The number and distribution of marine mammals in the Fall of Warness, Orkney July 2005 - July 2006

SMRU Ltd

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Summary

- Land-based surveys of the Fall of Warness were carried out from 11th July 2005 to 14th July 2006, encompassing a total of 219 days, and 964 hours of observation. Two observers recorded the information. The change of observers took place on 22nd October 2005.

- Since sighting probabilities of marine mammals would be strongly influenced by sea state, wind speed was used as a proxy to remove from the analyses any observation periods when sighting probabilities would be compromised. This reduced the total observation period used in the analyses to 731 hours.

- Grey seals, harbour seals, harbour porpoises, minke whales, white-beaked 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 legislation.

- Generalised Additive Models (GAMs) and Chi-squared (χ^2) tests were used to estimate the patterns underlying the seal and harbour porpoise observation data. There was insufficient information on the other species to support anything beyond descriptive statistics.

- Grey seals were the most frequently seen species, with a significant peak in occurrence during September and October (their breeding season). Sightings were concentrated close to the shore area, especially to Muckle Green Holm. The probability of sighting grey seals was lower during windy conditions but did not appear to be influenced by state of tide or time of day.

- Harbour seals were rarely seen in August, and not at all in November and December. The former may be due to seals remaining ashore during their annual moult (August) and the latter to a change in observer during the study (from 22nd October). A strong distance and location effect was observed in sightings, probably as a function of a reduced ability to identify species with distance. The small numbers of sightings was probably responsible for the lack of any other significant factors in the data analysis.

- Harbour porpoises were seen in the study area between July and November, mainly in small groups. Observations were concentrated in both the centre of the study area and close to the observation point. 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 whale, white-beaked dolphin and basking shark are consistent with existing knowledge of these species behaviour and distribution in Orkney waters.

- The complexity of the patterns observed using GAMs suggests that straightforward comparisons of average results between times and location is

unlikely to be productive. It would be more efficient to repeat these analyses using the additional data collected under changed conditions (e.g. after the installation of a tidal flow device). This would examine the significance of the effect of the change in conditions but it would also be essential to include this as an integral part of the testing regime for any device because of the importance of including the state of the device (e.g. operational versus non-operational) as a covariate in any analysis.

- 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

As part of the ongoing Prime Contracting Framework Agreement, Highlands and Islands Enterprise engaged Tulloch Prime Contracting Limited (Tulloch) to undertake the design and construction of the proposed European Marine Energy Centre (EMEC) tidal turbine test facility, located within the Fall of Warness, Eday, Orkney.

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 the 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). 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.

1.3 Aims

Before this study no detailed information existed on the species or number of marine mammals (or animals) that use the Fall of Warness in Orkney. This study aims to determine which species use this stretch of water, to identify variation in seasonal use and to highlight any particularly sensitive times, should these occur. Note that the scope of this study was extended to include basking sharks, even though they are not marine mammals.

The results and discussion presented aim 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,

2 Methods

2.1 Data collection

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 for ease of recording and to allow assessment of sightings in the area surrounding the proposed location of the tidal turbines. In August 2005, an extra row (labelled 0) was added at the north end of the observation area to accommodate a shift in the siting of the northern most test site (Figure 3).

Surveys were carried out between July 2005 and July 2006 during daylight hours, ranging between 04:00hrs and 22:00hrs. 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 tide recorded at Kirkwall. Thus, observations made from 0h to 1h 29min since last high tide, were classified as high tide, observations made between 1h 30min and 4h 29min since last high tide were classified as ebb. Observations made between 4h 30min and 7h 29min since last high tide were classified as low tide. Observations made between 7h 30min and 10h 29min were classified as flood tide, and observations made 10h 30min or more since last high tide, were classified as high tide.

The Study Area was continually scanned in hour-long periods. In addition to the time and location of any marine mammal sighting, data were recorded on tidal 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.

2.2 Data Analysis

2.2.1 Descriptive statistics

The total number of days and hours of observations were summarised throughout the survey period, and variation in wind force over this time was also investigated. The probabilities of sighting marine mammals will be substantially affected by sea state, general visibility and distance, with sea state having the greatest potential impact. Sea state was not recorded throughout the survey period, so wind strength was used as a proxy for this variable. The total numbers of sightings for each species were summarised. In addition, 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)

Generalised additive modelling is a modern regression technique (Wood, 2006). It 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 on consecutive days and in nearby areas, but the patterns of change are complex or difficult to predict. By letting the data determine these patterns GAMs produce more precise results than could be obtained by considering each area or time period separately without 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.

The models used here have a 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, models of hourly observations including a first order autocorrelation term were constructed. These are very computationally intensive (taking up to than 24 hours to converge), but were essential to properly represent the data. Simply ignoring temporal autocorrelation at this scale substantially exaggerated the amount of information available and led 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. Various models were fitted to the July 2005 to January 2006 observations, and those that best captured the patterns within this data were identified and subsequently fitted to the full dataset Akaike's Information Criterion (AIC) was used here for model selection. It should be noted that this assessment is only approximate for GAMs, and small differences in AIC values between complicated models may not be very meaningful, but there is currently no completely satisfactory alternative available. The models presented here attempt to draw out the main patterns while avoiding the overcomplicated patterns that can indicate over-fitting.

Model covariates

Categorical

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

WIND DIRECTION

TIDE STATE

PRECIPITATION — descriptions rather than quantities were recorded during data collection.

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 — It is usually 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.

LOCATION	row & column coordinates of the grid cells were smoothed across to attempt to capture some of the pattern between them.
DATE	days were counted from 1 January 2005[1] and a smooth function used to represent the corresponding change in observations. This explicitly models the seasonal pattern in animal abundance.
HOUR	the daily pattern of observation numbers was also represented by a smooth.

The two temporal smooths (date and hour) directly and explicitly model the changes in animal abundances over time.

[1] 1st January 2005 was chosen as the start date in the analysis for ease of computation and future analysis

3. Results

Surveys were carried out between July 2005 and July 2006, Table 1 provides a summary of the dates on which surveys were made. This encompassed a total of 964 observation hours over 219 days. It should be noted that there was a change in observer from 22^{nd} October 2005.

Table 1: Detail of survey dates each month

Month	Dates surveyed
July 2005	11^{th} - 24^{th}
August 2005	10^{th} - 18^{th}
September 2005	15^{th} - 22^{nd}
October 2005	2^{nd} -31^{st}
November 2005	1^{st} – 5^{th}, 7^{th} – 11^{th}, 13^{th}, 15^{th} -19^{th}, 21^{st}-23^{rd} & 27^{th}
December 2005	1^{st}, 5^{th} – 8^{th}, 12^{th} -18^{th}
January 2006	9^{th} -11^{th}, 14^{th}, 16^{th} -23^{rd}, 27^{th}, 28^{th}, 30^{th}, 31^{st}
February 2006	1^{st} - 4^{th}, 7^{th} – 13^{th}, 15^{th} -17^{th}, 20^{th} – 23^{rd}, 26^{th}
March 2006	3^{rd}, 6^{th} – 9^{th}, 11^{th}, 15^{th} – 18^{th}, 20^{th} -23^{rd}, 28^{th} – 31^{st}
April 2006	3^{rd} -4^{th}, 7^{th} -8^{th}, 10^{th} – 15^{th}, 18^{th} – 21^{st}, 23^{rd} – 29^{th}
May 2006	2^{nd} – 4^{th}, 6^{th} -12^{th}, 16^{th} – 20^{th}, 22^{nd}, 24^{th} - 26^{th}
June 2006	2^{nd} -7^{th}, 11^{th}, 13^{th} - 16^{th}, 18^{th} - 30^{th}
July 2006	1^{st} – 4^{th}, 6^{th}, 8^{th} -12^{th}, 14^{th}

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

Month	Total survey hrs	Total survey hrs with wind force 0-3	Total survey hrs with wind force ≥4
July 2005	100	**80**	20
August 2005	73	**72**	1
September 2005	41	**15**	26
October 2005	135	**69**	66
November 2005	58	**39**	18
December 2005	38	**22**	16
January 2006	65	**48**	17
February 2006	80	**61**	19
March 2006	80	**69**	11
April 2006	80	**58**	22
May 2006	79	**72**	7
June 2006	90	**80**	10
July 2006	46	**46**	0

The total numbers of sightings of each species in all weather conditions throughout the study period (July 2005 to July 2006) 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. Since sea state is strongly influenced by wind speed and direction, in all subsequent analysis observation periods where the wind was Force 3 (Beaufort scale) or less were used. This resulted in a reduction of at least 25% in total observation time in all autumn months (September to November 2005), and January, February and April 2006. The largest reduction in suitable observation periods was in September (63.4%; Table 2). By minimising the observation periods in this way 731 survey hours were used in the analysis. During this time a total of 1260 sightings were made of (one or more) marine mammals.

3.1 Descriptive statistics

Grey seals

Overall, grey seals were observed in the study area on 171 of 215 observation days. Only the sightings made during wind force 0-3 have been used to calculate average 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 May, when harbour seal sighting rates were higher. The peak average sighting rate in this species was 7.23 individuals per hour during September closely followed by October (6.76 per hour). The sighting rates of grey seals were less than $1 hr^{-1}$ in December, January 2005 and between March and July 2006. There was, however, considerable variability around the hourly sighting rates as shown by the large error bars in Figure 6a. 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 =2476, df = 12, p<<0.001[2]).

[2] The null hypothesis in all these tests was that the expected numbers of sightings were proportional to the time spent looking. For the monthly comparisons only gridrows 1:4 were included because row 0 was introduced in August 2005, after the study had begun.

The average 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 high tide (2.55 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 (χ^2 =89, df = 3, p<<0.001).

Grey seals were sighted throughout the day between 05:30 and 20:30 (Figure 8a) with the peak in sighting rates around 15:30. 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 (70%) were in zone A, the area of water closest to Muckle and Little Green Holm. Only 80 sightings, 5.2% of all grey seal sightings, were in zone C. Results of χ^2 test for homogeneity showed that there was a significant difference in the frequency of sightings between each zone (χ^2 =2409, df = 4, p<<0.001).

Harbour seals

In all months, except May 2006, harbour seals were seen less frequently than grey seals (Figures 4 and 6b). Average hourly sighting rates of harbour seals were highest in May, June and July 2006, at a rate of more than one per hour. There was a great deal of variability in the observation rate during the whole survey period (Figure 6a). Only one harbour seal was seen in August 2005, and none were seen in November or December 2005. During the remaining months (July and September 2005 and January to April 2006) sighting rates were comparable. Similarly to the grey seal data, there was a lot of variability around these data. Results of χ^2 test for homogeneity showed that there was a significant difference in sighting rates between the months when sightings occurred (χ^2 =498, df = 12, p<<0.001).

