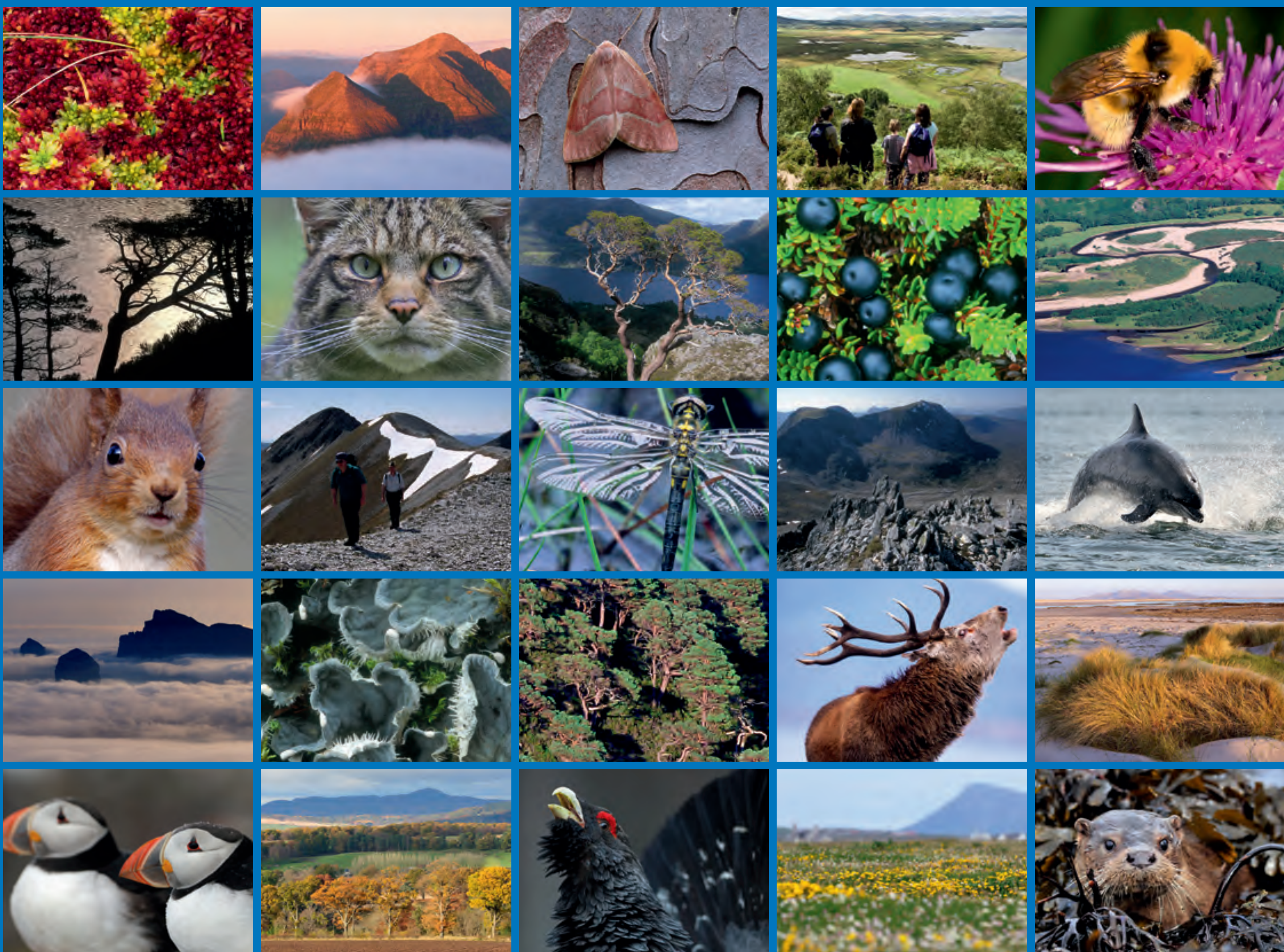
Scottish Natural Heritage
Commissioned Report No. 614

Analysis of Bird and Marine Mammal Data for Fall of Warness Tidal Test Site, Orkney



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Analysis of Bird and Marine Mammal Data for Fall of Warness Tidal Test Site, Orkney

For further information on this report please contact:

Alex Robbins
Scottish Natural Heritage
Battleby
Redgorton
PERTH
PH1 3EW
Telephone: 01738 458653
E-mail: alex.robbins@snh.gov.uk

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COMMISSIONED REPORT

Summary

Analysis of Bird and Marine Mammal Data for Fall of Warness Tidal Test Site, Orkney

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Background

The purpose of this report is to provide a review of the bird and marine mammal observation data for the EMEC Fall of Warness tidal test site from 2005 to 2011. The aims were to explore relationships (if any) between the more frequently observed bird and mammal species' site usage and habitat and environmental variables. This report can assist in understanding the spatial and temporal distribution of wildlife at the test site, and specifically enable identification of where and when particular species are more likely to encounter test devices or related deployment activity.

