4, p<0.001).

3.1.5 Other species (minke whales, basking sharks and white-beaked dolphins)

Although seals and harbour porpoises were the most commonly observed species, white-beaked dolphins, minke whales, basking sharks, otters, Risso's dolphins, and killer whales were also seen in the Study Area. The sightings of these species were considerably less frequent than of the 'regular' species (Figures 4 and 5).

Minke whale sightings were made in July, August and October 2006, and June 2007. Numerous sightings on each of these days were most likely, but not necessarily, repeat observations of a single animal within that day. The minke whales were observed in all zones of the Study Area (except zone A) and during all tide states (Figure 7b).

Basking shark sightings were made in the study area between July and October 2006, and June and July 2007. On numerous occasions, the sightings of this species were most likely repeat sightings of one individual moving through the study area. Only on one occasion were two individuals reported (September 2006). Basking sharks were seen in all zones of the Study Area (except zone A) with most sightings in zone E (85%). Basking sharks were observed in the Study Area at all states of tide (Figure 7b).

Groups of white-beaked dolphins were observed on three days during the study (25th and 31st August 2006 and 17th September 2006). Five individuals were observed on 25th August 2006. One hour later a further five individuals were sighted which may have been a repeat observation of the same group. Two groups of three individuals were sighted on the 31st August 2006 in different zones of the Study Area. Two individuals were sighted on 17th September 2006 in zone C.

A total of five otters were sighted during July, September and October 2006 and June 2007.

3.2 GAMs

The data were considered as 1-hour long blocks of observations in the 25 grid cells. Many of these observations are likely to have been of the same animals using a range of grid cells at various times on a number of days, the measure is therefore of relative usage and cannot realistically be converted into absolute numbers of individuals. There were six occasions when disturbance on land was noted, and large numbers of seals were seen in the water. These six hours were assumed to be unrepresentative of the general pattern and the observation data recorded for them was deleted prior to analysis.

The small number of harbour seals and harbour porpoises limited the complexity of the models of these species that could usefully be investigated. The models presented here attempt to draw out the main patterns while avoiding the overcomplicated patterns associated with over-fitting.

3.2.1 All seals (grey, harbour and unclassified combined)

When all the seal observations were considered together, the best models contained time of day, tidal state, observer identity, wind strength and direction, with smooths of location and date. Table 4 shows the magnitude of the linear effects.

It is clear that the numbers of animals observed increases through the day and is highest during the ebb tide on calm days, while westerly winds reduce observed numbers substantially. The observer effect might indicate that the original observer recorded more sightings, though even that would not indicate which observer was more accurate. However it is also possible that this indicates an overall drop in animal numbers at this time. As this was preferred to either a simple smooth or a linear effect, this would at least seem to indicate any change was more likely to have been sudden than gradual.

Table 4: Environmental effects on the numbers of seals (of either or unknown species) observed during the study. Each multipler shows the expected numbers seen under those conditions, as compared to a baseline level, so only 60% as many sightings were made per hour at low tide compared to on the ebb tide.

Parameter	Unit/Level	Multiplier (95% CI)
Time of Day	per hour	1.02 (1.01-1.04)
Wind strength	0	1
	(per Beaufort level)	0.80 (0.76-0.85)
Wind direction	East	1
	North	1.21 (1.06-1.38)
	South	1.11 (0.98-1.27)
	West	0.64 (0.55-0.74)
	Variable	1.38 (1.10-1.73)
	None	1.14 (0.92-1.42)
Tide state	Ebb	1
	Low	0.60 (0.52-0.69)
	Flood	0.71 (0.63-0.80)
	High	0.79 (0.71-0.88)
Observer.id	1	1
	2	0.76 (0.68-0.86)

There was some autocorrelation ($\varphi = 0.15$) in the data, which can be interpreted as seven hours of observations providing the equivalent information to six independent data points. The autocorrelation is lower than in the simpler model identified from the first year's data alone. The highest densities of observations were around the shore, at either side of the observation point and near the far-shore islands (Figures 10 and 11). Distance from the observer did not appear in the final model, but since that is largely confounded with the general spatial smooth, which gives little indication of the strength or absence of such an effect.

3.2.2 Grey seals

Sixty-five percent of the 4147 seals observed were identified as grey seals. Given this, it is unsurprising that results are similar to the unclassified seals (Table 5; Figure 12 and 13). However, the model differed in some details, with a broad peak in numbers during the afternoon, rather than a decline through the day and a steady decline in numbers rather than a sudden decrease associated with the change in observer. There was a clear peak in the numbers of animals seen in the Study Area early during autumn. The autocorrelation ($\varphi=0.12$) and over-dispersion (residual variance/mean=1.5) are similar those for all seals combined.

Table 5: Environmental effects on the numbers of grey seals observed during the study.

Parameter	Unit/Level	Multiplier (95% CI)
Wind strength	0	1
	(per Beaufort level)	0.75 (0.70-0.80)
Wind direction	East	1
	North	1.21 (1.01-1.43)
	South	1.12 (0.96-1.30)
	West	0.98 (0.82-1.18)
	Variable	1.50 (1.15-1.96)
	None	1.07 (0.83-1.39)
Tide state	Ebb	1
	Low	0.54 (0.45-0.64)
	Flood	0.67 (0.57-0.78)
	High	0.85 (0.74-0.97)
Elapsed time	per Year	0.61 (0.54-0.68)

3.2.3 Harbour seals

The best harbour seal model contains smooths of location, season and time of day (Figures 14, 15 and 16) The temporal patterns contrast with those for grey seals with peaks earlier in the year and at night rather than during the afternoon. The number of sightings of harbour seals seems to be increasing at a rate similar to the decline in grey seals. The model is based on a total of 911 sightings over the 1547 hours observation in good weather. The data is mildly autocorrelated (φ=0.07), but there is no sign of over-dispersion. Comparing figures 12 and 14 suggests that the harbour seals made relatively more use of the central channel than the grey seals did.

Table 6: Environmental effects on the numbers of harbour seals observed during the study.

Parameter	Unit/Level	Multiplier (95% CI)
Tide state	Ebb	1
	Low	0.64 (0.50-0.82)
	Flood	0.85 (0.68-1.06)
	High	1.24 (1.01-1.53)
Elapsed time	per Year	1.36 (1.18-1.57)

3.2.4 Harbour Porpoises

A total of 349 individuals were seen in 132 groups during the 345 observations. This low sighting frequency limits the analysis. The best model had negligible autocorrelation (φ=0.003) and has a seasonal smooth (Figure 17) and a 50% decline in observation frequency for each Beaufort unit increase in with wind strength (95% confidence interval on multiplier 0.69-0.65). Adding in spatial patterns did not improve the fit of the model, giving no reason to consider any particular area to be used preferentially. The best models allow for the animals tendency to be observed in small groups through a moderate degree of over-dispersion (scale=5.1). This means that, based on the 349 individuals seen in this survey, 95% of future repeats of the study under similar conditions could be expected to observe between 270 and 435 individuals.

4 Discussion

This study has provided a current assessment of the relative usage patterns of the Fall of Warness by marine mammals and basking sharks. Furthermore, it has built upon the previous data (Duck, Black et al. 2006) and has provided a series of robust models to predict the temporal and spatial patterns of use within the area. It should be noted that all the observations were of animals on the surface of the water and these data do not reflect the underwater movement of animals through the Fall of Warness, or the absolute abundance of animals that use this area. A total of eight species of marine mammal (harbour and grey seals, harbour porpoises, minke whales, white-beaked dolphins, otter, killer whale, Risso's dolphin) and basking sharks were seen during the 13 month observation period July 2006 to July 2007, although not all species were seen in each month.

4.1 Seal observations

Unclassified seals in this study are likely to have included individuals of both species, but the majority were likely to have been grey seals, as a large number of sightings were in zone A where far fewer harbour seal sightings occurred. However, this zone was also the furthest from the observer, and this may have led to a reduced ability to identify seal species correctly over such a distance. It was considered more informative to extract the patterns within the complete seal dataset as well as each species on its own, rather than investigating the distribution of unclassified seals in their own right. The majority of the seal sightings were of grey seals, thus the results of modelling all of the seal observations together produced very similar results to the grey seal modelling process.

Grey seals were the most frequently sighted species in the study area. Results from the descriptive statistics show that temporal and spatial patterns of use have been generally consistent between the 2 survey years. They were seen in each survey month, with most sightings close to Muckle and Little Green Holm (zone A) where grey seals are known to breed in large numbers. There was a clear seasonal pattern in grey seal sightings during the survey period (month appeared as a significant factor in the χ^2 test, and day of the year was selected by the GAM process) and an overall decline over the duration of the study. The greatest hourly sighting rates of grey seals were in September and October 2006, coinciding with this species' breeding season. The lowest sighting rates were in December to June. Their presence in the Study Area was related to the state of tide. Increasing wind strength was associated with decreasing numbers of sightings. As the study continues it may be possible to identify further temporal and spatial patterns.

As with the grey seals, results from the descriptive statistics show that harbour seal temporal and spatial patterns of use have been generally consistent between the 2 survey years. Harbour seals were sighted most frequently between July to October 2006. Only very few harbour seals were observed between December 2006 to February 2007 (14 sightings in total). They were seen most frequently at high tide. In general, low numbers of harbour seals in the Fall of Warness may be related to high numbers of grey seals; competition between the two species has previously been cited as causing local declines in harbour seal abundance (Thompson, Van Parijs et al. 2001; Bowen, Ellis et al. 2003). Over the two-year study period, as grey seal sightings have declined, the numbers of harbour seals observed has increased.