Harbour seals were sighted at all tide states (Figure 7a). The highest sighting rate was at high tide (an average of 0.56 per hour). However, the sighting rates only varied between 0.44 and 0.56 per hour across all tide states. Therefore unsurprisingly, results of χ^2 test for homogeneity showed there was no significant difference in the sighting rates between all states of tide (χ^2 =1.6, df = 3, p>0.05). In contrast to the grey seal sightings, harbour seals were sighted more frequently during early morning and late afternoon/evening (Figure 8b). During the middle portion of the day, between 09:30 and 18:00, sighting rates remained very low (below 0.5 per hour) with the exception of 12:30. The averaging sighting rate during this middle portion of the day was 0.23 per hour, compared with 0.57 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 in both zone E (40.4%) and zone A (32.2%). Only 2.9% of the harbour seal 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 =224, df = 4, p<<0.001).

Seals (unclassified to species)

Seals which could not be identified to species were named 'unclassified seals'. In July, the sighting rate of unclassified seals was as high as the sighting rate of grey seals (averaging 1.16 per hour, Figure 6c). In other months, sighting rates were more variable, ranging between zero (no sightings in November 2005, January or February 2006) and 1.06 per hour in October 2005. There was only one sighting in December 2005. Sighting rates in October peaked due to land based disturbance of a shooting party on Muckle Green Holm (4th October) displacing large numbers of animals, most likely grey seals, into the water. This event goes some way to explaining the large variability around the average sighting rate in this month. Even excluding these animals, the 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 =593, df = 12, p<<0.001).

Unclassified seals were sighted at all tide states (Figure 7a). The highest sighting rate was during the ebb (an average of 0.68 per hour). However, the rates only varied between 0.24 and 0.67 per hours over the whole tidal cycle. Results of χ^2 test for homogeneity in the frequency of sightings between all states of tide show that there was no significant difference in the sighting rates (χ^2 = 48, df = 3, p<<0.001). Unclassified seals were seen relatively consistently throughout the day, although there was a slight increase in late evening (Figure 8c). A peak was observed at 16:30, relating to the observations following the shooting party disturbance referred to earlier.

Unclassified seals were sighted in all zones of the study area (Figure 9). Most sightings (79.3%) were in zone A (closest to Muckle and Little Green Holm and furthest from the observation point). Only 7% of sightings were in zone C. Results of χ^2 test for homogeneity showed that there was significant difference in the sighting rates between each zone (χ^2 =658, df = 4, p<<0.01).

Harbour porpoises

Harbour porpoises were seen in the study in all months except December 2005, and January, March and April 2006 (Figures 4 and 6d). The majority of the sightings (75%) were of groups of two or more individuals. A maximum group size of seven was observed on four separate occasions (during July and August 2005 and February 2006). Two of these groups contained adults and calves. The highest sighting rate of harbour porpoises was in August (an average of 1.16 per hour), with lower rates (<0.4 per hour) during the other months. Results of χ^2 test for homogeneity show that there was a significant difference in sighting rates between months where sightings occurred (χ^2 =287, p<<0.001 [3]).

Harbour porpoises were sighted at all tide states (Figure 7a). The highest average sighting rate was during the ebb tide (0.39 individuals per hour), rates were similar between other tide states; ranging between 0.16 and 0.24 individuals per hour. Results of χ^2 test for homogeneity showed significant differences in the sighting rates between the different states of tide (χ^2 =26, df=3, p<0.005). 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 18:30 (Figure 8d).

[3] Probability calculated by simulation because of low expected numbers in September and December under the null hypothesis of a constant rate of sightings.

Harbour porpoises were seen in all zones of the study area (Figure 9). Sightings were most frequently made in zone C (35.6%) and least frequently in zone A. Results of χ^2 test for homogeneity show that there was a significant difference in the sighting rates between each zone (χ^2 =54, df = 4, p<<0.001).

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 and an otter were also seen in the Study Area. The sightings of these three species were considerably less frequent than of the 'regular' species (Figures 4 and 5).

Minke whale sightings were made in July, August and September (wind Force >3) 2005, as well as in June 2006. Numerous sightings on each of these days were most likely, but not necessarily, repeat observations of a single animal within that day. On the 19th of July, one whale was observed to be feeding in close association with terns and gulls. All the minke whales seen in favourable weather during 2005 were in the centre of the study area (zones B and C) during flood, high and low tide states (Figure 7b). The single sighting in June 2006 was in zone E during the flooding tide.

Basking shark sightings were made in the study area in September and October 2005, and June and July 2006. The September sightings of this species were most likely repeat sightings of one individual moving through the study area. They were made in zone E (the observation area closest to Eday) where the shark appeared to be feeding. The single October sighting was in zone C. Sightings were made during flood, high and low tide states. In addition to these sightings, basking sharks were also seen in less favourable weather conditions on the 22nd September and 3rd October 2005, all in zone E. Repeat sightings of one individual feeding were most likely for the June 26th 2006 sightings during which the animal was observed to be feeding in zone E. Feeding behaviour was also observed in zone D on the 27th June, and zone E on the 3rd July. Basking sharks were observed in the study area at all states of tide (Figure 7b).

Two separate groups of white-beaked dolphins were observed on the 15th August travelling through zone B of the study area. The first group, estimated to be four individuals, passed through at 14.00 at low tide, the second group (estimated to be two individuals) passed through at 17.00 on the flooding tide. Both groups were heading north.

On 10th May 2006 an otter was observed feeding close to the shore of Eday in area 1E.

3.2 GAMs

The data were considered as 1-hour long blocks of observations in the 25 grid cells. 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 that can indicate over-fitting.

All seals (grey, harbour and unclassified combined)

When all the seal observations were considered together, the best models contained the wind strength and distance, with smooths of location and date. The numbers observed declined 20% (95% confidence interval: 16-24%) with each Beaufort point increase in wind strength. This doesn't mean that the recorded variables have no effect; just that it is not possible to separate them out from all the other variability in the data. Precipitation and cloud cover appeared to have some effect, though no clear pattern could be discerned. Including the log of distance marginally improved the model's fit, suggesting that this effect was contributing to the patterns observed. There was substantial autocorrelation ($\varphi = 0.24$) in the data, which can be interpreted as meaning that observing a grid cell for four hours effectively produces as much information as three separate one-hour visits. The highest densities of observations were around the shores of the islands opposite the observation point (Figures 10 and 11).

Grey seals

Of the 2908 seals observed, 2163 (74%) were identified as grey seals. Considering only these animals identified as grey seals produced unsurprisingly (since they made up the majority of the sightings) similar results to the unclassified seals. The same model was selected, with very similar spatial patterns (Figures 11 and 12). The seasonal pattern of occurrence in grey seals is shown in Figure 13. There is a clear peak in the numbers of animals seen in the Study Area early in autumn.

Harbour seals

The best harbour seal model contains a smooth of location and distance from the observation point. The model is based on a total of 393 animal sightings over the 731 hours of observation. The data is moderately autocorrelated (φ=0.17), but there is no sign of over-dispersion. There was a strong distance effect on the observation rates of harbour seals; probably a reflection of ability to identify this species. This was estimated to be approximately a 79% reduction per grid cell traversed (95% confidence intervals 66-88%). The model suggests that there is an underlying gradual increase in numbers away from the observation point (Figure 14 and 15). This is probably an artefact of the linear distance effect used. The most reasonable interpretation of these data seems to be that, unless it is believed that the animals do actually congregate beside the observer, there is too little information to go much beyond a simple average of the data, and a recognition that harbour seals may be difficult to reliably identify at long distances. There may well be variation in the numbers of sightings over time and with tidal state, with a best guess of the latter being a doubling of numbers between low and high water with intermediate states lying between these values, but adding these covariates did not improve the model overall.

Harbour Porpoise

A total of 177 individuals were seen over a total 47 hours during the 345 hours of observations. This low sighting frequency limits the analysis. The best model had negligible autocorrelation (φ=0.01) and only a spatial smooth. It suggested that usage by porpoises was concentrated in the centre of the Study Area (zone C, Figures 16 and 17). Inclusion of an additional smooth term to represent seasonal changes did not improve the overall model fit, though it did appear significant in itself, and all the sightings of this species were in the late summer-winter. The relatively high densities estimated immediately adjacent to the observation point (cell 2E) may well be due to it being easier to see nearby animals, though incorporating a linear term representing this effect did not improve the model. The best models allow for the animals tendency to be observed in small groups through a moderate degree of over-dispersion (scale=2.8). This means that, based on the 177 individuals seen in this survey, 95% of future repeats of the study under similar conditions could be expected to observe between 142 and 209 individuals.

4. Discussion

Note 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 are using or resident in this area. A total of six species of marine mammal (harbour and grey seals, harbour porpoises, minke whales, white-beaked dolphins, otter) and basking sharks were seen during the 13 month observation period July 2005 to July 2006, although not all species were seen in each month.

4.1 Seal observations

Grey and harbour seals are protected species under European legislations; both are listed in Annex II of the European Habitats Directive.

Unclassified seals in this study would have included individuals of both species, but the majority were probably grey seals, as a large number of sightings were in zone A where no harbour seal sightings occurred. However, this zone was also the furthest from the observer, and this may also have lead to an inability to identify seal species correctly over such a distance. Insufficient data existed for the GAM method to be usefully applied to the unclassified seal data in isolation. It was also felt to be more informative to attempt to extract the patterns within the complete seal dataset as well as each species on its own. 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. 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. Month appeared as a significant factor in the χ^2 test, and date was selected by the GAM process. There was a clear seasonal pattern in grey seal sightings during the survey period. The greatest hourly sighting rates of grey seals were in September and October, coinciding with this species' breeding season. The lowest sighting rates were in December, January and May and June. Their presence in the Study Area was, according to the χ^2 analysis, related to the state of tide. The majority of grey seal sightings were close to the breeding sites of Muckle and Little Green Holm, and location was selected by the modelling process, and found to be significant in the χ^2 analysis. The only environmental variable selected for in the GAM process was wind strength; with increasing wind strength associated with decreasing numbers of sightings. This doesn't mean that the other variables have no effect; just that it is not possible to separate them out from all the other variability in the data. As the study continues it may be possible to identify further patterns.