Main findings

- Almost all species analysed showed seasonal variation in their use of the site, which reflected the breeding and wintering habits that are typical for the species. Harbour porpoise, grey seals and some birds, including eiders, diver and cormorant species, black guillemots and puffins, were found to vary in their usage of the site throughout the day.

- The usage of pelagic and coastal areas of the site was found to differ between species. Auks, including common guillemot, razorbills and puffins, and harbour porpoise were observed more frequently in pelagic areas. Harbour and grey seals, eider, gannets, cormorant species and black guillemots were all observed more frequently in the areas adjacent to the coastline.

- Several species showed preferences for particular tidal states, including common and black guillemots, cormorants and shags, and harbour seals. Encounter rates for some species were also found to differ under particular environmental conditions.

For further information on this project contact:
Alex Robbins, Scottish Natural Heritage, Battleby, Redgorton, Perth, PH1 3EW.
Tel: 01738 458653
For further information on the SNH Research & Technical Support Programme contact:
Knowledge & Information Unit, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW.
Tel: 01463 725000 or research@snh.gov.uk

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1. INTRODUCTION

The purpose of this report is to provide a review of the bird and marine mammal observational data, for the EMEC Fall of Warness tidal test site. In addition, recommendations are made for improving data collection. The principal aims are:

1. To explore the relationships (if any) between bird and marine mammal distributions and site usage with habitat variables.
2. To explore the relationships (if any) between bird and marine mammal distributions and site usage with the collected environmental variables.
3. To provide any further recommendations for improving the wildlife monitoring protocols and data management.

1.1 Hypotheses

In order to achieve the aims, the following hypotheses will be tested for birds and marine mammals at the Fall of Warness test site:

1. There will be a seasonal difference in the use of the Fall of Warness site, by marine birds and mammals.
2. The number of marine birds and mammals observed at the Fall of Warness site will vary between different periods of the day.
3. The spatial distribution of marine birds and mammals will vary across the site, between areas of different water depth.
4. The spatial distribution of marine birds and mammals will vary across the site, between coastal and pelagic habitats.
5. The number of marine birds and mammals observed at the Fall of Warness site will vary under different tidal conditions.
6. The number of marine birds and mammals observed at the Fall of Warness site will vary with changing wind conditions.
7. The number of marine birds and mammals observed at the Fall of Warness site will vary between dry and precipitation conditions
8. The number of marine birds and mammals observed at the Fall of Warness site will vary with changing cloud cover.

<u>Initial Limitations</u>

1. To date, only actively foraging birds have been recorded at the Fall of Warness, and any birds sitting on the sea surface have not been recorded. Therefore these data cannot be used to analyse behavioural disturbance.

2. Due to the commercial sensitivity of the test site devices, data on when these devices were operational were not available at the time of analysis and could not be included.

3. Due to the scale of the grid system used for the wildlife monitoring, it was not possible to undertake a detection analysis for the more frequently seen species.

4. Due to the number of bird sightings exceeding the Excel spreadsheet row limit, only data between 11th July 2005 and 19th December 2010 were included in the bird analyses.

2. METHODS

2.1 Data Collection

Land-based vantage point observations take place from a trailer shelter on Ward Hill, Eday, Orkney (59˚08.975'N, 002˚47.396'W), approximately 50m above sea level. The survey area is defined by grid squares approximately 500m x 500m. The observations for birds and marine mammals commenced at the Fall of Warness on 11th July 2005, with a four-hour watch format, 5 days per week (i.e. approximately 80 hours of observation per month).

2.2 Data Preprocessing

These data required preparation prior to analysis, which included:

- Alteration of misspelled species names, codes and other categorical variables.
- Alteration of reversed grid squares, removal of impossible grid squares.
- Inference of missing values, where possible.
- Ensuring consistency in naming of categorical variable levels.

2.3 Data Analysis

All data analyses were completed using the statistical data package R, with relevant packages (R Development Core Team 2011). The total survey effort (in hours) is summarised for the entire data set. For all bird and marine mammal species with sufficient data, modelling of the effects of habitat and environmental variables was then undertaken.

2.3.1 Environmental Variables

In addition to the wildlife count data, a range of environmental variables were monitored during observations. These variables included:

Wind direction	This was subdivided into the following six categories "North", "South", "East", "West", "Variable" and "None".
Wind strength	This was defined using the Beaufort scale.
Sea state	This was defined also using the Beaufort scale.
Cloud cover	This was recorded as a percentage.
Precipitation	A range of descriptive categories and values have been applied to this variable during data collection. Previous reports have analysed precipitation in the binary form of "dry" or "precipitation". The latter approach was adopted for this analysis, but, as mentioned in previous reports, an intermediate approach with a manageable number of categories may be more informative in any future analysis.
Tidal state	This was subdivided into "Ebb", "Flow" and "Slack".
Tidal flow speed	Flow speed has been recorded with the following categories "Very Fast", "Fast" Moderate/Fast", Moderate", "Slow", "Slack", "High" and "Low".
Flow direction	Flow direction has been recorded as "North", "South", "Northwest", "Southeast" and "Slack".