4.2 Cetacean and basking shark observations

Harbour porpoises represented the most common species of cetacean sighted in the Fall of Warness, and it is the most common species of cetacean in north-western European continental shelf waters (Reid, Evans et al. 2003). Sightings in inshore waters are more common in summer, and are probably related to prey distribution (Carwardine 1995). Results from the descriptive statistics show that temporal and spatial patterns of use in the Fall of Warness have been generally consistent between the 2 survey years. During 2006-07, they were sighted in the Fall of Warness in all months except January and February, although this does not imply that they were not present in these months. Harbour porpoises were seen with the greatest frequency during the flood tide and with very low frequency during ebbing tide. Sighting rates appeared to be lower during the middle of the day. Despite these apparent trends in the data from early analysis, GAMs indicated that the best model included only wind strength and a summer seasonal peak. Adding in spatial patterns did not improve the fit of the model, giving no reason to consider any particular area to be used preferentially. This is in contrast to the results of the analysis of the first year's data alone, which gave some support to the idea that usage by porpoises was concentrated in the centre of the Study Area.

In support of sightings patterns around Scotland, minke whale sightings in the Fall of Warness occurred primarily between June and October. Furthermore, the Fall of Warness is likely to be a good foraging habitat for whales as favoured feeding locations include upwelling areas around headlands and small islands, and areas where strong currents flow (Reid, Evans et al. 2003). This is supported by the fact that large numbers of seabirds were seen feeding in the area (SMRULtd 2007), and shoals of fish were regularly observed breaking the surface of the water during the study.

White-beaked dolphins are present over the continental shelf year round, but inshore sightings are more common between June and October (Reid, Evans et al. 2003). In support of this, observations of white-beaked dolphins in the Fall of Warness were in August and September 2006.

In addition to sightings of cetaceans and seals, basking sharks were also observed in the study area between July to October 2006 and again in June and July 2007. These are very large, plankton-feeding pelagic sharks that are most regularly recorded in coastal areas of the UK with seasonally persistent tidal fronts. The majority of sightings in UK waters are between the Hebrides and north coast of Brittany, there are, relatively few sightings on the east coast of the UK (Southall, Sims et al. 2005). Although surface sightings of basking sharks are possible due to their feeding behaviour, it is difficult to assess whether the absence of surface sightings may equate to feeding deeper in the water column, or an absence of sharks in the area.

4.3 General comments

Data collected during disturbance times from a shooting party on Muckle Green Holm were excluded from the GAM analysis as being atypical observation periods. However, the importance of such disturbances that displaces large numbers of seals into the water during short periods of time should not be ignored. Such disturbances could occur at critical times of tide or during testing the tidal stream devices. Animals that are focused upon an apparent threat from land may exhibit reduced awareness of threats within the water column and it is such conditions could affect the possibility of interactions with moving objects such as tidal stream devices.

In addition to the species of cetacean seen as occasional visitors to the Fall of Warness during the survey periods, other species may use this stretch of water. Infrequent observations of humpback whales, pilot whales, fin whales, bottlenose dolphin and Atlantic white-sided dolphin are also a possibility in the Fall of Warness due to the distribution of previous sightings of these species (Reid, Evans et al. 2003).

It should be noted that the Study Area encompasses a large stretch of water where accurate species identification and determination of location of sightings was not always possible. The results presented here support the likelihood that distance from the observer is important in the identification of seal species (especially harbour seals) and also reduces the ability to sight harbour porpoises. In addition, poor environmental conditions such as high winds, high sea states, precipitation and cloud cover will all reduce the probability of sighting individual animals on the water surface. Therefore, the observations made to date in the Fall of Warness and the data analyses here will most likely only represent a minimum estimate of the sighting frequencies of any marine mammal (and basking sharks) in the area.

It might be useful to consider including information on physical features, such as water depth and relative water speeds across the area, in any future studies and analyses. At present, the geographic smooths in the GAMs act as proxies for these differences, so the practical gains may be limited. However, more detailed information might improve the models' precision. It is unlikely, however that more detailed analysis of the porpoise or harbour seal distributions would be possible without larger studies being carried out using a longer time series of data. The most appropriate future approach for examining these data using GAMs would be reanalysis in combination with additional data collected from the experimental operation of tidal stream devices. The presence of experimental devices can be included in the model as an additional covariate. Straightforward comparisons of average results from the current models with later experiments are likely to be less effective at producing any informative results.

The modelling strategy, using Generalised Additive mixed Models with overdispersed and autocorrelated errors explicitly represents the main features of the data. Although it is computationally intensive, it reduces the risk of overfitting or producing spuriously overly detailed interpretations of the data.

4.5 Effects of tidal stream devices: adoption of standard methods

Assessing the environmental effects of tidal stream power generators on large bodied animals in the water column is a subject of considerable interest and concern. It remains an open question as to what impact tidal steam devices could have on these species and only careful, adaptive approaches to the installation, testing and operation of these devices will provide confidence that any effects have been appropriately mitigated. Management and mitigation of impacts needs to include appropriate methods for measuring effects at large (population-wide), medium (in the vicinity of the device) and fine scales (around the device itself). This analysis has concerned mainly the medium spatial scale. The major constraint encountered involves the quality and quantity of data that can be collected about animals that spend a large proportion of their time submerged and that can move rapidly through the region of interest during both day and night. The exercise reported here has allowed us to develop a methodology that could apply broadly to other circumstances in which tidal stream devices may be deployed. It counterbalanced the limitations of the data by applying state-of-the-art analytical methods. We propose that the methods applied, including both the field techniques and the subsequent analyses, could be worked up into a standard that could be adopted by the industry, similar to the COWRIE methodology adopted for offshore wind farms.

This study has developed a method that could be used to detect some of the effects of installing tidal stream power generators on potentially vulnerable species. To date, the application of the method at the Fall of Warness has been to provide a base-line assessment of the use made of the region by some of the vulnerable species and against which it may be possible to assess changes occurring after installation of an experimental generator. However, it is logical that the methodology should be modified in the post-installation phase of the development of the site to reflect the need for more rapid updates of potential effects. The methodology also needs to be an integrated part of the test regime for any device because of the importance of identifying effects in relation to the state of the device (e.g. operational versus non-operational). This methodology would need to be applied whenever an installation of a new device takes place.

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Figures

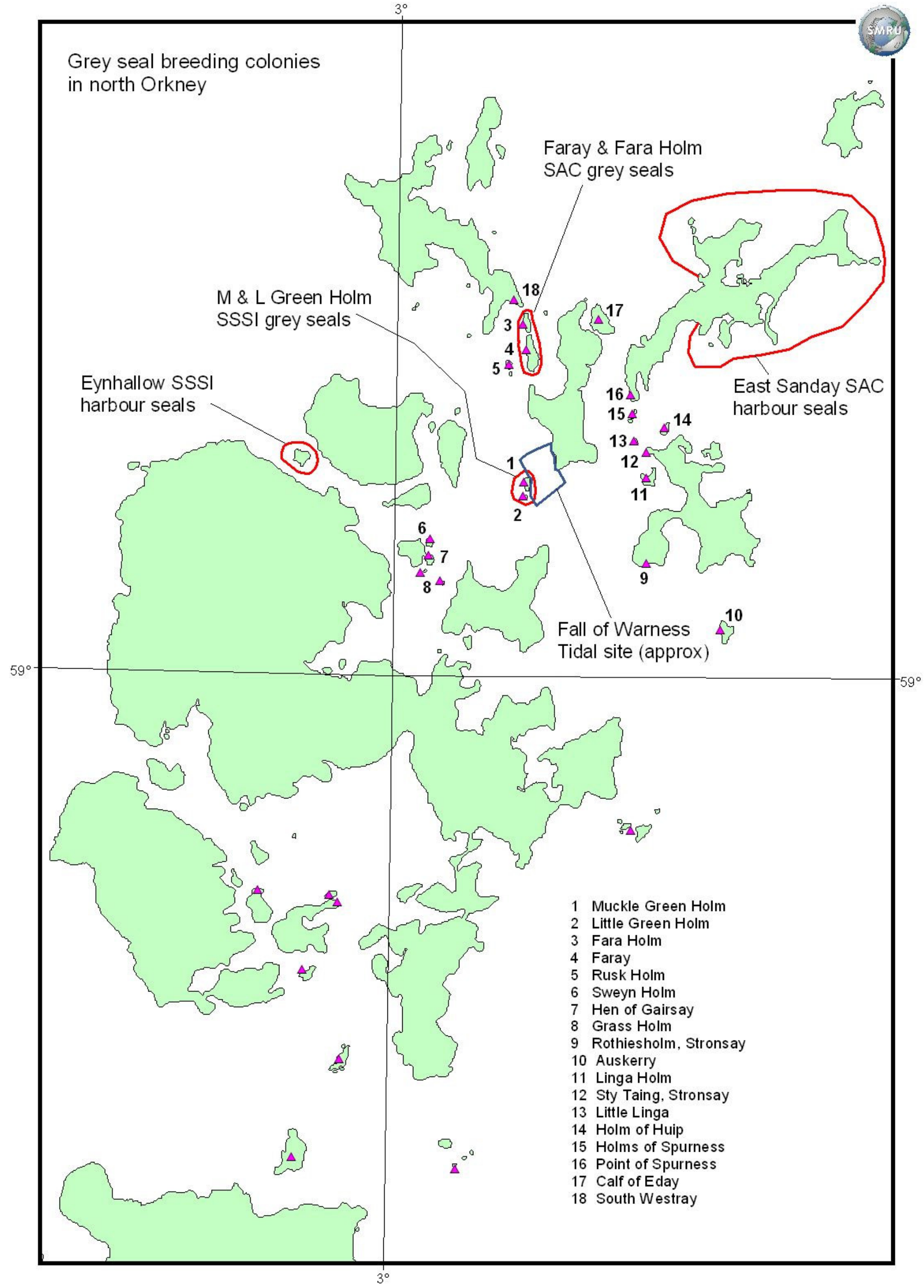


Figure 1: The main grey seal breeding colonies in Orkney, autumn 2005.