Harbour seals were sighted most frequently between May and July 2006. Harbour seals were not observed in November or December, and only one was seen in August. Harbour seals undergo an annual moult in August during which they spend a larger proportion of time hauled out (Thompson & Rothery, 1987; Thompson, 1989). Therefore, low numbers of individuals sighted in the water is not surprising during this month. There may also be an effect of observer in the recorded sightings of harbour seals because a change in observer occurred at the end of October. 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 (Bowen et al, 2003; Thompson et al., 2001). During the remaining months sighting rates were similar. In addition, sighting rates did appear to increase with distance from Muckle and Little Green Holm, peaking in zones D and E, closer to Eday. Analyses using χ^2 tests indicated that month, time of day and location were significant factors in the occurrence of harbour seal observations. However, the best harbour seal GAM contained a smooth of location and distance from the observation point only, with the other factors being on minimal importance. The strong distance effect is most probably a result of the difficulty in reliably identifying this species at long distances. Harbour seals were sighted at all states of tide with similar frequency, and this did not appear to be an important factor in the models.

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 & Northridge, 2003). Sightings in inshore waters are more common in summer, and are probably related to prey distribution (Carwadine, 1995). They were sighted in the Fall of Warness in all months except December 2005 and January, March and April 2006, although this does not imply that they were not present in these months. Harbour porpoise were seen with the greatest frequency during the ebbing tide, but with very low frequency during low tide. Sighting rates appeared to be lower during the middle of the day, probably related to prey distribution. Despite these apparent trends in the data from early analysis, GAMs indicated that the best model included the spatial smooth only. Indeed, the majority of observed sightings were in the centre of the channel (zone C). In addition the GAM predicted relatively high densities estimated immediately adjacent to the observation point (cell 2E). In common with the harbour seal model, this may purely be a function of sighting probability in relation to distance from the observer. The harbour porpoise is listed on Appendix II of CITES, Appendix II of the Bern Convention and Annexes II and IV of the EC Habitats Directive. It is also on Appendix 2 of the Bonn Convention and is covered by the terms of the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), a regional agreement under the Bonn Convention. It is protected under Schedule 5 of the WCA 1981.

It is not unexpected that minke whale sightings in the Fall of Warness occurred during July, August and September as they are commonly sighted in Scottish waters in late summer often feeding in association with flocks of sea birds. Favoured feeding locations include upwelling areas around headlands and small islands, and areas where strong currents flow (Reid, Evans & Northridge, 2003). During the whole period of observation, the Fall of Warness appeared to contain quite large numbers of fish, with shoals breaking the surface of the water. This, in combination with large numbers of seabirds seen feeding, would indicate that the Fall of Warness may also be a good location for minke whales to feed. In common with all baleen whales, minke are protected under schedule 5 in both the Wildlife and Countryside Act 1981 and the Wildlife (Northern Ireland) Order 1985. All whales are listed on Annex A of EU Council Regulation 338/97 and therefore treated by the EU as if they are on CITES, Appendix I, thus prohibiting their commercial trade. They are listed in Appendix I of CITES, Appendix II of the Bern Convention and Annex IV of the EC Habitats Directive.

White-beaked dolphins are present over the continental shelf year round, but inshore sightings are more common between June and October (Reid, Evans & Northridge, 2003). Observations of two groups of animals in the Fall of Warness were in August. In common with all species of cetacean, white-beaked dolphins are given protection under the Wildlife and Countryside Act 1981 and the Wildlife (Northern Ireland) Order 1985. All cetacean species are listed on Annex IV (Animal and Plant Species of Community Interest in Need of Strict Protection) of the EC Habitats Directive. All cetacean species are listed on Annex A of EU Council Regulation 338/97 and therefore treated by the EU as if they are on CITES Appendix I, thus prohibiting their commercial trade.

In addition to sightings of cetaceans and seals, basking sharks were also observed in the study area in September and October and again in June and July. These are very large, plankton-feeding pelagic sharks, which represent the largest fish found in UK waters. Basking sharks appear to be 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 et al., 2005). Although surface sightings of basking sharks are possible due to their feeding behaviour, the absence of surface sightings may equate to feeding deeper in the water column out of sight. The basking shark is protected under Schedule 5 of the Wildlife and Countryside Act 1981. Their global status is assessed as *Vulnerable* (A1a,d, A2d) in the 1996 IUCN Red List.

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 displace 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 are less likely to be aware of threats within the water column and it is under these conditions that there may be a sharp increase in the probability of interactions with a 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 killer whales, humpback whales, pilot whales, fin whales, bottlenose dolphin, Atlantic white-sided dolphin, Risso's dolphin are also a possibility in the Fall of Warness due to the distribution of previous sightings of these species (Reid, Evans & Northridge, 2003).

It should be noted that the Study Area encompasses a large stretch of water and accurate species identification, and location of sightings was not always be possible. The results presented here suggest 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. The observations made to date in the Fall of Warness and the data analyses here therefore 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.

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. Most of the species involved are protected under a variety of different national and international legal frameworks. 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 effects 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 become 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 potential vulnerable species. To date, the application of the method at the Falls 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, the methodology needs to 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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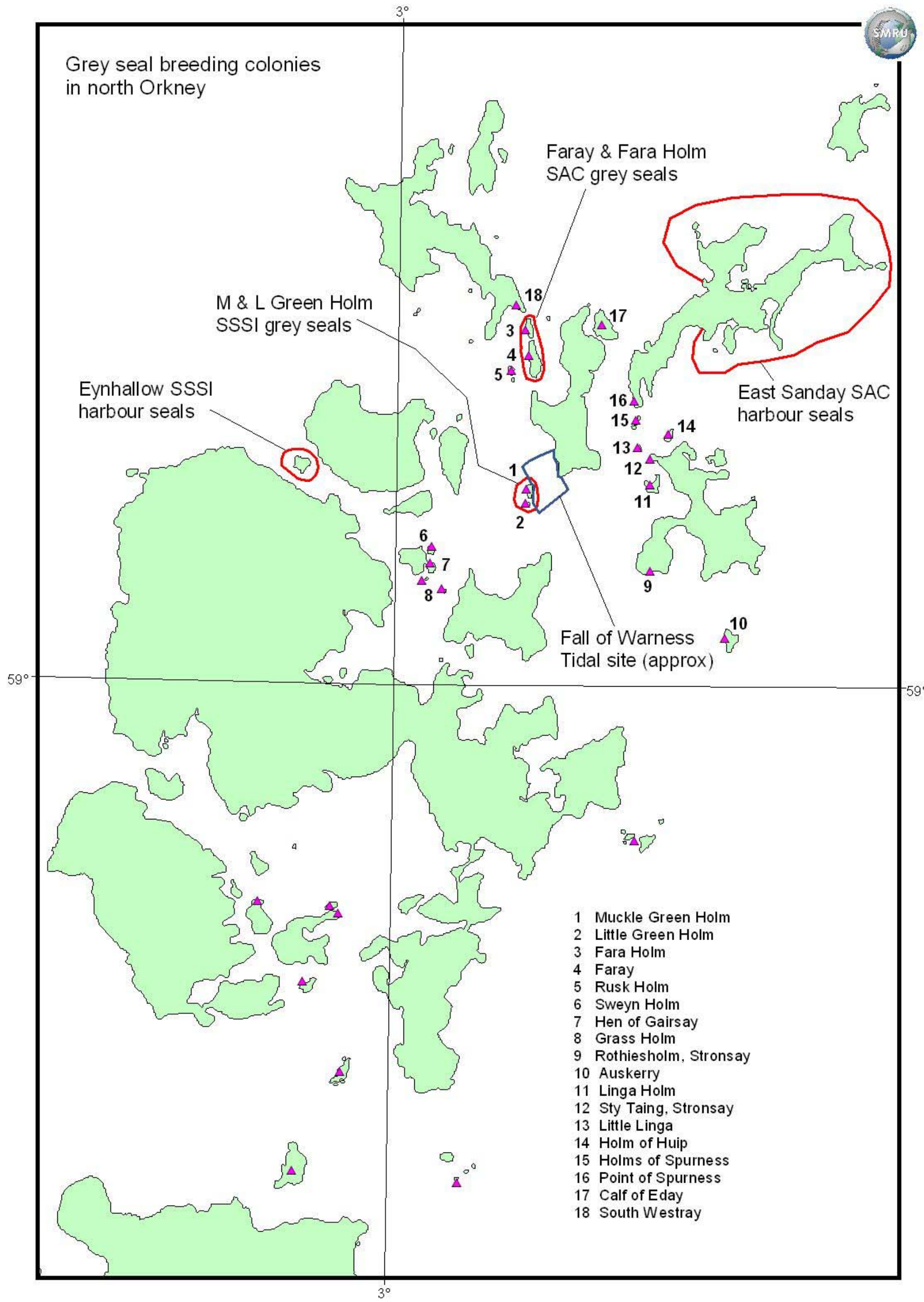


Figure 1: The main grey seal breeding colonies in Orkney, autumn 2005.