Habitat type	Limited data is available on the habitat types within the Fall of Warness monitoring site (Finn 2009) and is not available for every grid square. It was therefore only possible to describe each cell as either “Coast” (if coastline was present in the cell) or “Pelagic” (if there was no coastline).
Depth	Depth data was only available from the MCA Bathymetry Survey in Finn (2009). The cell depths were grouped as “1 – 10m”, “11 – 20m”, “21 – 31m”, “32 – 42m”, and “43 – 54m”.
Grid square	The study site is divided into rows (-1 to 5) and columns (A to E).
Season	The months were grouped into “Winter” (December, January and February); “Spring” (March, April and May); “Summer” (June, July and August) and “Autumn” (September, October and November).
Time of day	This was recorded as the hour in which the observation occurred, e.g. 10:30 was “10” and 14:15 was “14”.
Observer ID	An important element in modelling of observation data is accounting for variation between observers (even of the same experience and skill). This information was not available and would ideally be included in future analyses.

2.3.2 Co-linearity

Similar variables were tested for co-linearity using Variance Inflation Factors (VIF). Tide state, flow direction and flow speed were all found to have co-linearity. Tide state was found to be the most representative variable and was subsequently used in the analysis. As with previous reports, wind state was used as a proxy for sea state.

2.3.3 Modelling

Modelling of marine bird and mammal abundance with the EMEC Fall of Warness tidal test site was achieved by using two extensions of generalized linear model (GLM) techniques. The counts of each species were used as the response variable to investigate the influence of the different habitat and environmental conditions. An inherent issue with this dataset is the temporal autocorrelation, i.e. where counts that occur in consecutive hours or days are correlated, which if unaccounted for may result in a Type I error. Therefore, generalized linear mixed models (GLMM) were used with a Poisson error distribution and log link, and the inclusion of a random effect variable to allow for correlation between observations within the same day and grid square. The top five models were selected using ANOVA function and comparing AIC values. GLMM model validation was undertaken by plotting and reviewing the distribution of the selected model’s Pearson’s residuals. In addition, another GLM extension, generalized estimation equations (GEE), was also used to estimate robust standard errors, adjusted for temporal autocorrelation. Observations that occurred within the same day and grid square were assumed to have an AR1 autocorrelation. The results reported include the GEE model coefficient estimates and standard errors.

The plots presented within this report incorporate GEE model coefficient estimates, the encounter rate of mean number of birds or mammals observed (per hour), or percentage of overall observations. The higher model coefficient values represent a greater number of predicted birds or marine mammals.

Another appropriate modelling technique not used within this report is Generalised Additive Models (GAMs). These additive models can be used when data are non-linear, and a transformation of the data is inappropriate. They allow for non-linear relationships between response and explanatory variables through the use of smoothing models (Zuur *et al*. 2009).

3. RESULTS AND DISCUSSION

The results are presented in two sections: first the results for each of the key foraging bird groups and species are outlined. This is then followed by an outline of the modelling results for the most frequently observed marine mammals. The observations were carried out between July 2005 and March 2011. The total hours of survey that birds and mammals were observed in (by month) are summarised in Table 1a and 1b.

3.1 Birds

Eider *Somateria mollissima*

A total of 66,254 eider were observed between July 2005 and December 2010 at the Fall of Warness tidal test site. The numbers observed within the site showed seasonal variation, which was strongly selected for within the chosen models (refer to table 2 and figure 1), with more eider being observed in the spring months and less in the summer months.

Time of day was selected for in four out of the top five models and figure 3 highlights that the higher numbers of eider per hour were seen at 10:00 (peak mean = 2.46), after which the hourly encounter rate decreased. The GEE and GLMM coefficient estimates both indicate that eider were observed more frequently during flooding tides and slack tides (refer for figure 2). The depth of the grid squares and habitat type (pelagic v. coastal) were also selected for, in all of the top models. Figure 4 shows the mean number of eider observed was highest in grid squares between 1-10 m deep (mean = 53.53). Of the 1028 days eider were observed at the Fall of Warness, they were seen in coastal grid squares on 1011 days and in pelagic grid squares on 359 days. This is consistent with literature on eiders, which notes that, as benthic feeders, they forage close to shore and in water up to 4m deep (Owen *et al*. 1986).

Figure 5 suggests the mean hourly encounter rate of eiders was found to decrease with increasing wind strength, with a mean peak at Force 1 of 2.29 eider per hour and low of 1.75 eider per hour under Force 5 conditions. Figure 6 shows the mean hourly encounter rate of eider varied across the range of cloud coverage conditions, with the lowest hourly encounter rates occurring when there was 59% and 99% cloud coverage and the peak hourly encounter rate at 33% cloud coverage. Precipitation was only selected for in two out of the top five models, and was not included within the GEE models.