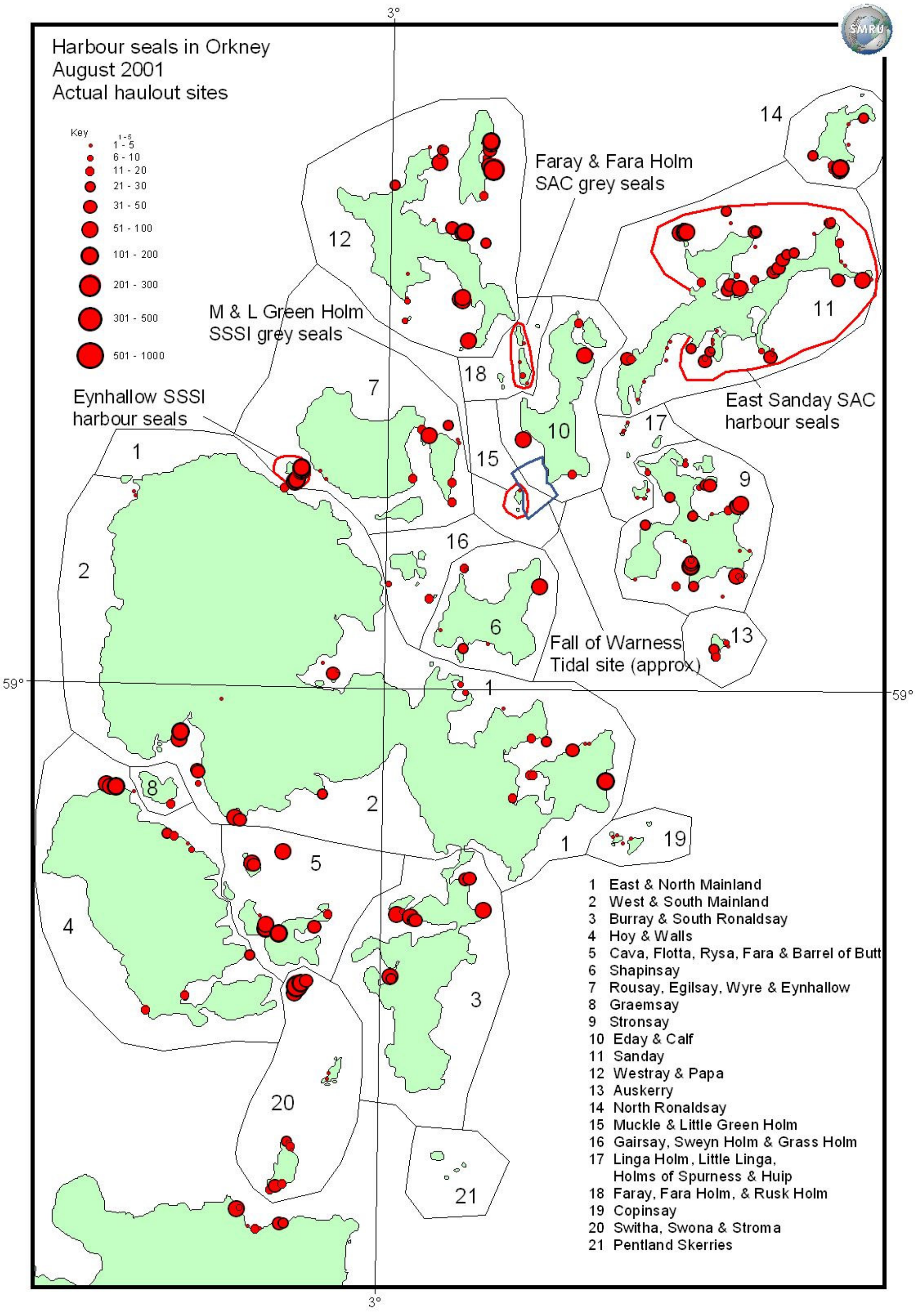


Figure 2: Harbour seal haul-out sites in Orkney, August 2001.

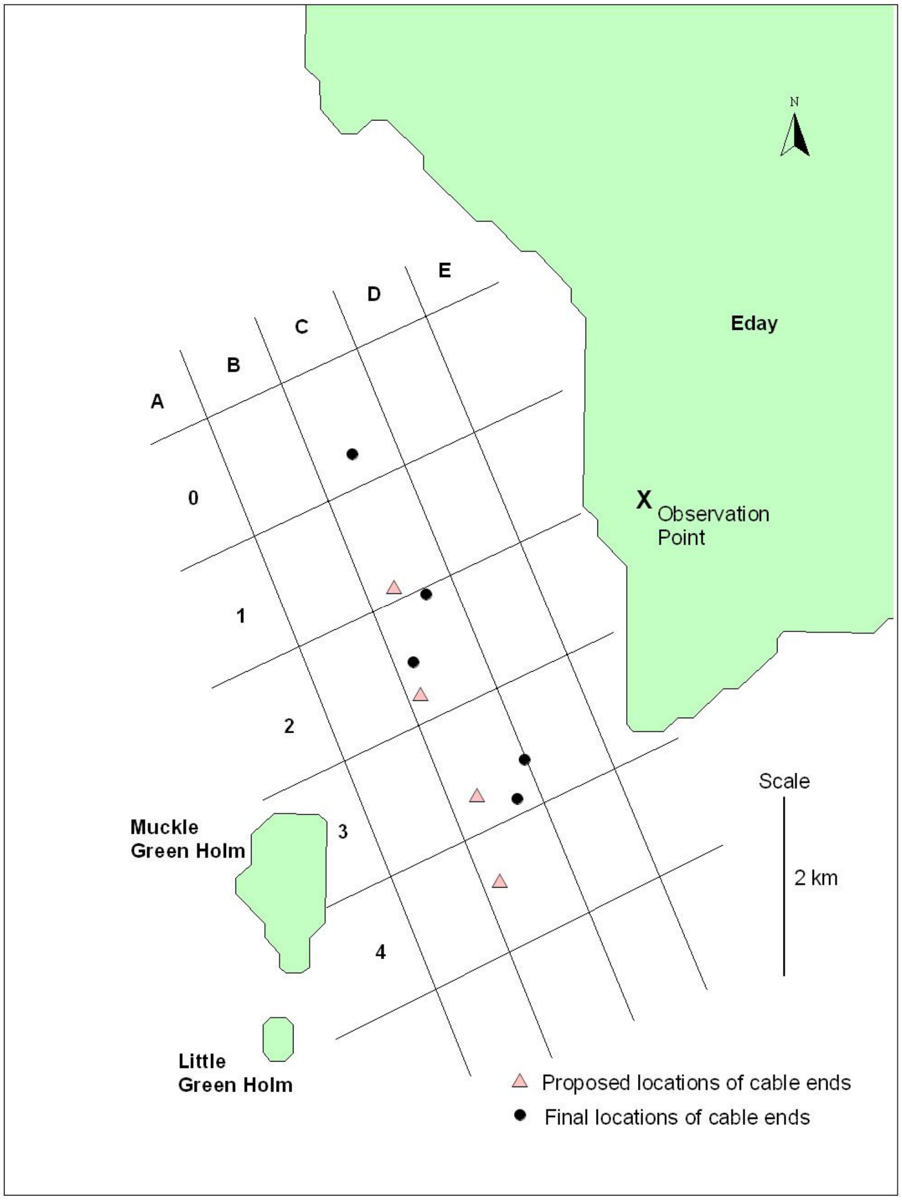


Figure 3: The observation grid in the Fall of Warness, between south-west Eday and Muckle and Little Green Holm, in Orkney. The approximate locations of the proposed tidal turbine test sites are marked as triangles, the approximate final locations are marked as circles.

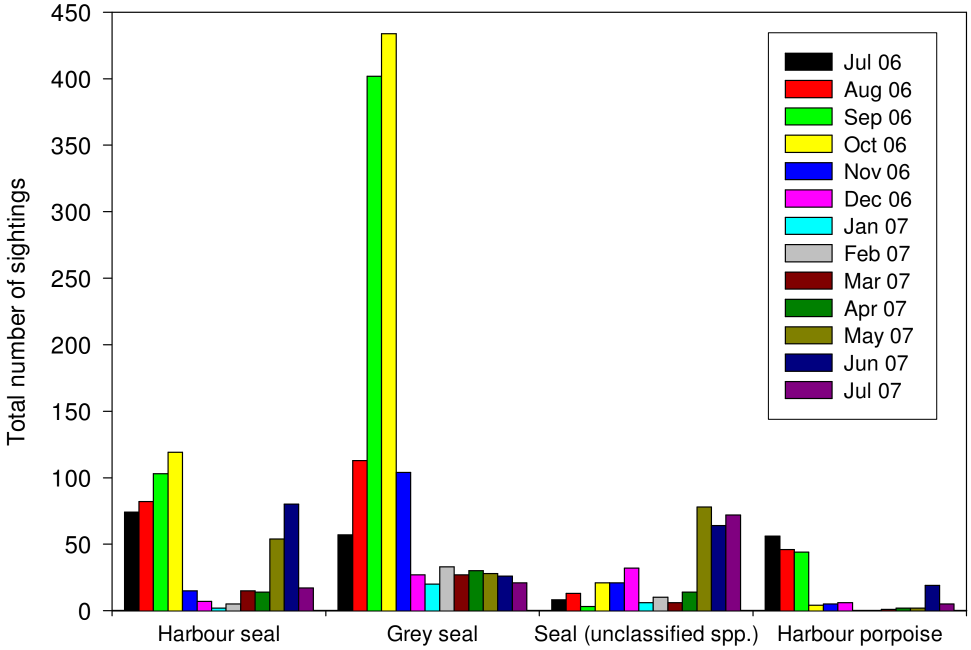


Figure 4: Total number of sightings of harbour seal, grey seal, seal (unclassified species) and harbour porpoise in the study area between July 2006 and July 2007.