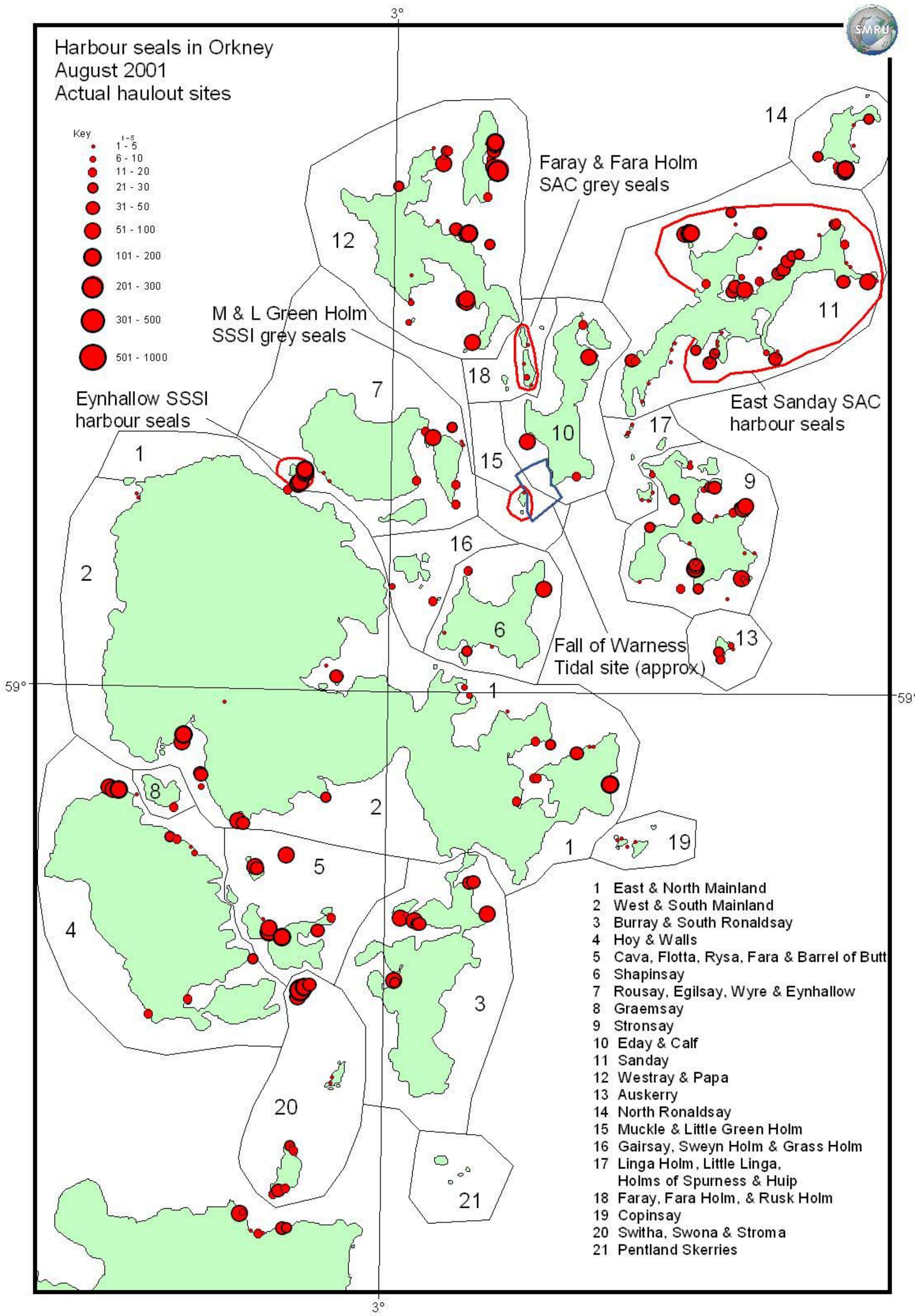


Figure 2: Harbour seal haul-out sites in Orkney, August 2001.

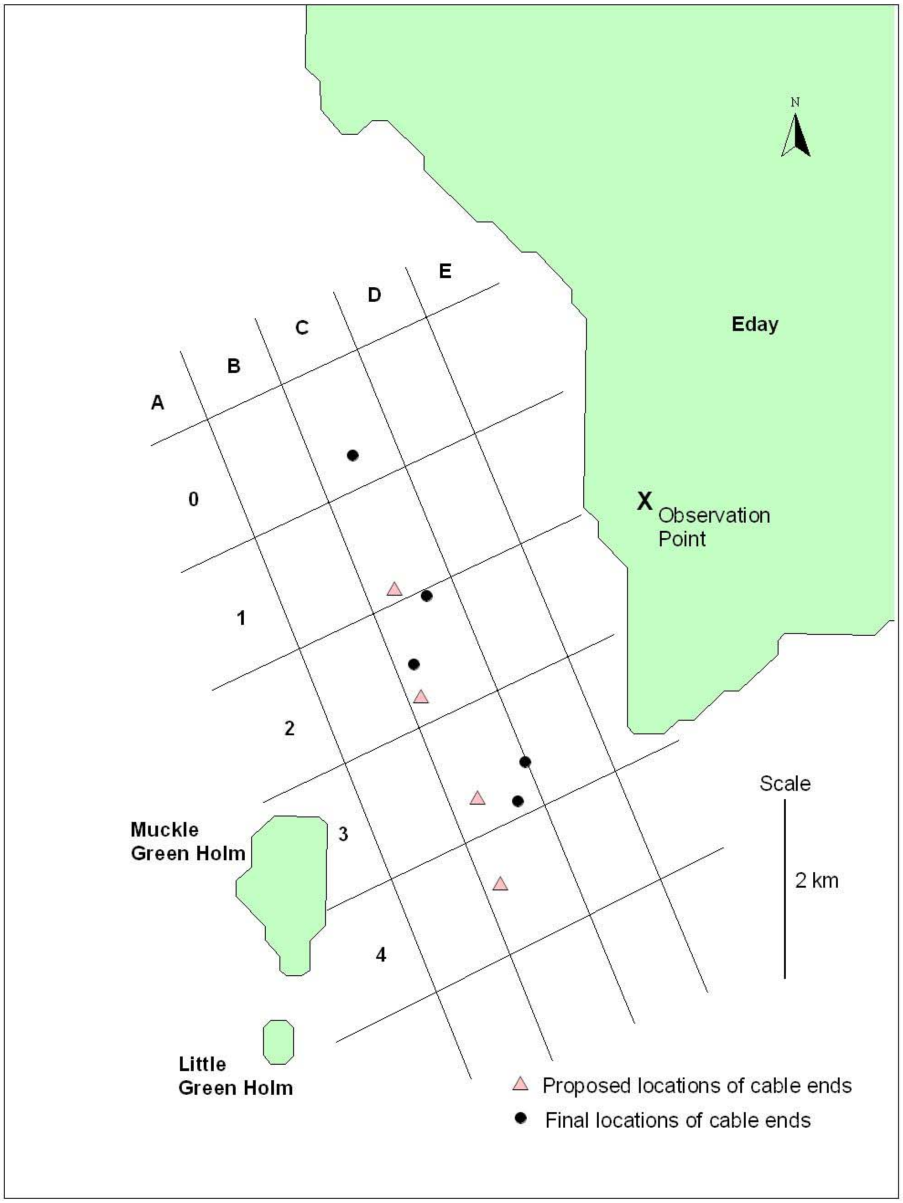


Figure 3: The observation grid in the Fall of Warness, between south-west Eday and Muckle and Little Green Holm, in Orkney. The approximate locations of the proposed tidal turbine test sites are marked as triangles, the approximate final locations are marked as circles. The row labelled ‘0’ was included in surveys from August 2005 onwards.

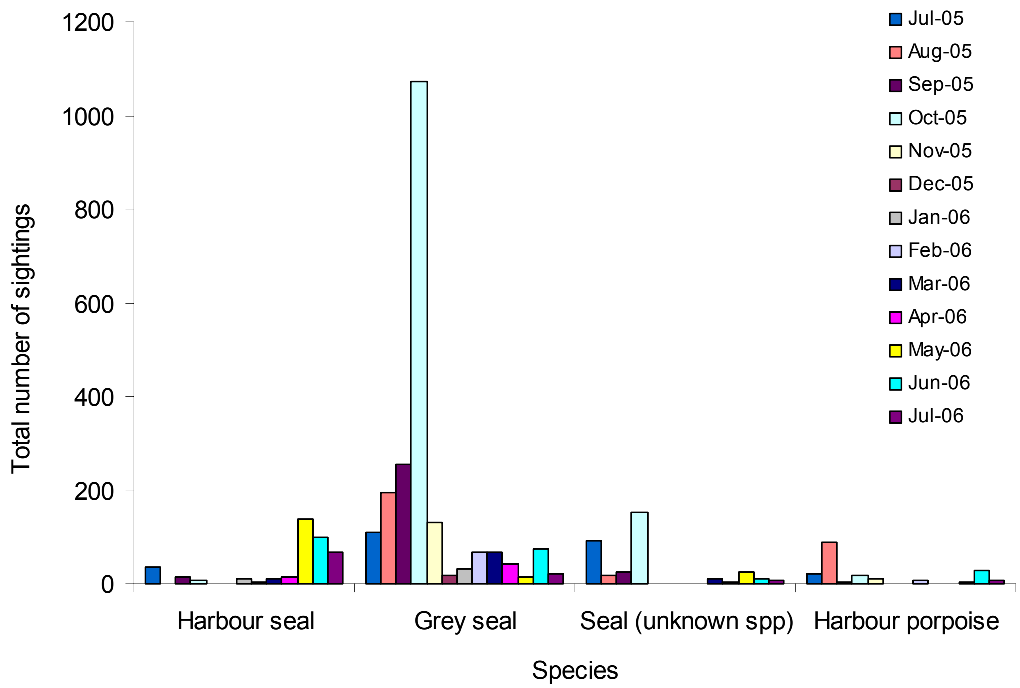


Figure 4: Total number of sightings of harbour seal, grey seal, seal (unclassified species) and harbour porpoise in the study area between July 2005 and July 2006.

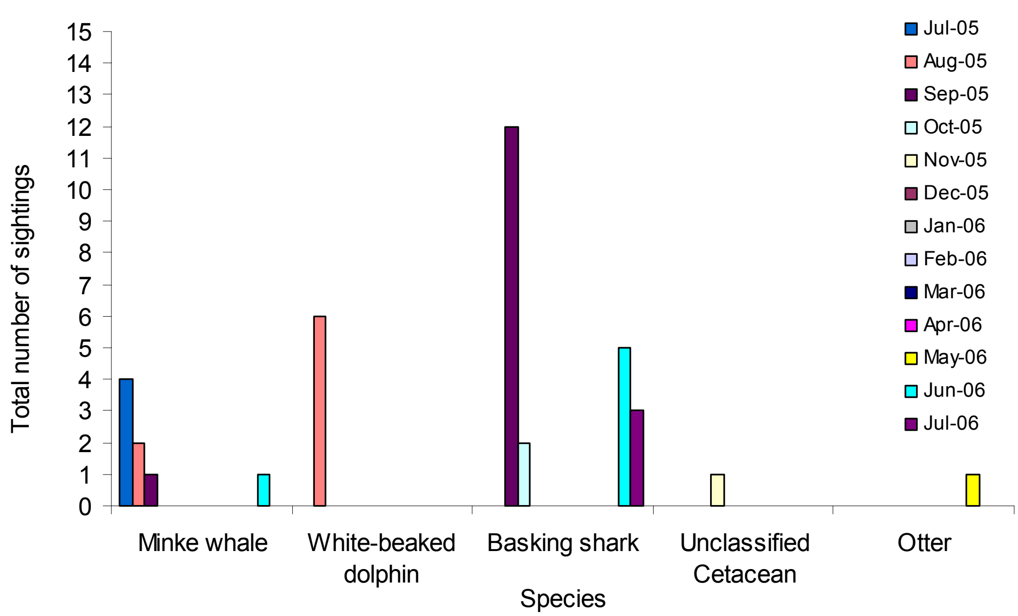
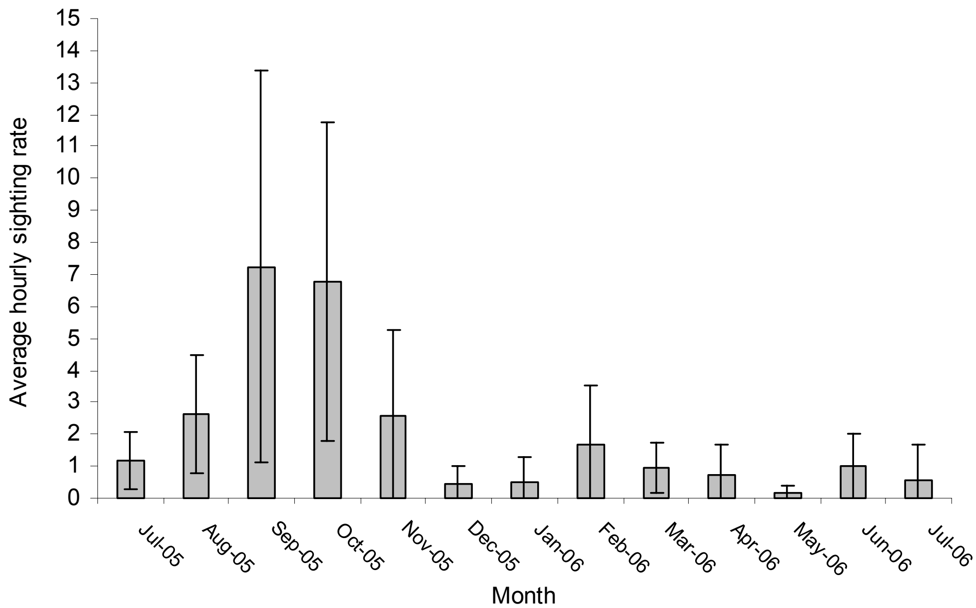