Divers *Gavia spp*.

Of the 4,638 divers observed between July 2005 and December 2010, >70% were red-throated divers (*Gavia stellata*), 24% were great northern divers (*G. immer*) and <1% were black-throated divers (*G. arctica*), the remaining 5% were unidentified to species (refer to figure 7). Of the top five GLMM models exploring the influence of environmental variables on numbers of divers observed, season, depth, wind strength and tide state were most frequently selected, however the top model also included time of day. The GEE model identified season, time of day, depth and wind strength to be significant. The GEE model estimated over-dispersion (scale parameter) to be 0.52 and correlation between observations on the same day and grid squares to be 0.55.

Figure 8 indicates higher model coefficients in summer, with lower in winter and spring; figure 9 highlights that a greater proportion of diver observations occurred in autumn (38.98%) compared with only 8.45% in the summer. However, the model coefficient estimates reflect the mean number of birds per hour, which was higher during the summer (1.59 divers/hour) compared with autumn (1.47 divers/hour), winter (1.35 divers/hour) and spring (1.41 divers/hour). One possible reason for this is that divers were observed more during the autumn, winter and spring, but the concentration of birds was higher during the observations in the summer months. Red-throated divers are known to forage on inshore waters during the breeding season (Gibbons *et al*. 1997; Jackson 2002). Outside of the breeding season they are considered to use the marine environment extensively, spending a large proportion of their time on the sea, including sleeping (Stone *et al*. 1995).

Figure 10 (and table 5) highlights that the encounter rate of divers per observation was greater during slack tides, compared with ebb and flood tides. However figure 11, suggests that a greater proportion of divers were observed during flood tides (<42%) than ebb (39%) or slack tides (18%). Figure 12 suggests that divers were observed more frequently in the early morning and then again in the evening: the mean number of divers per hour increases and peaks at 06:00 (1.66 divers/hour) before decreasing during the day and peaking again at 18:00 (1.89 divers/hour).

The depth of the grid squares was also selected for in all of the top models. Figure 13 shows that for <55% of observations, divers were recorded in grid squares between 21-31m deep. Figure 14 shows the mean number of birds encountered per hour decreases as wind strength increases from Force 0 to 4 (Beaufort Scale), however, the mean hourly encounter rate peaks at Force 5 (1.63 divers/hour). Precipitation and cloud cover were only selected for in one and two of the top 5 models, respectively.

Northern Gannet *Morus bassanus*

A total of 10,623 gannets were counted during the observation period. Of the top five GLMM models exploring the influence of environmental variables on numbers of gannets observed, season, habitat type and tidal state were most frequently selected and the GEE model also highlighted these as significant. Time of day, depth, wind strength and cloud cover were also selected for in the top five GLMM models. The GEE model estimated over-dispersion (scale parameter) to be 3.4, and correlation between observations on the same day and grid squares to be 0.165.

Figure 15 highlights that gannets were encountered more frequently during observations in the summer and autumn months, compared with winter and spring. Gannets were also more frequently observed during flood (43% of observations) and ebb tides (44% of observations) compared with slack tide (<13% of observations) (refer to figure 16 and 17). The mean number of gannets observed per hour showed peaks and troughs throughout the day, with greater mean numbers observed per hour around 07:00 (7.23 gannets/hour) and 16:00 (6.28 gannets/hour) (refer to figure 18).

The models consistently selected for habitat type, and tables 6 and 7 highlight that gannets were observed more frequently in coastal grid squares (75% of observations) compared with pelagic grid squares (25% of observations). Figure 19 also shows that 62% of all observations of gannets were in grid squares that were 21-31m deep, with 23% of observations of gannets in grid squares of 1-10m deep.

Cormorants *Phalacrocorax spp.*

Of the 145,613 *Phalacrocorax spp.* observed at the Fall of Warness during the period analysed, 30% were European shags (*P. aristotelis*), 7% were cormorants (*P. carbo*) and 63% were unidentified to species. The best *Phalalcrocorax spp.* GLMM models contained the variables for season, time of day and tide state (with an interaction), depth, habitat type, wind strength and cloud cover (refer to tables 8 and 9). The GEE model indicated that season, time of day, depth, wind strength and cloud cover were significant. The GEE model estimated over-dispersion (scale parameter) to be 38.1 and correlation between observations on the same day and grid squares to be 0.094.

Figure 20 indicates that the hourly encounter rate of *Phalacrocorax spp.* observed varied between seasons, with greater numbers observed during the autumn and winter months. The models also selected for tidal state: figure 21 shows that fewer birds were encountered during flood and slack tidal states. The top two GLMM models included an interaction between time of day and tidal state: figure 22 demonstrates that the *Phalacrocorax spp.* mean hourly encounter rate, in all tidal states, peaked between 09:00 and 14:00 (mean of 8.58 birds per hour), after which the numbers steadily decreased. Figure 22 also indicates that the mean hourly encounter rate was higher during ebbing tides compared with flooding or slack tides.