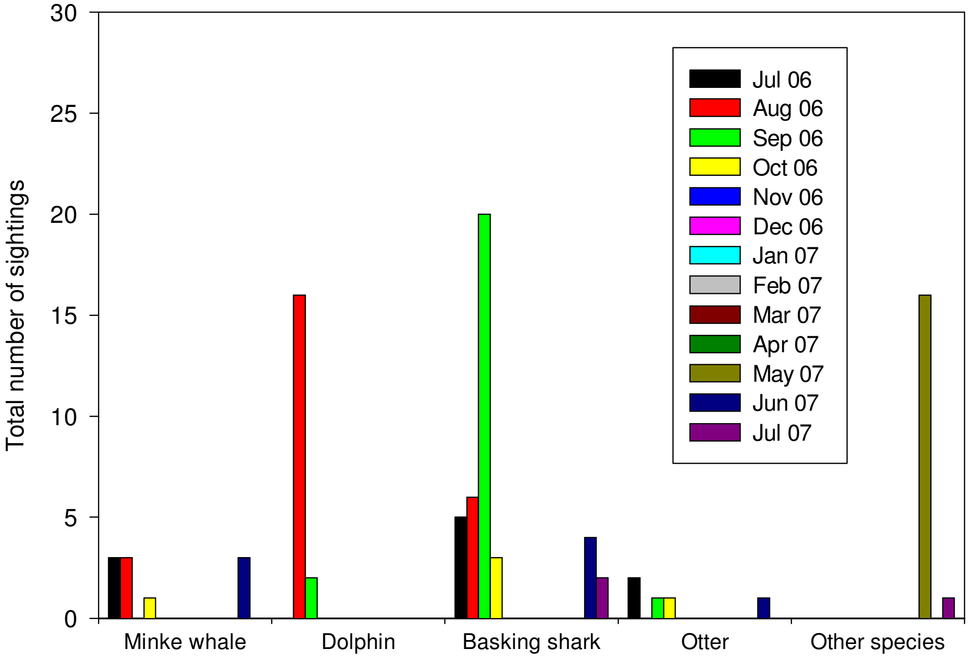


Figure 5: Total number of sightings of minke whale, white-beaked dolphin, basking shark, otter and other species (killer whale and Risso’s dolphin) in the study area between July 2006 and July 2007.

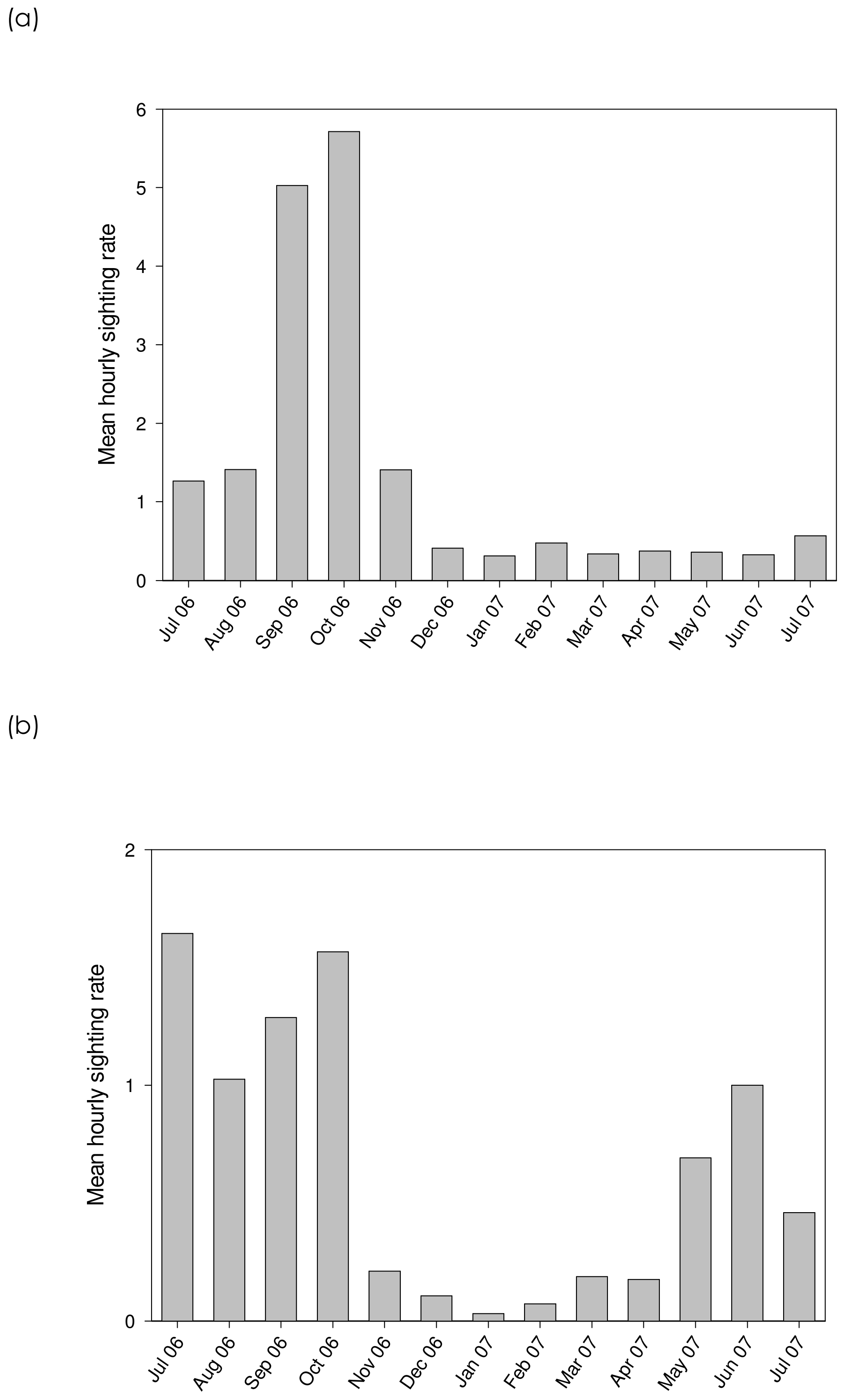
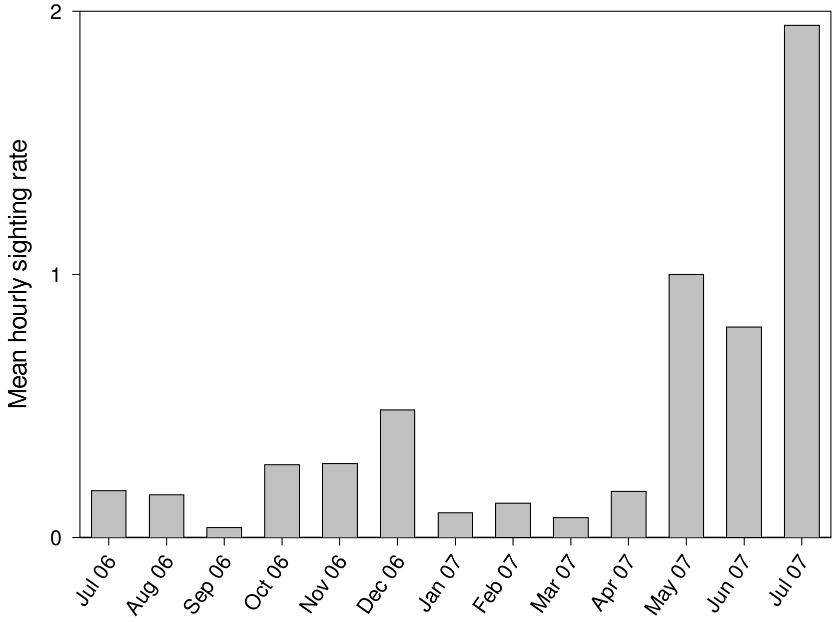

(a)
Mean hourly sighting rate
0
1
2
3
4
5
6
Jul 06
Aug 06
Sep 06
Oct 06
Nov 06
Dec 06
Jan 07
Feb 07
Mar 07
Apr 07
May 07
Jun 07
Jul 07
(b)
Mean hourly sighting rate
0
1
2
Jul 06
Aug 06
Sep 06
Oct 06
Nov 06
Dec 06
Jan 07
Feb 07
Mar 07
Apr 07
May 07
Jun 07
Jul 07

Figure 6...