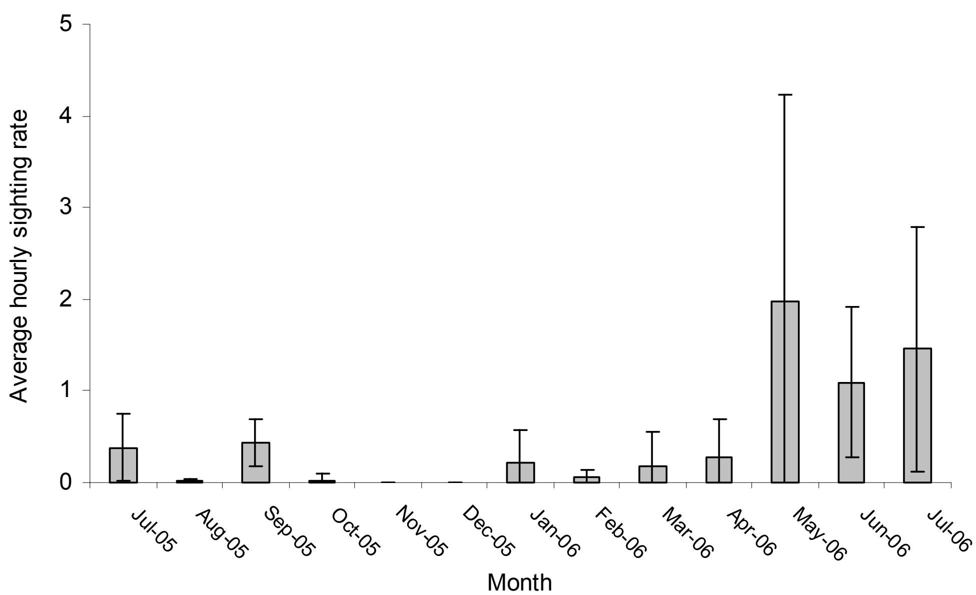
Figure 5: Total number of sightings of minke whale, white-beaked dolphin, basking shark, unclassified cetacean and otter in the study area between July 2005 and July 2006.

Figure 6: Average hourly sighting rate of (a) grey seals, (b) harbour seals, (c) seals unclassified, and (d) harbour porpoise within each month (error bars represent +/- 1SD). NB Note change in scale between Figure (a) and subsequent figures.

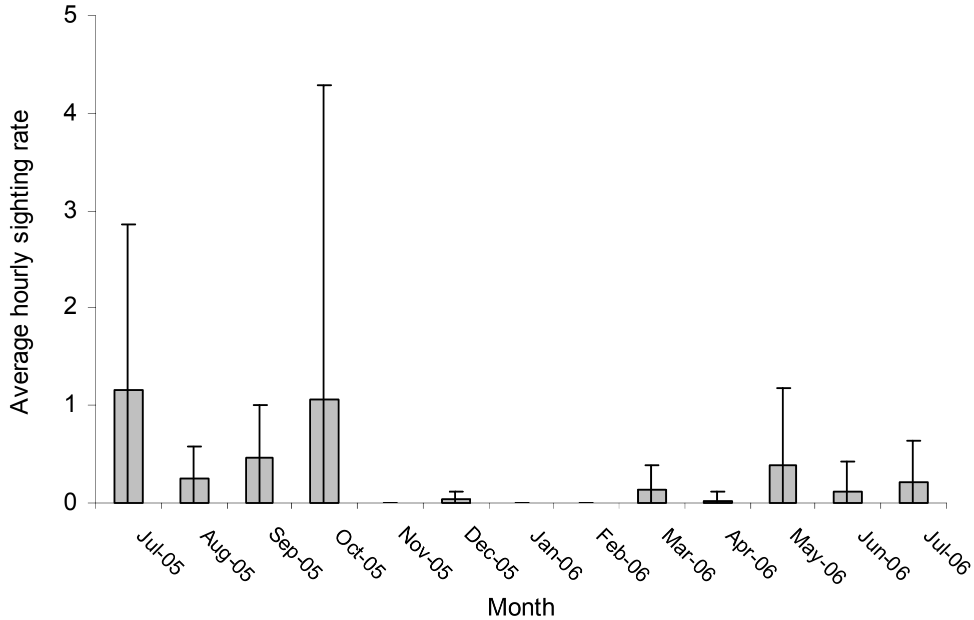
(a)



(b)



(c)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Average hourly sighting rate
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Aug-05
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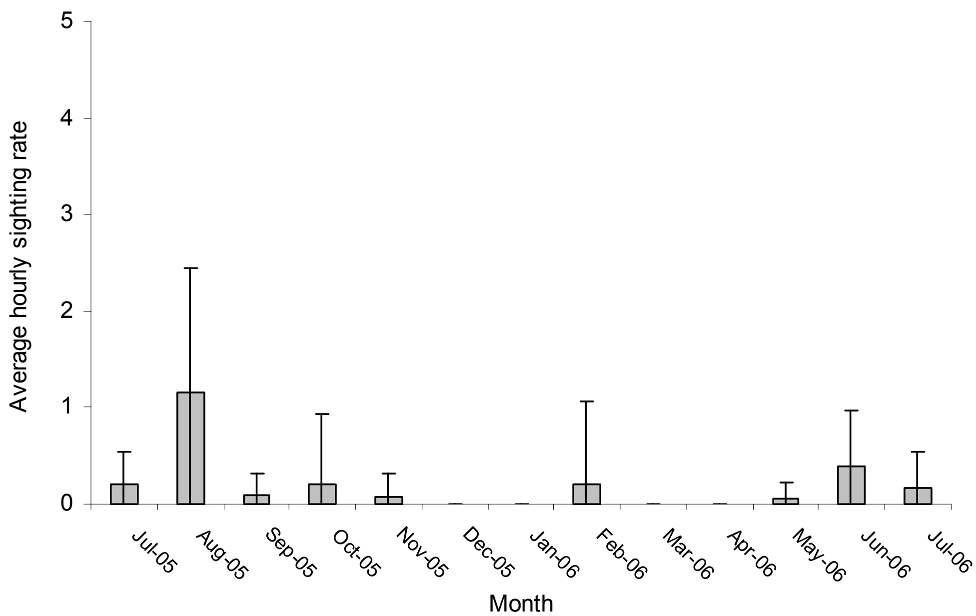
Jul-06
Month

(d)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Average hourly sighting rate
Jul-05
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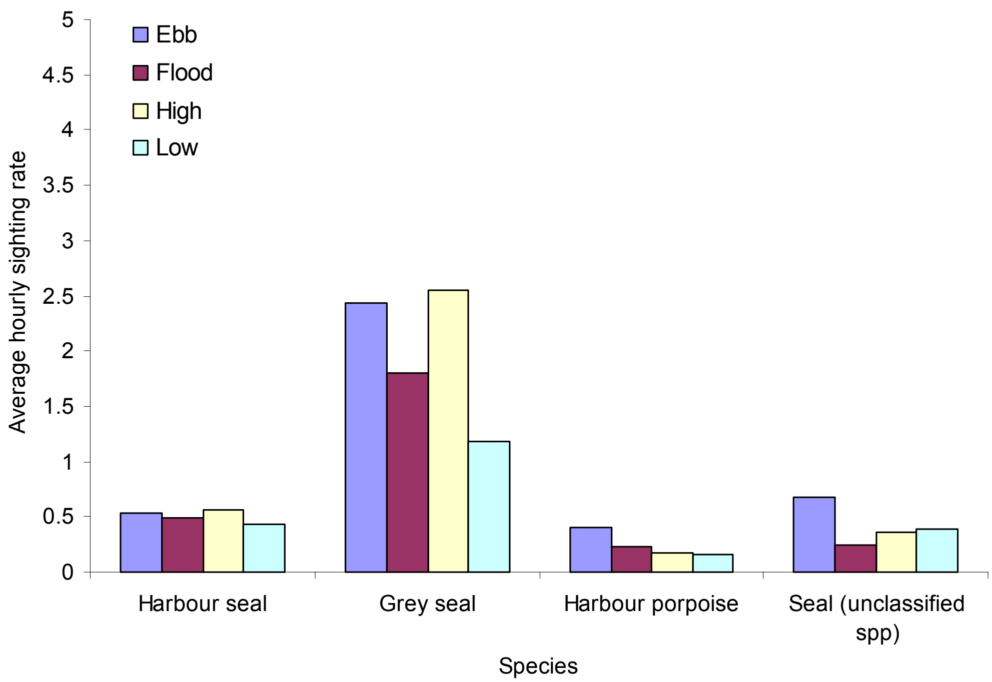
(a)



(b)