The depth of the grid squares was also selected for in the top models. Figure 23 highlights that 48% of the shags and cormorants observed were within grid squares of between 1-10m deep, while >44% were observed within 21-31m deep grid squares. Similarly, the GEE model coefficients indicate that a greater number of shags and cormorants were observed in coastal grid squares, as opposed to pelagic grid squares (refer to table 9).

The mean hourly encounter rate of shags and cormorants was found to decrease with increasing wind strength (refer to figure 24); and the mean hourly encounter rate increasingly fluctuated with a higher percentage of cloud cover (refer to figure 25).

Guillemot *Uria aalga*

A total of 54,771 guillemots were counted during the observation period at the Fall of Warness. The top five GLMM models for guillemot counts all included the variables for season, time of day, habitat type, wind direction, tide states and cloud cover (refer to tables 10 and 11). The GEE results indicated that the influence of season, habitat type, wind direction and tide state was significant. The GEE model estimated over-dispersion (scale parameter) to be 173 and correlation between observations on the same day and grid squares to be 0.453.

Figure 25 highlights the variation in guillemot numbers across the seasons, with higher numbers being seen in the spring and summer months. The mean hourly guillemot encounter rate also showed variation throughout the day, with a peak of 25.7 birds per hour between 16:00 and 17:00 (refer to figure 26), however 53% of all guillemot observations occurred between 06:00 and 09:00.

84% of all guillemots observed were recorded in pelagic grid squares (refer to figure 27), similarly 91% of all observations were in water 20m deep or more. Figure 29 indicates that greater numbers of guillemots were observed during flood tides, and fewer during slack tides.

The top models selected for wind direction over strength and figure 28 suggests that greater numbers of guillemots were observed during southerly or variable winds. Cloud cover was also selected for and figure 30 shows fluctuations in the means, with the peak hourly encounter rates occurring at 50% and 100% cloud cover.

Razorbill *Alca torda*

A total of 1,699 razorbills were counted during the observation period. Of the top five GLMM models for razorbill, counts included the variables for season, time of day, habitat type, wind direction, tide states and cloud cover, with precipitation and depth selected for, in two and three of the top five models (refer to tables 10 and 11). The GEE model estimated over-dispersion (scale parameter) to be 7.7 and correlation between observations on the same day and grid squares to be 0.395.

Figure 31 shows the GEE model coefficient estimates for razorbill numbers by season, which predict that higher numbers would be observed during the spring months, compared with summer, autumn and winter months. The encounter rate (mean number of razorbills per hour) shows temporal variation during the day, with a peak at 09:00, however due to the fewer number of razorbills observed this may be skewed (refer for figure 32). Furthermore the GEE model did not highlight time of day as significant (refer to table 11).

Razorbills were frequently observed in pelagic grid squares, compared with coastal grid squares (refer to figure 33). Figure 34 shows the razorbill numbers varied with different wind directions; the GEE model predicts a greater number of razorbills likely to be observed with no wind, and fewer razorbills likely to be observed during westerly winds. This may be a result of the wind direction affecting sea state (i.e. causing “choppiness”) and subsequently reducing the observers’ ability to observe and/or identify razorbills. Figure 35 also suggests that razorbills were observed more frequently during flooding tides, compared with ebb or slack tides. Precipitation was not found to be significant be the GEE model.

Black Guillemot *Cepphus grille*

A total of 78,071 black guillemots were observed at the Fall of Warness site. The top GLMM models indicate that black guillemot numbers are a function of season, time of day interacting with tidal state, depth, habitat type, wind strength, precipitation and cloud cover (refer to table 14). The GEE model coefficient estimates (and standard errors) suggest that all these variables were significant, excluding precipitation. The GEE model estimated over-dispersion (scale parameter) to be 7.38 and correlation between observations on the same day and grid squares to be 0.531.

Black guillemots were observed more during the spring and summer months (refer to figure 36), with 35% of all observations occurring in the spring and 45% in the summer. Figure 37 highlights a clear decreasing temporal trend in black guillemot encounter rate (mean number of birds per hour), with peak encounters occurring between 04:00 and 08:00 (peak mean of 8.2 birds per hour at 06:00) and decreasing throughout the day. The GEE model coefficient outputs indicate that the black guillemot numbers are significantly affected by time of day and tidal state, with an interaction. The model coefficients suggest that fewer black guillemots were seen during flooding tides (-0.445 ± 9.079SE), compared with ebb and slack tides (0.03±0.096) (refer to figure 41). Figure 38 shows the mean number of birds encountered per hour during flooding tides is less between 04:00 and 09:00, compared with ebbing and slack tides (the ebb mean peak at 07:00 = 9.353 black guillemots/hour, the flood mean = 6.542 black guillemots/hour, and the slack mean = 9.207 black guillemots/hour). However, figure 38 also suggests that after 14:00 the black guillemot encounter rate during flooding tides was slightly higher than the encounter rate during ebbing or slack tides.