(c)



(d)

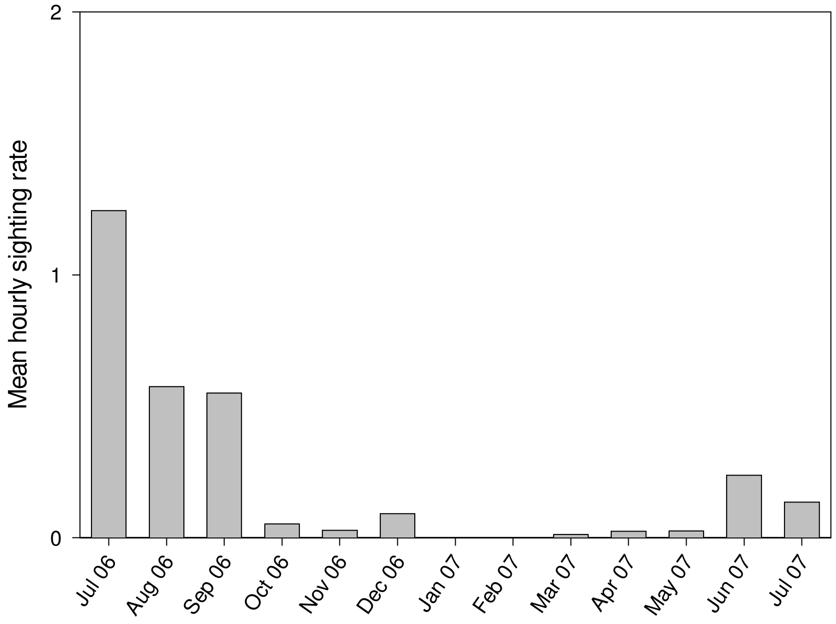
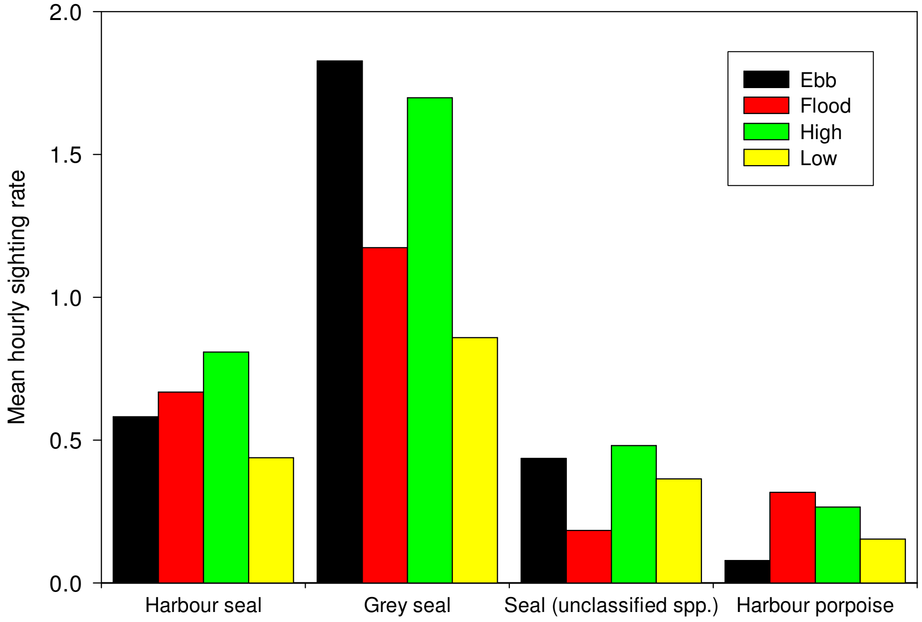


Figure 6: Mean hourly sighting rate of (a) grey seals, (b) harbour seals, (c) seals unclassified to species, and (d) harbour porpoise within each month. NB Note change in scale between Figure (a) and subsequent figures.

(a)



(b)

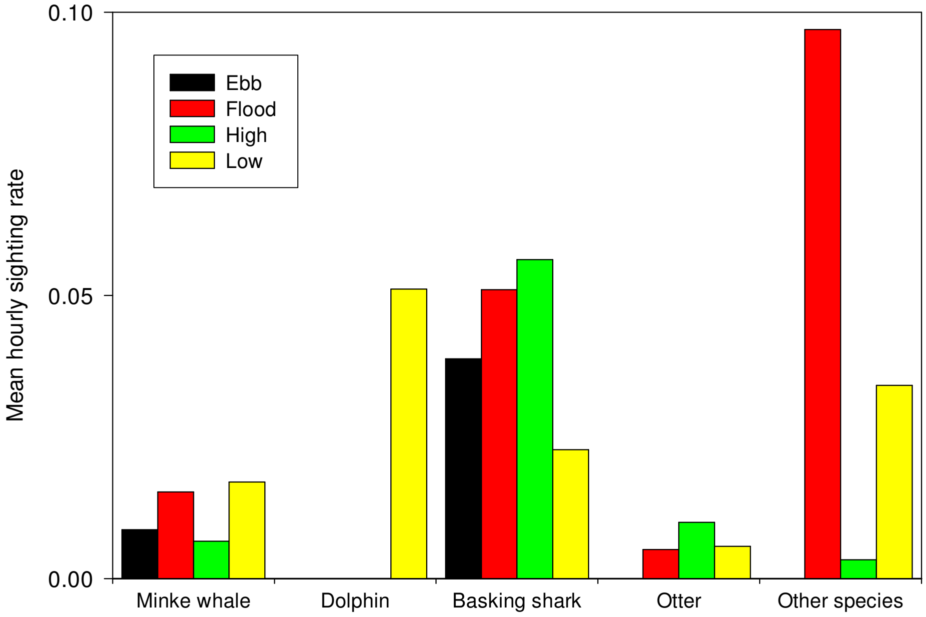
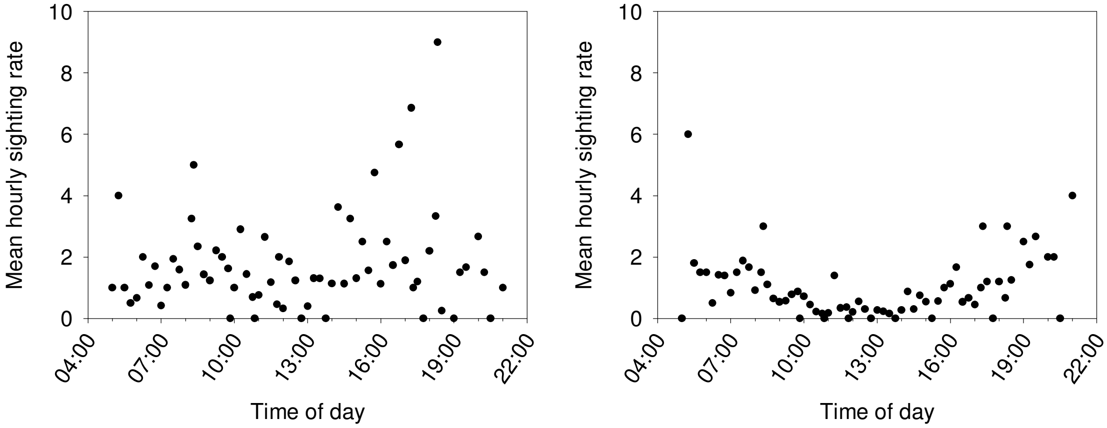


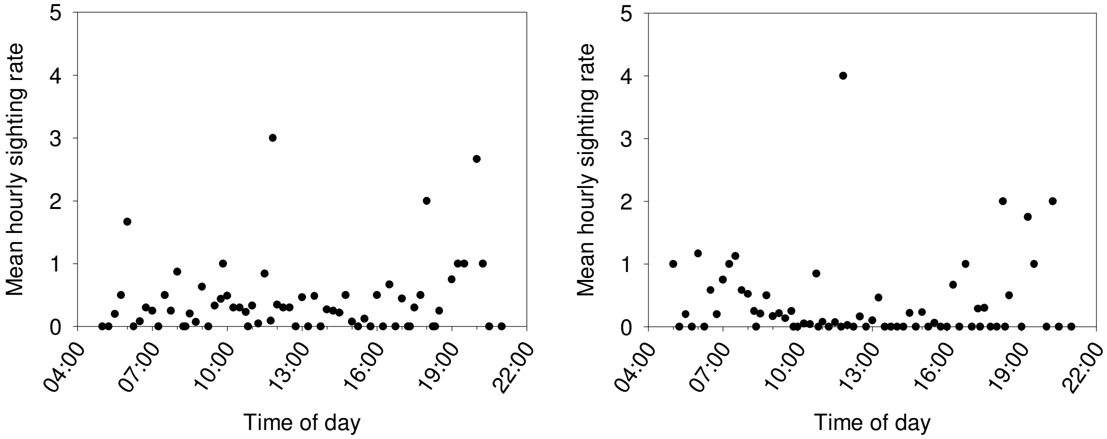
Figure 7: Mean hourly sighting rates of each species during each tidal state for (a) harbour seals, grey seals, unclassified species of seal and harbour porpoise, and (b) minke whale, white-beaked dolphin, basking shark, otter and other species (killer whale and Risso's dolphin).



a) Grey seal

b) Harbour seal

c) Seal (unclassified species)



d) Harbour porpoise

Figure 8: Mean hourly sighting rates of a) grey, b) harbour, c) unclassified species seals and d) harbour porpoise throughout the day. Data for all months combined.

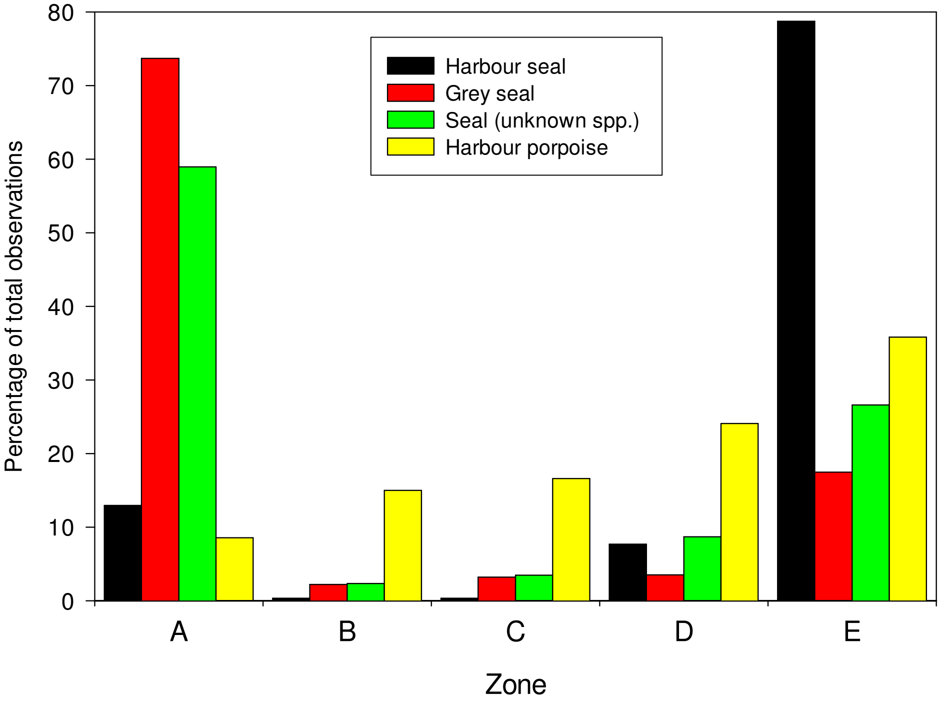


Figure 9: Percent of all observations harbour, grey and unclassified seals, and harbour porpoise made within each zone of the study area. Data for all months have been combined.