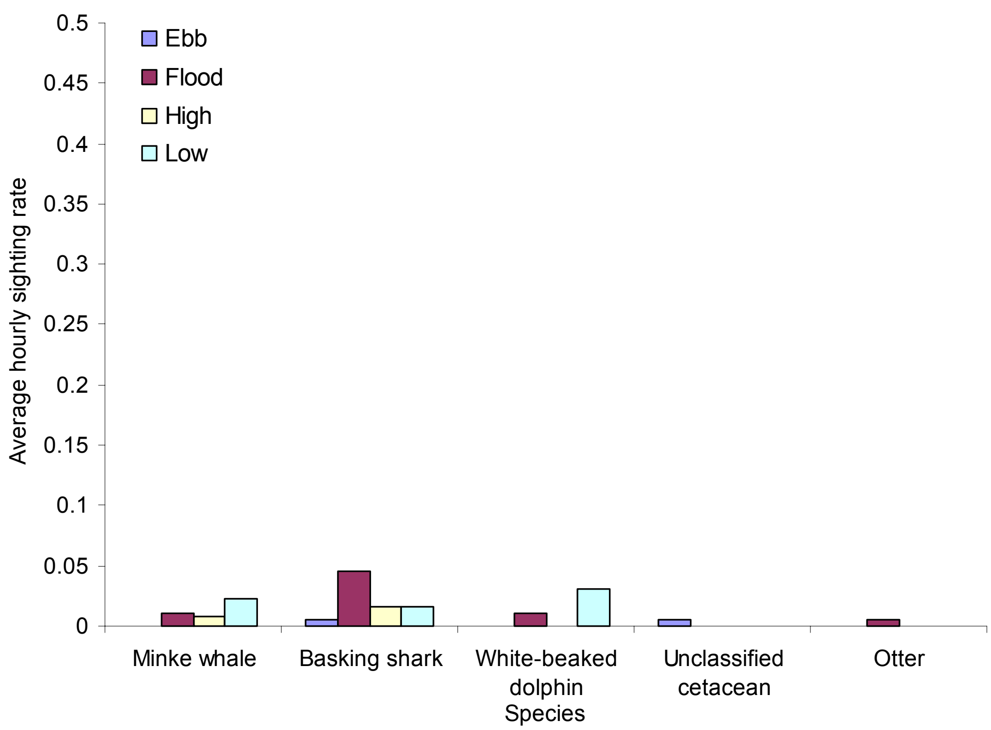


Figure 7: Average hourly sighting rates of each species during each tidal state for (a) harbour seals, grey seals, harbour porpoise, and unclassified species of seal, and (b) minke whale, basking shark, white-beaked dolphin, unclassified cetacean and otter.

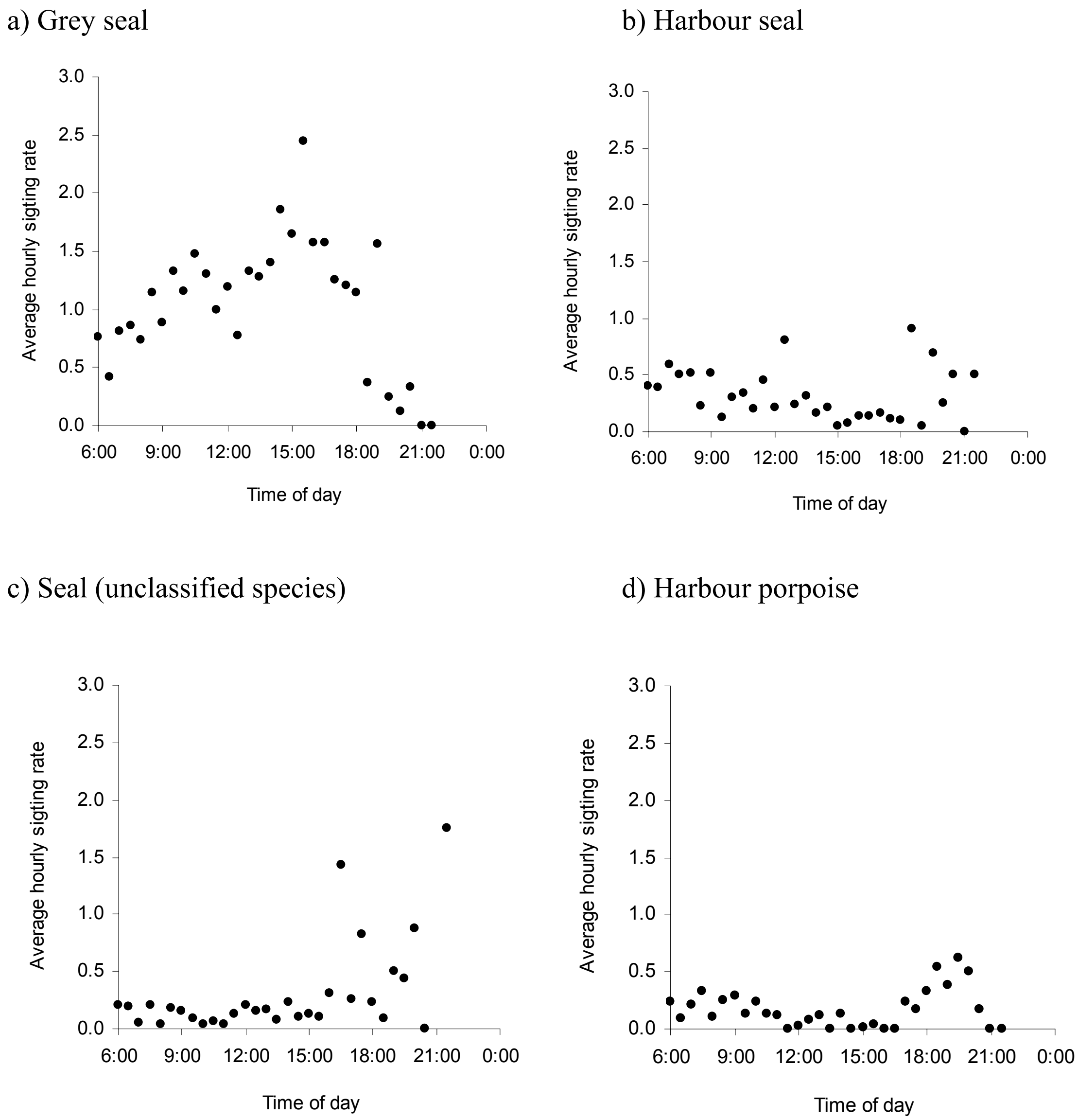


Figure 8: Average hourly sighting rates of a) grey, b) harbour, c) unclassified species seals and d) harbour porpoise throughout the day. Data represent all months combined.

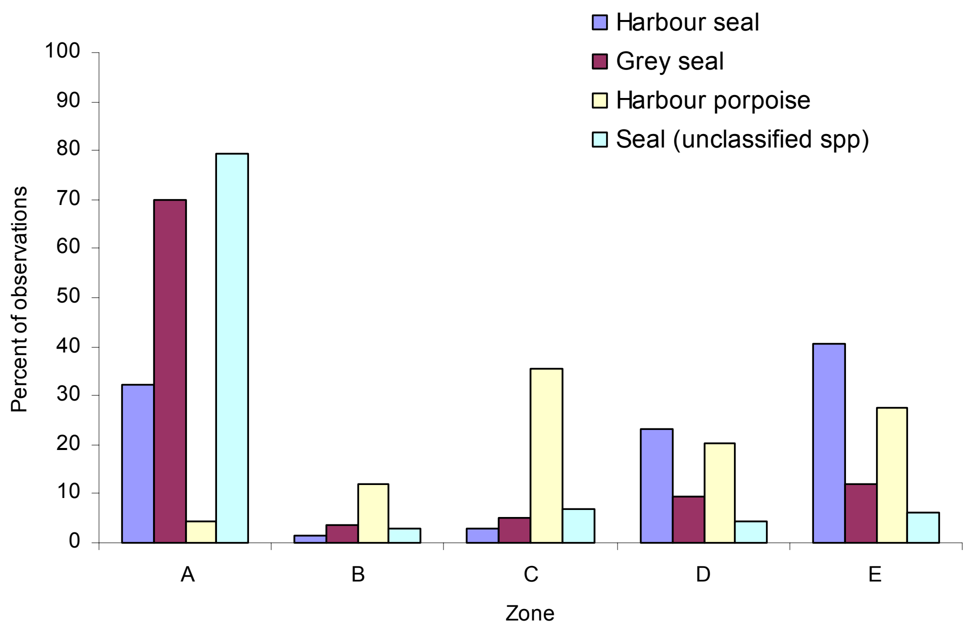


Figure 9: Percent of all observations harbour, grey and unclassified seals, and harbour porpoise made within each zone of the study area. Data for all months have been combined.