Unlike the other auk species, black guillemots were observed more frequently in coastal grid squares than in pelagic grid squares (refer to figure 39). This was only partially reflected by water depth, with 40% of all observations occurring in water between 1 and 10m deep and 42% in water between 21 and 31m deep.

The mean hourly encounter rate for black guillemots showed an overall decrease with increasing wind strength (refer to figure 42). Figure 43 shows fluctuation in the hourly black guillemot encounter rate under different cloud cover conditions.

Atlantic Puffin *Fratercula arctica*

A total of 7,882 puffins were observed at the Fall of Warness site. The top GLMM models indicates that puffin numbers are a function of season, time of day, tidal state, habitat type, depth and cloud cover (refer to table 16). The GEE model coefficient estimates (and standard errors) suggest that all these variables were significant, excluding tide state and cloud cover (refer to table 17). The GEE model estimated over-dispersion (scale parameter) to be 1.47 and correlation between observations on the same day and grid squares to be 0.476.

Puffins were observed more frequently during the spring and summer months (refer to figure 44). The mean numbers of puffins encountered per hour increased throughout the day, peaking at 3.33 puffins per hour at 18:00. Figure 46 (and table 17) highlights the model coefficient estimates and standard errors for tidal state: the difference between the numbers observed between flooding, slack and ebbing tides is not significant.

Puffins, like razorbills and guillemots, were observed more in pelagic grid squares compared with coastal grid squares (refer to figure 47), and 44.24% of all puffin observations were in water between 21 and 31 m deep. However, figure 48 also highlights that 37.74% of all puffin observations were in water of between 1 and 10m deep. The mean hourly encounter rate for puffins was found to fluctuate more with increasing cloud cover (figure 49).

3.2 Marine Mammals

A total of 11,415 seals were recorded during the observation period, 12% of these were harbour seals, 49% of these were grey seals and 39% were unidentified to species.

Harbour Seal *Phoca vitulina*

A total of 1,379 harbour seals were observed at the Fall of Warness site. The top GLMM model indicates that harbour seal numbers are a function of season and depth (refer to table 18), while the other top five models included tide state, cloud cover and habitat type. The GEE model coefficient estimates (and standard errors) suggest that only depth and season were significant, (refer to table 19). The GEE model estimated over-dispersion (scale parameter) to be 1.05 and correlation between observations on the same day and grid squares to be 0.154.

The modelling results suggest that harbour seals show seasonal variation in their use of the Fall of Warness site. The two figures (50 and 51) show two different forms of seasonal variation: figure 50 highlights the coefficient estimates for each season, with more harbour seals being recorded per observation (hourly encounter rate) during the autumn months, while figure 51 shows that 42.72% of all harbour seal observations occurred during the summer, compared with only 28.53% of observations that occurred during the autumn. This suggests that harbour seals were seen during more observations in the autumn months, but that the numbers recorded per observation were higher during the summer. Harbour seals breed during the summer months, giving birth on land, but spend most of the lactation in the sea with their pups. During this period females have been found to have a reduced range size during the summer, when they concentrate in inshore haul-out areas (Thompson *et al*. 1994).

Figure 52 shows the GEE model estimates indicate more harbour seals were seen in slack tides, (0.057) compared with ebb and flood tides (-0.079), however this was not significant. Just under half of all harbour seals (49.67%) were observed in water between 1 and 10 m deep, with 39.54% observed in water between 21 and 31 m deep. 1.3% of all harbour seal observations occurred in the deepest area of the Fall of Warness tidal site.

Grey Seal Halichoerus grypus

A total of 5,636 grey seals were observed at the Fall of Warness site. The top GLMM models indicates that grey seal numbers are a function of season, time of day, depth, habitat type, wind direction, precipitation and cloud cover (refer to table 20). The GEE model coefficient estimates (and standard errors) suggest that only season, time of day, depth, habitat type and wind direction are significant (refer to table 21). The GEE model estimated over-dispersion (scale parameter) to be 4.66 and correlation between observations on the same day and grid squares to be 0.365.

Grey seals were also found to show seasonal variation in their use of the Fall of Warness site. Figures 54 and 55 highlight that the encounter rate and highest proportion of all grey seal observations (67%) occurred during the autumn months, which coincides with their pupping season (Bonner 1981). The peak hourly encounter rate for grey seals occurred between 15:00 and 17:00 (peak mean of 2.69 grey seals per hour at 16:00) (refer to figure 56).

Grey seals were seen less in the pelagic areas of the study site in comparison with coastal areas (refer to figure 57), with 48.14% of all observations occurring in water of between 1 and 10m deep. The proportion of grey seals observed can be seen to decrease with increasing water depth (refer to figure 58).