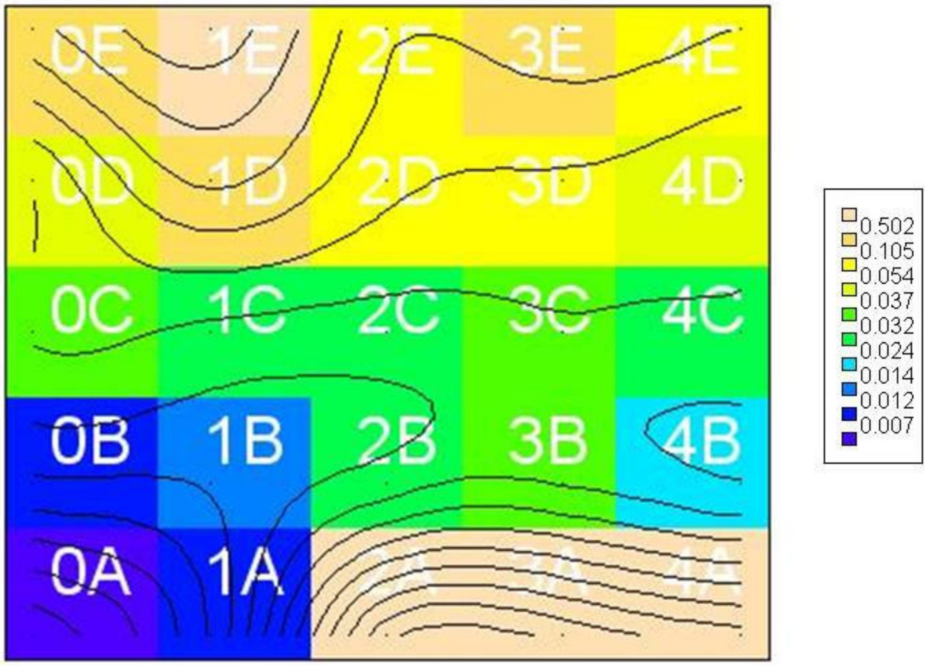


Figure 10: The estimated number of sightings of seals across the study area. The colours are overall estimates for each cell (animals observed hour^{-1}) going from dark blue where few animals were seen through to green and brown to yellow for the highest values. The contours are interpolated from the same model and are largely indicative, and details in their structure are unlikely to be important. The observation point was located above cell 2E in the study area. It can be seen that the overall pattern is of the animals being generally near to land and particularly close to Muckle Green Holm (cells 2A, 3A and 4A, the south west corner of the study area).

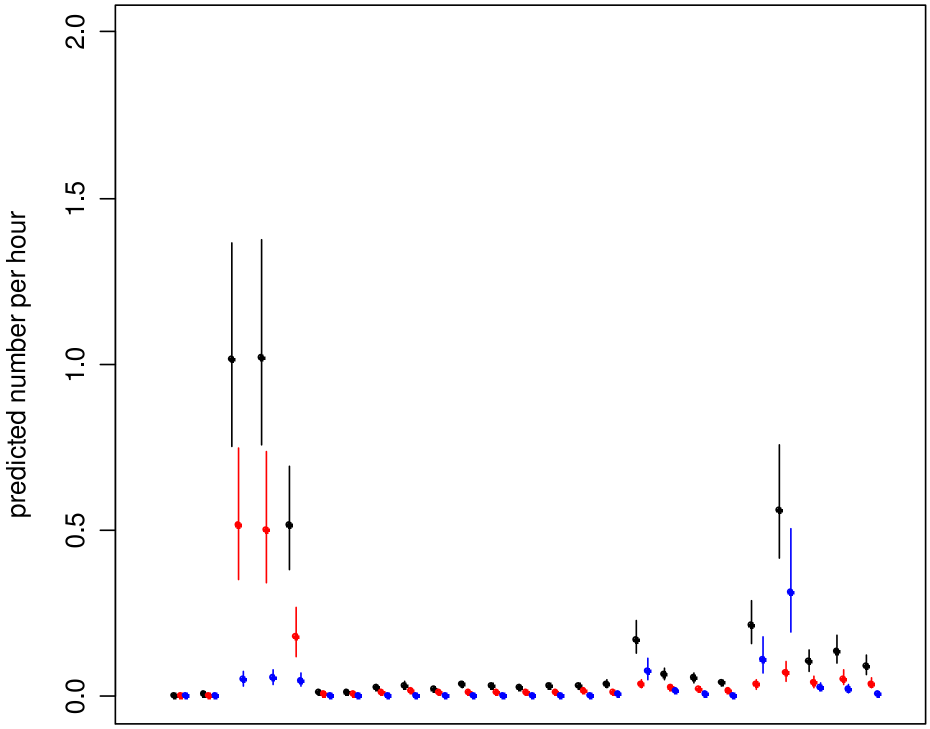


Figure 11: Estimated usage (in animals observed cell^{-1} hour^{-1}) and approximate 95% confidence intervals for each cell by seals. Black values are all seals combined, red only those identified as grey seals, and blue harbour seals. All values are calculated for October 1st, the relatively fewer identified grey seals earlier in the year merely alters the relative heights of the red and black points without changing the overall pattern.

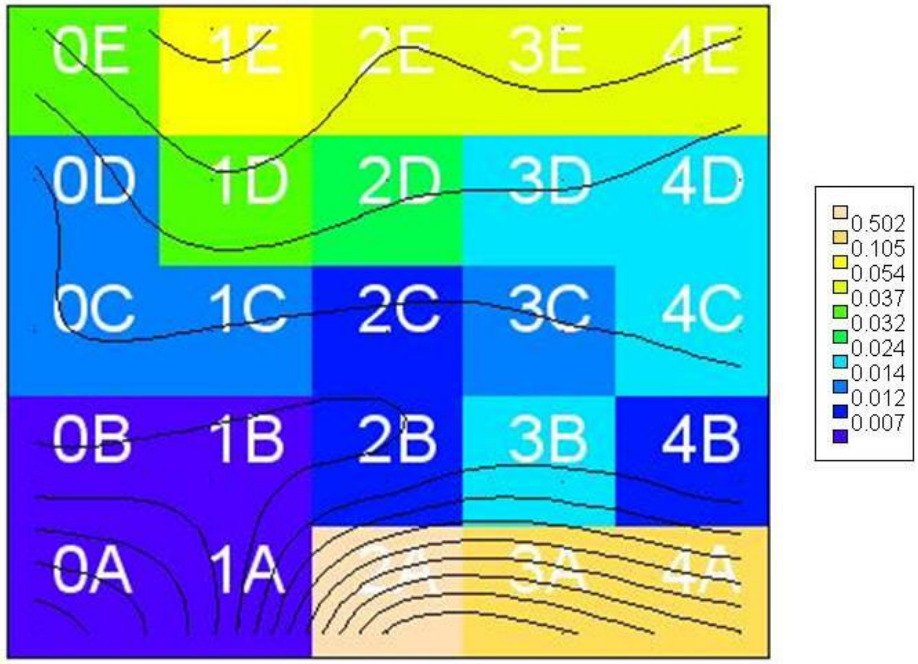


Figure 12: The estimated numbers of sightings of grey seals across the study area (animals observed hour^{-1}). The colours are the same as in the all seals equivalent. It can be seen that the patterns are very similar to those in that figure.