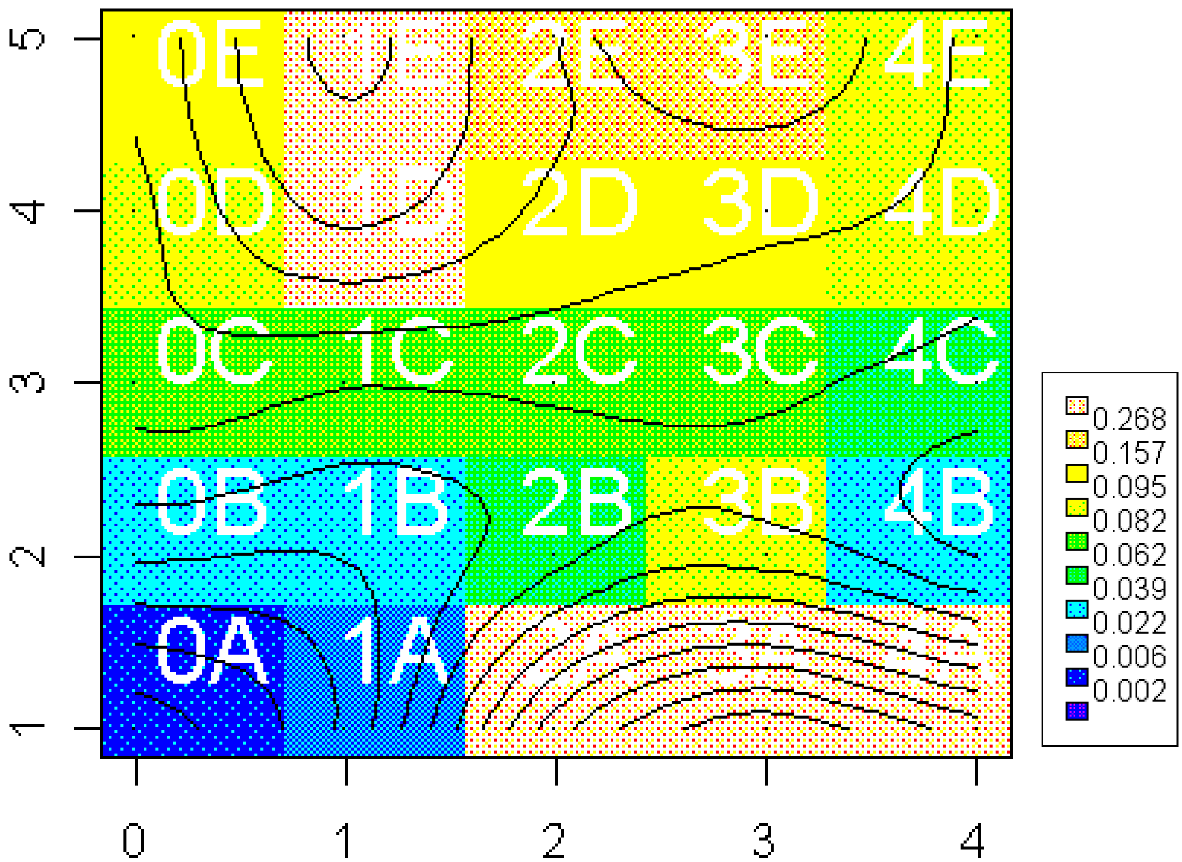


Figure 10: The estimated number of sightings of seals across the study area. The colours are overall estimates for each cell (animals observed hour^{-1}) going from dark blue where few animals were seen through to green and brown to yellow for the highest values. The contours are interpolated from the 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).

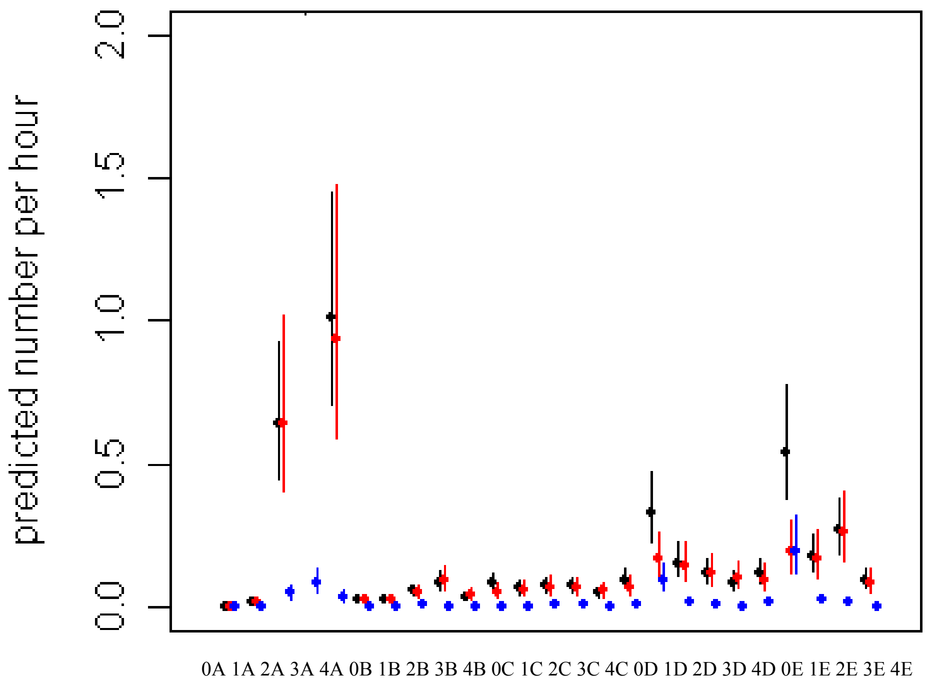


Figure 11: Estimated usage (in animals observed cell^{-1} hour^{-1}) and approximate 95% confidence intervals for each cell by seals. Black values are all seals combined, red only those identified as grey seals, and blue harbour seals. All values are calculated for October 1st, the relatively fewer identified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

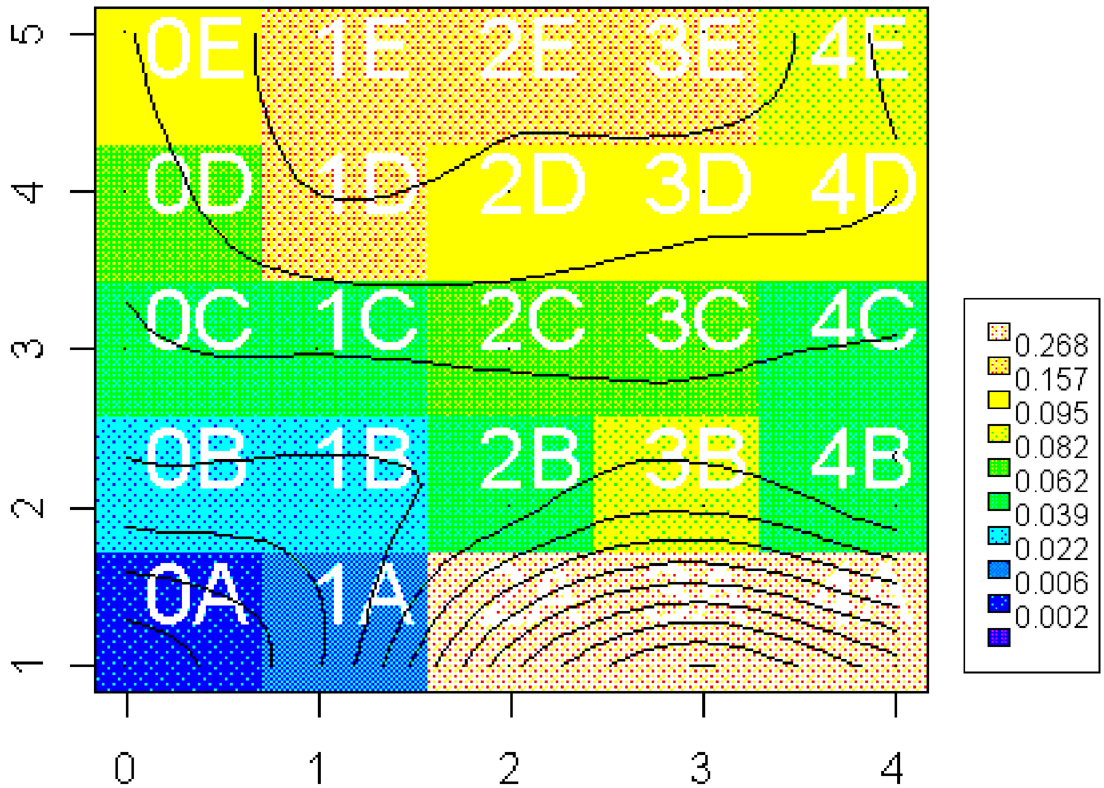


Figure 12: The estimated numbers of sightings of grey seals across the study area (animals observed hour^{-1}). The colours are the same as in the all seals equivalent. It can be seen that the patterns are very similar to those in that figure.

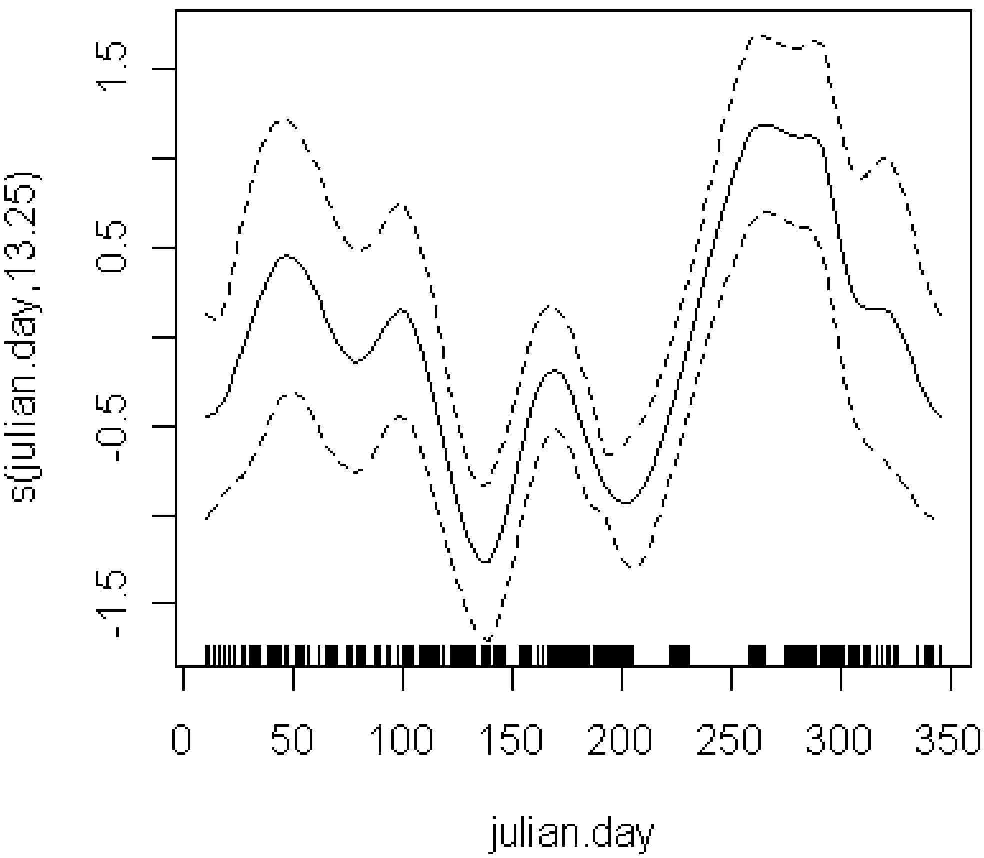


Figure 13: Predicted seasonal pattern of changes in the relative numbers of sightings of grey seals over the year. Again there is a clear peak in the numbers of animals seen in the study area early in autumn (day 274 is October 1st). Note that the y axis uses a log scale.