Figure 59 suggests that fewer grey seals were observed with winds from an easterly or westerly direction, with the highest numbers of seals observed with variable or no wind. Figure 60 shows the hourly encounter rate fluctuates with cloud cover. The peak mean encounter rates occurred when cloud was covering 15-25% of the sky.

Harbour Porpoise *Phocoena phocoena*

A total of 657 harbour porpoise were observed at the Fall of Warness site. The top GLMM model indicates that harbour porpoise numbers are a function of time of day and habitat type, although other variables including season, depth, tidal state, wind direction and cloud cover were also selected for within the top five GLMM models (refer to table 20). The GEE model coefficient estimates (and standard errors) suggest that time of day and habitat were significant (refer to table 21). The GEE model estimated over-dispersion (scale parameter) to be 0.75 and correlation between observations on the same day and grid squares to be 0.142.

Harbour porpoise encounters fluctuated during the day, however the hourly encounter rate increased in the late afternoon/evening. Figure 61 highlights the mean harbour porpoise hourly encounter rate peaked between 17:00 and 19:00 (mean of 4.4 harbour porpoise per hour at 18:00). 52% of all harbour porpoise observations were recorded in pelagic areas. Figure 62 also highlights that a higher number of porpoise were found in pelagic v. coastal areas.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study provides information on how the most frequently occurring bird and marine mammal species use the Fall of Warness tidal test site. This information can be used in understanding the spatial and temporal distribution of wildlife at the test site, and specifically enable identification of where and when particular species are more likely to encounter test devices or related deployment activity.

Almost all species analysed showed seasonal variation in their use of the site, which reflected the breeding and wintering habits that are typical for the species. Harbour porpoise, grey seals and some birds, including eiders, diver and cormorant species, black guillemots and puffins, were found to vary in their usage of the site throughout the day.

The usage of pelagic and coastal areas of the site was found to differ between species. Auks, including common guillemot, razorbills and puffins, and harbour porpoise were observed more frequently in pelagic areas. Harbour and grey seals, eider, gannets, cormorant species and black guillemots were all observed more frequently in the areas adjacent to the coastline.

Several species showed preferences for particular tidal states: common guillemots were observed more frequently in flooding tides. Cormorant species were observed more in ebbing tides and common seals were observed more frequently at slack tides. Both black guillemots and cormorants were found to have different hourly encounter rates during peak times of day at different tidal states.

Encounter rates were found to differ under particular environmental conditions, in particular eider, diver and cormorant species and black guillemot numbers were found to decrease with increasing wind strength. Encounter rates for grey seals, razorbills and guillemots were all found to vary with wind direction, which is likely to be a result of the wind direction affecting sea state (i.e. causing “choppiness”) and subsequently reducing the observers’ ability to observe and/or identify the species. Cloud cover was selected for in top models for several species, although encounter rates tended to fluctuate with increasing cloud cover. It is likely that cloud cover affected the level of glare, and consequently visibility, which may have in turn also affected the observers’ ability to observe and/or identify the individuals. Precipitation was not found to be significant with any species.

4.2 Recommendations

There are several recommendations for methodology improvements that would benefit future analyses:

1. The observer should be identified for each watch (or record), as it is important to account for variation between observers (even of the same experience and skill) in analyses.

2. It would be useful to have a defined number of categories for both viability and precipitation variables. This would enable inclusion of visibility within future analyses, and may also enable more informative modelling of precipitation.

3. There is currently only limited data available on the habitat types and depth within the Fall of Warness monitoring site (Finn 2009) and is not available for every grid square. Therefore it was not possible to consider, for example, the seabed substrate or slope, which may influence which species forage where within the site. This information and other habitat variables may be useful in future analyses.

An inherent concern with land-based observations is that there is a decreased probability of detecting wildlife with an increase in distance from the observation point (Bibby *et al*. 2000; Buckland *et al*. 2001). As mentioned in previous reports, the grid system prevents the inclusion of detection probabilities, as the spatial accuracy of the observations is much coarser and it is possible that the usages of the most distant grid squares (from the observer) are being underestimated. It is therefore recommended that boat-based surveys undertake line-transects randomly across the test site to calibrate these land-based vantage point observations. These surveys should be carried out according to standardized methodologies (e.g. Buckland *et al*. 2001 and Camphuysen *et al*. 2004).