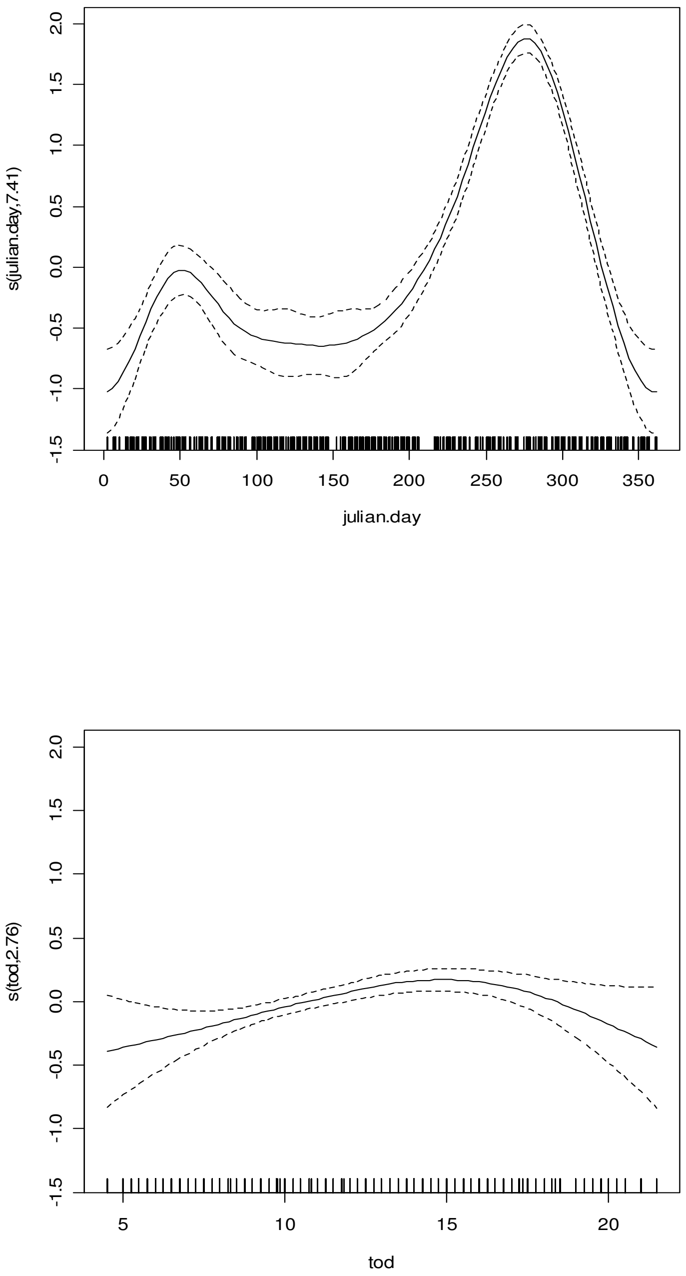


Figure 13: Estimated seasonal and diurnal pattern of changes in the relative numbers of sightings of grey seals over the year. There are clear peaks in the numbers of animals seen in the study area early in autumn (day 274 is October 1^{st}) and early afternoon (15:00 hours). Note that the y axes use log scales.

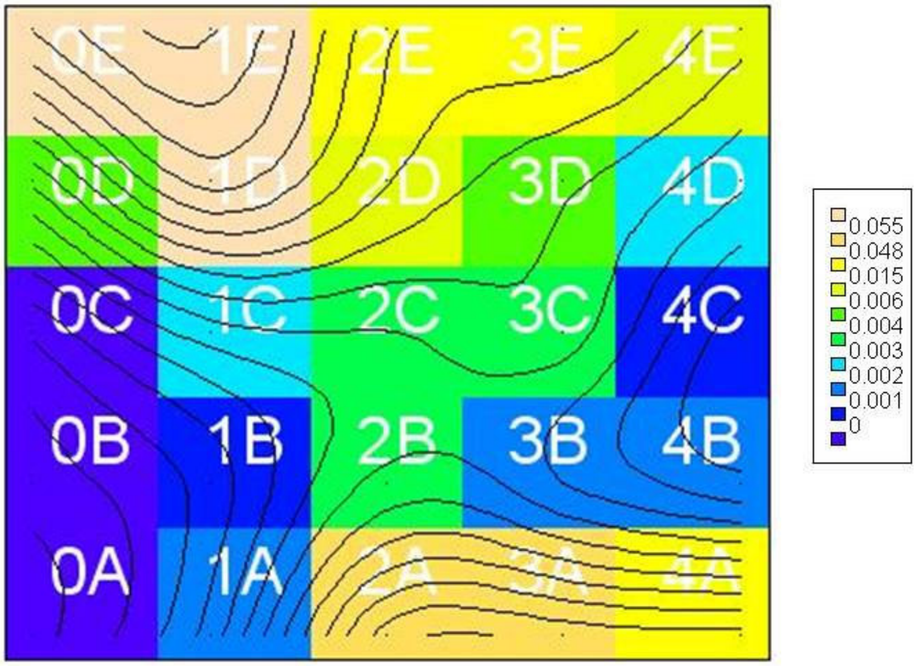


Figure 14: The estimated number of sightings of harbour seals across the study area (animals observed hour^{-1}). The colours are overall estimates for each cell, going from dark blue where few animals were seen through to green and brown to yellow for the highest values. The contours are interpolated from the same model and increase away from the observation point (which was sited adjacent to cell 2E). They probably largely indicate that the detectability of animals does not decline exponentially away from the observer.

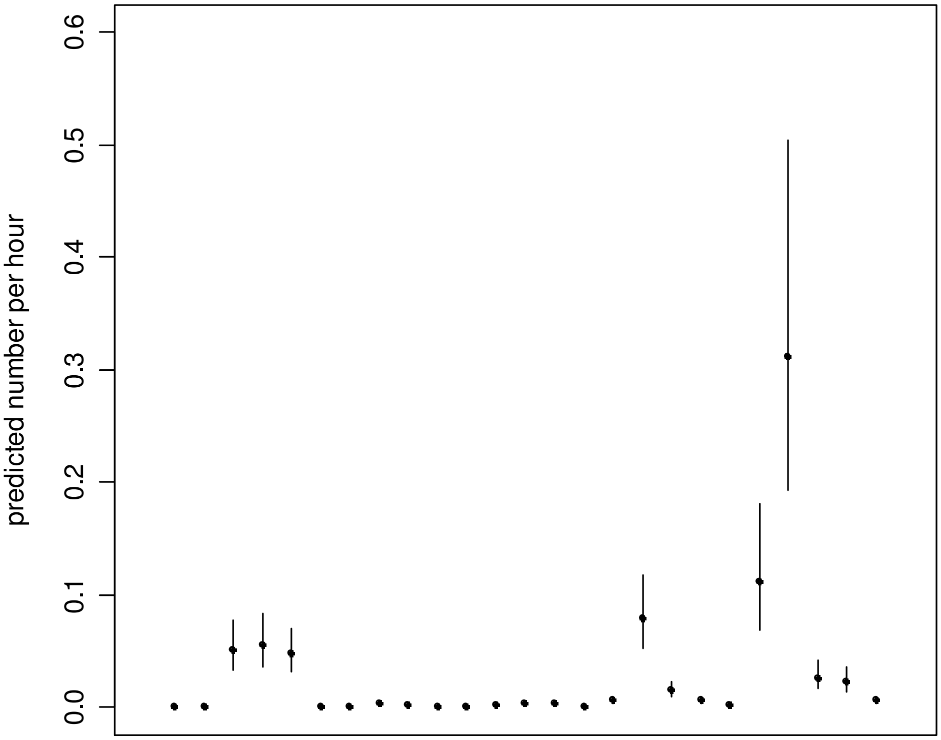
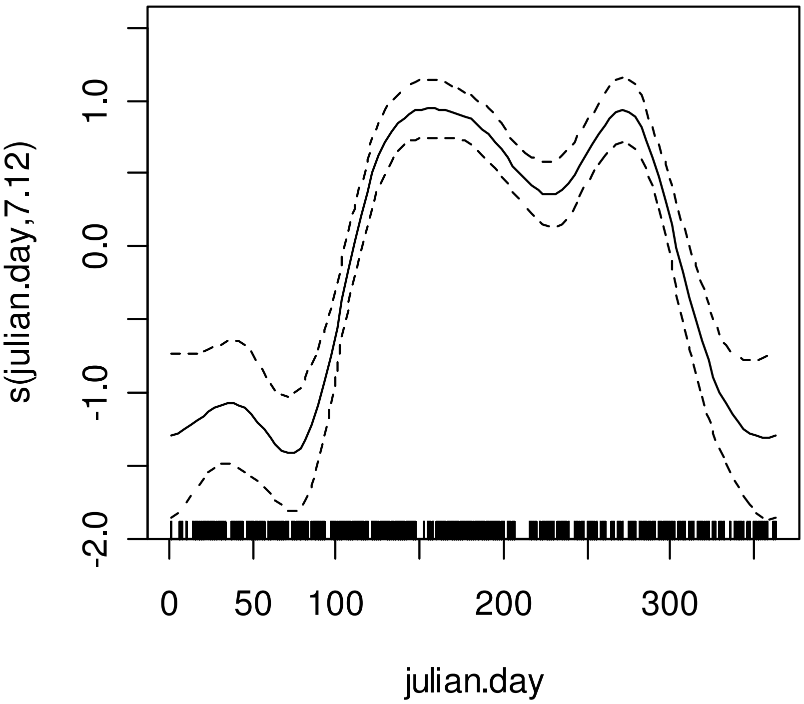


Figure 15: Estimated usage (in animals observed cell^{-1} hour^{-1}) and approximate 95% confidence intervals for each cell by harbour seals. It can be seen that, while including the spatial pattern significantly improves the model's representation of the data, relatively few cells can be distinguished individually.



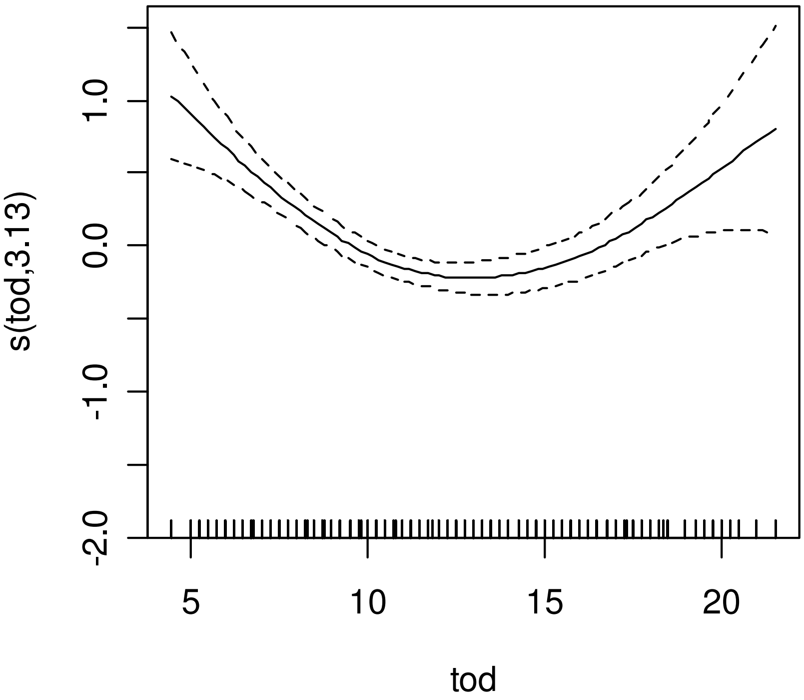


Figure 16: Estimated seasonal and diurnal pattern of changes in the relative numbers of sightings of harbour seals over the year. The seasonal peak is much broader than for grey seals and the dip around the middle of the day contrast with the increase observed for them.