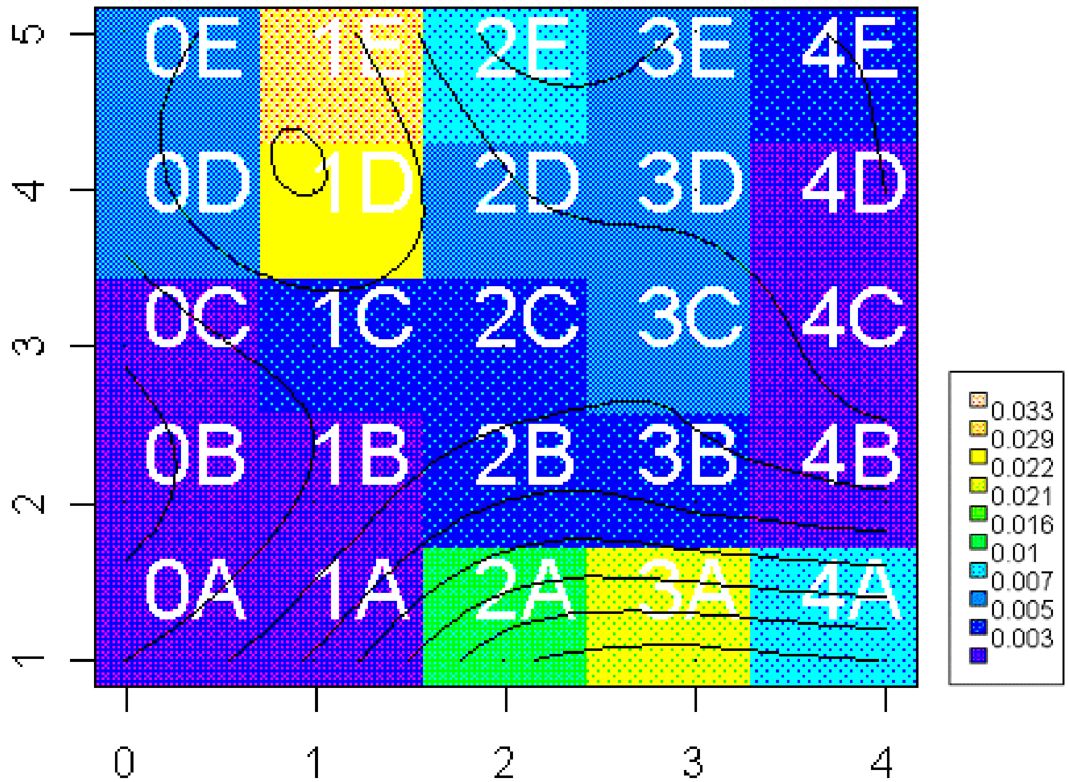


Figure 14: The estimated number of sightings of harbour seals across the study area (animals observed hour^{-1}). The colours are overall estimates for each cell, going from dark blue where few animals were seen through to green and brown to yellow for the highest values. The contours are interpolated 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.

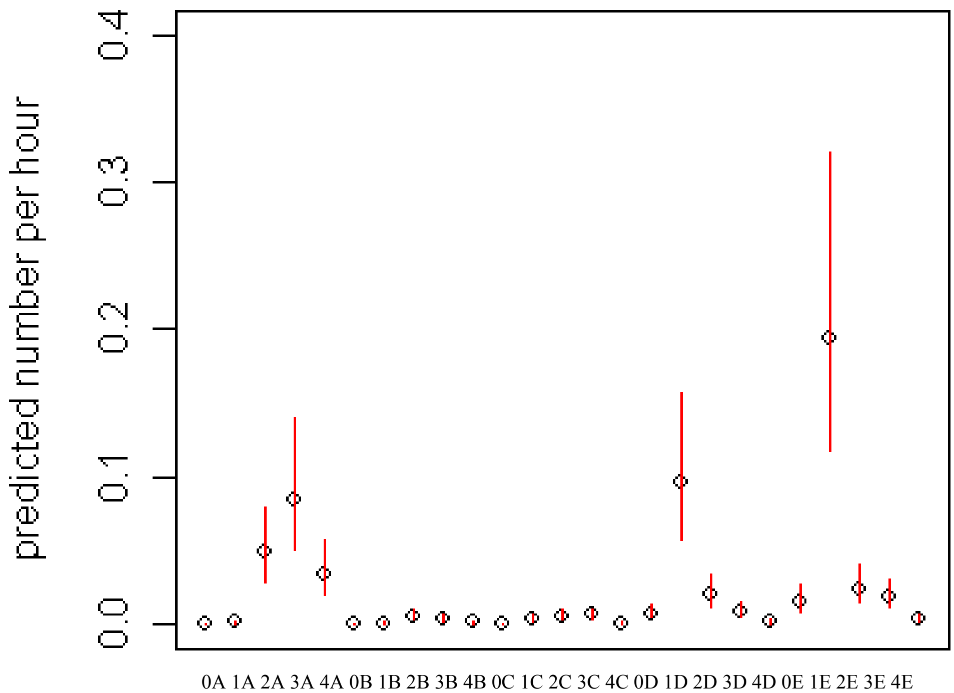


Figure 15: Estimated usage (in animals observed cell^{-1} hour^{-1}) and approximate 95% confidence intervals for each cell by harbour seals. It can be seen that, while including the spatial pattern significantly improves the model's representation of the data, relatively few cells can be distinguished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

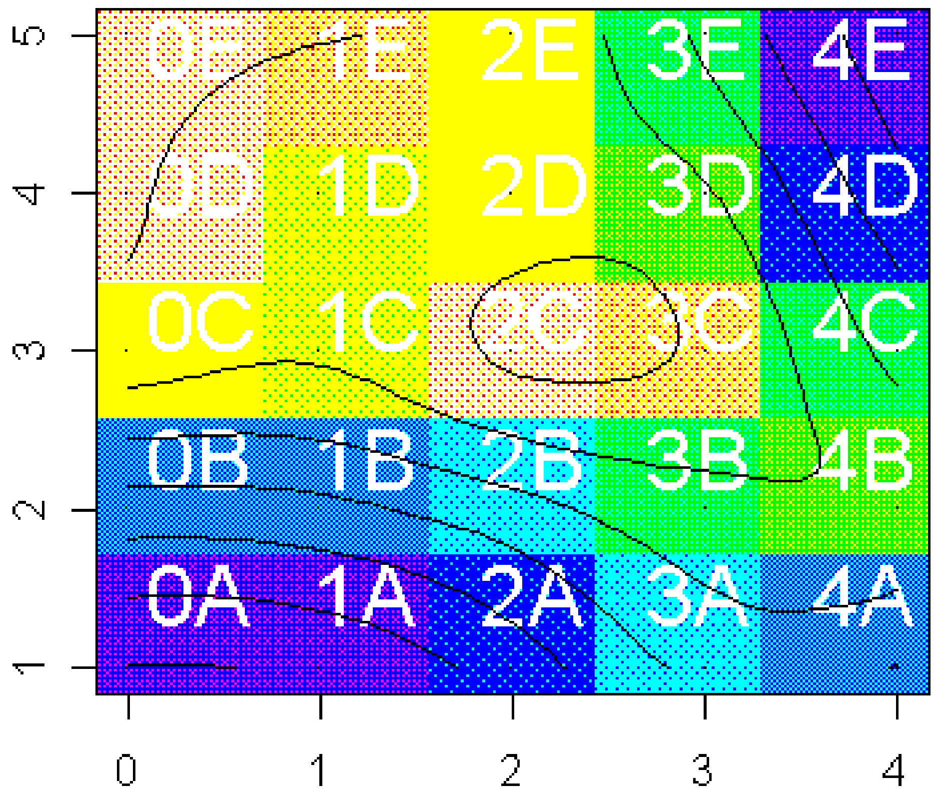


Figure 16: Estimated number of sightings of harbour porpoise across the study area (animals observed hour^{-1}). The colours are overall estimates for each cell, going from dark blue where few animals were seen through to green and brown to yellow for the highest values. Please note the change in scale from the seal figures.The contours are interpolated from the same model and are largely indicative, and details in their structure are unlikely to be important. Apart from near the observation point (which was sited adjacent to cell 2E), the main usage appears to be in the centre of the channel. The apparent patterns in this distribution should not be over interpreted, given the large uncertainties in the estimates for each individual cell (Figure 17).

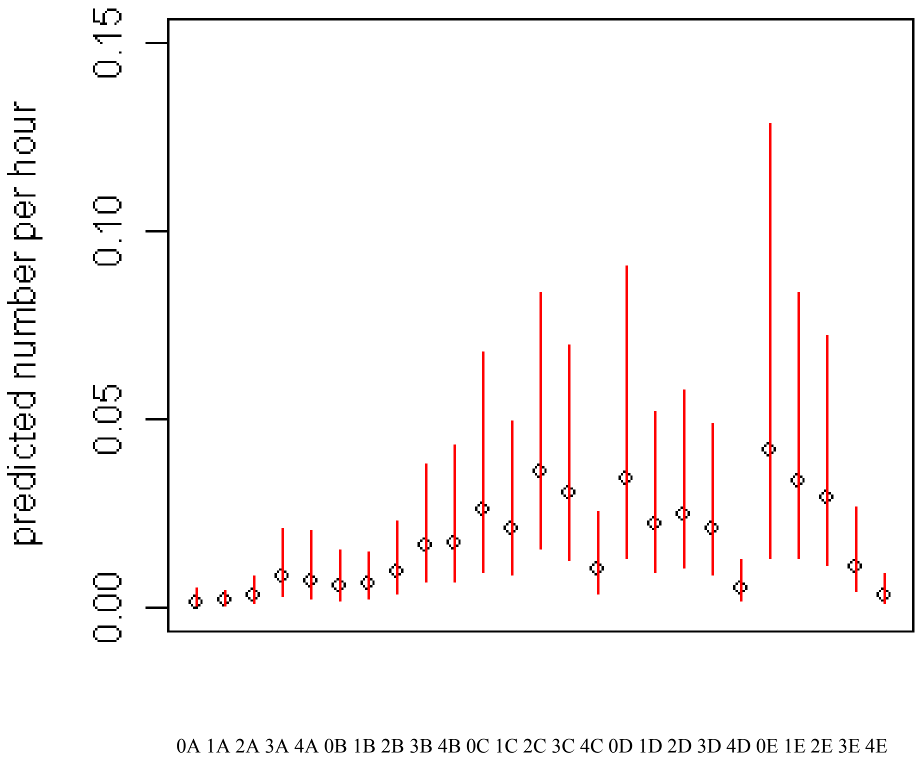


Figure 17: Estimated usage (in animals observed cell^{-1} hour^{-1}) and approximate 95% confidence intervals for harbour porpoises within each cell. Because of the limited number of observations, would be hard to confidently pull out any very detailed patterns from this data.