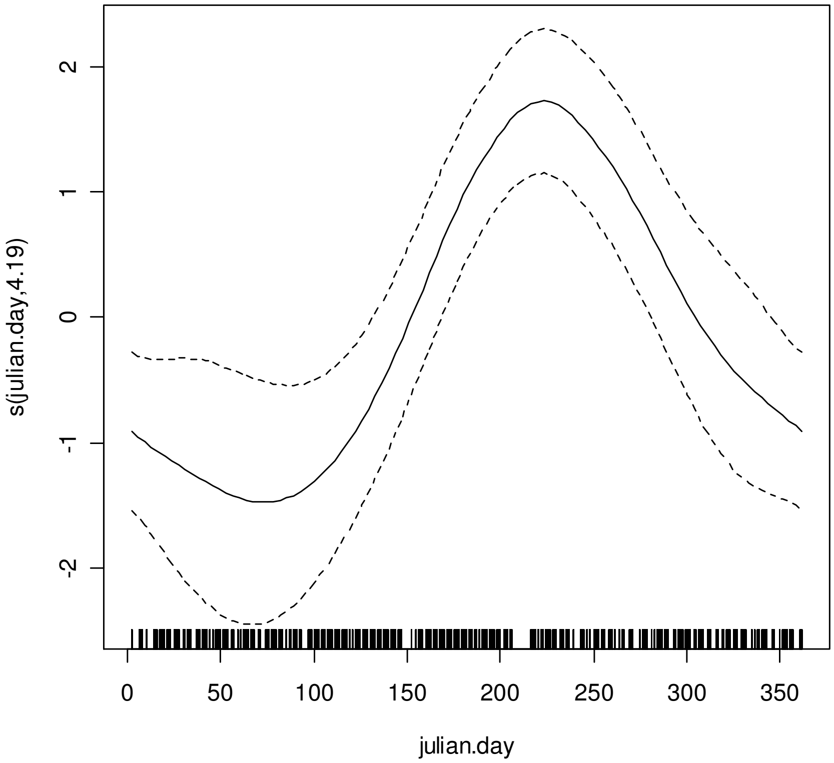


Figure 17: Seasonal pattern in the number of sightings of harbour porpoise within the study area (animals observed hour^{-1}).

Appendix 1: model structures and parameter values

The models were fitted using the mgcv library within R (R-Development-Core-Team 2007). The function calls used for the final models is presented here along with the summary of their gam components. This contains the estimated values and the uncertainties for the parametric terms long with the complexity of the smooth terms and the statistical significance of each one. The parameter names are hopefully obvious, except for “chunk”, which refers to one day’s data from a single gridcell. Using this rather than just “gridcell” in the autocorrelation term greatly reduces the time taken to fit the models without affecting the results.

all seals together

```
> asgamm <- gamm(allseals~s(gridrow,gridcol2,k=25,bs="ts")+
                                    s(julian.day,k=10,bs="cc")+ tod +
                   WIND.DIRECTION4 + OBSERVER.ID +
                                    NEW.TIDE.STATE + WIND.STRENGTH,
                  family=quasipoisson,gamma=1.4,
                                    cor=corCAR1(form=~tod|chunk))

> summary(asgamm)

Family: quasipoisson
Link function: log

Formula:
allseals ~ s(gridrow, gridcol2, k = 25, bs = "ts") + s(julian.day,
   k = 10, bs = "cc") + tod + WIND.DIRECTION4 + OBSERVER.ID +
   NEW.TIDE.STATE + WIND.STRENGTH

Parametric coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            -2.808122   0.180032 -15.598  < 2e-16 ***
tod                     0.020164   0.007111   2.835  0.00458 **
WIND.DIRECTION4NONE     0.135068   0.107527   1.256  0.20907
WIND.DIRECTION4NORTH    0.190639   0.066505   2.867  0.00415 **
WIND.DIRECTION4SOUTH    0.107842   0.063917   1.687  0.09157 .
WIND.DIRECTION4VARIABLE 0.324098   0.113464   2.856  0.00429 **
WIND.DIRECTION4WEST    -0.045197   0.073135  -0.618  0.53658
OBSERVER.ID            -0.270160   0.057679  -4.684 2.82e-06 ***
NEW.TIDE.STATEFLOOD    -0.343314   0.062610  -5.483 4.20e-08 ***
NEW.TIDE.STATEHIGH     -0.023623   0.054859  -0.431  0.66676
NEW.TIDE.STATELOW      -0.508682   0.069798  -7.288 3.21e-13 ***
WIND.STRENGTH          -0.220412   0.028592  -7.709 1.30e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                      edf Est.rank     F p-value
s(gridrow,gridcol2) 23.728       24 235.6  <2e-16 ***
s(julian.day)        7.672        8 116.8  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =   0.19  Scale est. = 1.4738    n = 38275
```

 # grey seals

```
> gsgamm <- gamm(Hg~s(gridrow,gridcol2,k=25,bs="ts") +
                            s(julian.day,k=10,bs="cc") + s(tod,bs="cs") +
                            WIND.DIRECTION4 + elapsed.hours +
                 NEW.TIDE.STATE+WIND.STRENGTH,
                             family=quasipoisson,gamma=1.4,
                            cor=corCAR1(form=~tod|chunk))

> summary(gsgammq4$gam)

Family: quasipoisson
Link function: log

Formula:
Hg ~ s(gridrow, gridcol2, k = 25, bs = "ts") + s(julian.day,
    k = 10, bs = "cc") + s(tod, bs = "cs") + WIND.DIRECTION4 +
    elapsed.hours + NEW.TIDE.STATE + WIND.STRENGTH

Parametric coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)             -2.750e+00  1.478e-01 -18.610  < 2e-16 ***
WIND.DIRECTION4NONE      6.776e-02  1.293e-01   0.524  0.60013
WIND.DIRECTION4NORTH     1.875e-01  8.393e-02   2.233  0.02553 *
WIND.DIRECTION4SOUTH     1.109e-01  7.722e-02   1.436  0.15112
WIND.DIRECTION4VARIABLE  4.070e-01  1.334e-01   3.052  0.00227 **
WIND.DIRECTION4WEST     -1.732e-02  9.178e-02  -0.189  0.85031
elapsed.hours           -5.724e-05  6.429e-06  -8.905  < 2e-16 ***
NEW.TIDE.STATEFLOOD     -4.051e-01  7.852e-02  -5.160 2.48e-07 ***
NEW.TIDE.STATEHIGH      -1.624e-01  6.627e-02  -2.450  0.01428 *
NEW.TIDE.STATELOW       -6.207e-01  8.940e-02  -6.943 3.89e-12 ***
WIND.STRENGTH           -2.922e-01  3.521e-02  -8.299  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                     edf Est.rank       F  p-value
s(gridrow,gridcol2) 23.51       24 139.515  < 2e-16 ***
s(julian.day)        7.41        8 148.290  < 2e-16 ***
s(tod)               2.76        6   4.408 0.000184 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.251  Scale est. = 1.4865    n = 38275
```

 # harbour seals

```
> hsgamm <-gamm(Pv~s(gridrow,gridcol2,k=25,bs="ts") +
                            s(julian.day,k=10,bs="cc") + s(tod,bs="cs") +
                            elapsed.hours + NEW.TIDE.STATE,
                           family=quasipoisson,gamma=1.4, cor=corCAR1(form=~tod|chunk))

> summary(hsgamm$gam)
```

```
Family: quasipoisson
Link function: log

Formula:
Pv ~ s(gridrow, gridcol2, k = 25, bs = "ts") + s(julian.day,
    k = 10, bs = "cc") + s(tod, bs = "cs") + elapsed.hours +
    NEW.TIDE.STATE

Parametric coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         -6.321e+00  1.506e-01 -41.978  < 2e-16 ***
elapsed.hours        3.512e-05  8.167e-06   4.300 1.71e-05 ***
NEW.TIDE.STATEFLOOD -1.675e-01  1.106e-01  -1.514 0.130023
NEW.TIDE.STATEHIGH   2.144e-01  1.045e-01   2.052 0.040177 *
NEW.TIDE.STATELOW   -4.391e-01  1.223e-01  -3.592 0.000329 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                      edf Est.rank       F  p-value
s(gridrow,gridcol2) 23.228       24 110.895  < 2e-16 ***
s(julian.day)        7.122        8  25.009  < 2e-16 ***
s(tod)               3.135        7   7.611 3.32e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0772  Scale est. = 1.1404    n = 38275
```

porpoise

```
> ppgamm <- gamm(Pp~s(julian.day,k=30,bs="cc")+WIND.STRENGTH,
                                family=quasipoisson,gamma=1.4,
                                cor=corCAR1(form=~tod|chunk))

> summary(ppgammq3$gam)

Family: quasipoisson
Link function: log

Formula:
Pp ~ s(julian.day, k = 30, bs = "cc") + WIND.STRENGTH

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    -4.1934     0.3152 -13.302  < 2e-16 ***
WIND.STRENGTH  -0.6907     0.1337  -5.167 2.39e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf Est.rank     F  p-value
s(julian.day) 4.195        9 4.732 2.59e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.00537  Scale est. = 5.1123    n = 38275
```