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ANNEX 1: TABLES AND FIGURES

Table 1a) The total number of hours of survey that birds were observed in between 11th July 2005 and 19th December 2010;

a)	2005	2006	2007	2008	2009	2010
January		12	22	16	24	38
February		16	26	26	31	48
March		23	35	26	28	52
April		37	29	26	46	52
May		20	35	37	36	28
June		32	35	39	28	42
July	24	47	36	34	33	30
August	18	36	27	29	31	47
September	18	38	27	23	32	49
October	17	32	32	31	55	45
November	22	25	17	25	47	38
December	11	16	21	23	38	20
Total	**110**	**334**	**342**	**335**	**429**	**489**

Table 1b) the total number of hours of survey that marine mammals were observed in between 11th July 2005 and 29th March 2010.

b)	2005	2006	2007	2008	2009	2010	2011
January		11	10	13	16	23	25
February		16	15	12	27	39	29
March		20	18	14	12	39	18
April		25	22	14	25	30	
May		18	27	24	24	17	
June		31	30	28	23	36	
July	24	45	33	32	27	21	
August	18	34	26	26	30	41	
September	18	37	27	22	31	40	
October	17	32	32	25	53	42	
November	21	19	17	19	39	34	
December	8	14	14	14	23	25	
Total	**106**	**302**	**271**	**243**	**330**	**387**	**72**

Common Eider

Table 2: The top 5 GLMM models, as selected by AIC values, for modelling eider use of the Fall of Warness.

Model	Df	AIC
Season + time of day + tide state + depth + habitat type + cloud cover	12	19028
Season + time of day + tide state + depth + habitat type + wind strength + precipitation + cloud cover	14	19029
Season + time of day + tide state + depth + habitat type + wind strength + cloud cover	13	19030
*Season + time of day*tide state + depth + habitat type + wind strength + precipitation + cloud cover*	17	19030
Season + tide state + depth + habitat type + cloud cover	11	19032

Table 3: Parameter estimates, standard errors, probability values for GEE investigating eider counts as a function of season, time of day, tide state, depth, habitat type and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.[1]
Intercept	2.1308	0.1200	5773 287.02	< 2e-16	***
Spring	0.6496	0.0535	147.23	< 2e-16	***
Summer	-0.9005	0.0602	224.12	< 2e-16	***
Autumn	-0.1703	0.0453	14.17	0.00017	***
Time of day	0.0174	0.0087	3.97	0.04643	*
Flood	0.5004	0.0504	98.55	< 2e-16	***
Low	-0.9914	0.4485	4.89	0.02708	*
Slack	0.4599	0.0642	51.3	7.90E-13	***
Depth	-0.0541	0.0021	640.96	< 2e-16	***
Pelagic	0.6901	0.0673	105.17	< 2e-16	***
Cloud cover	0.0035	0.0008	18.97	1.30E-05	***

[1] Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Figure 1: GEE coefficient estimates (and standard errors) for eiders observed by season at the Fall of Warness.

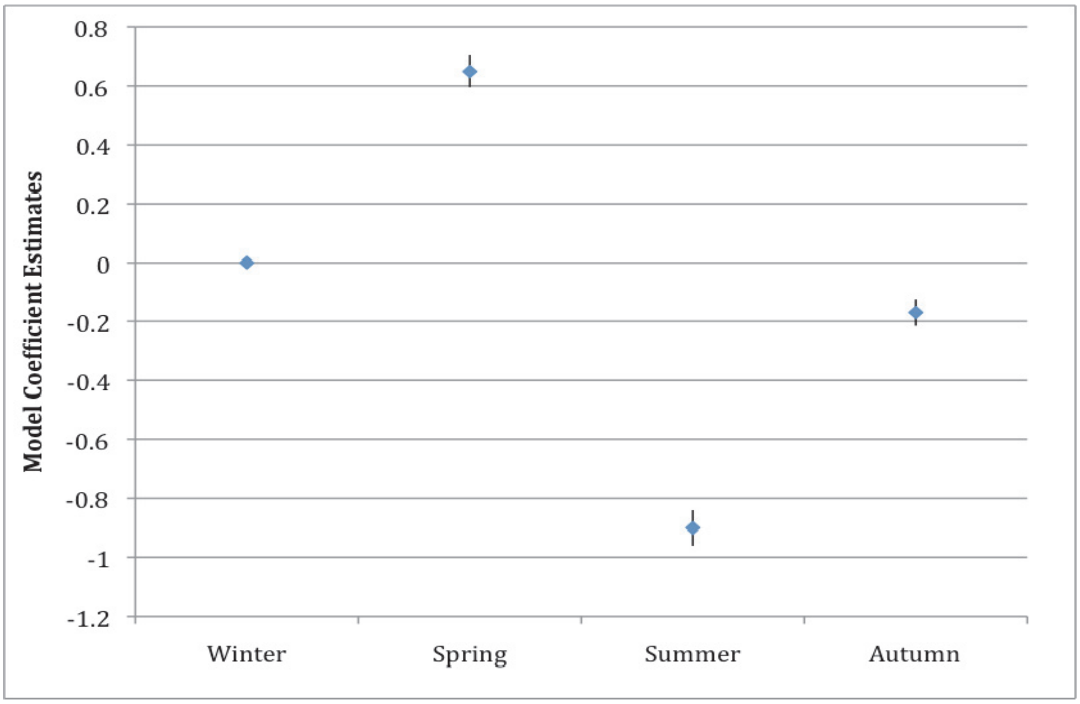


Figure 2: GEE coefficient estimates (and standard errors) for eiders observed by tidal state at the Fall of Warness.

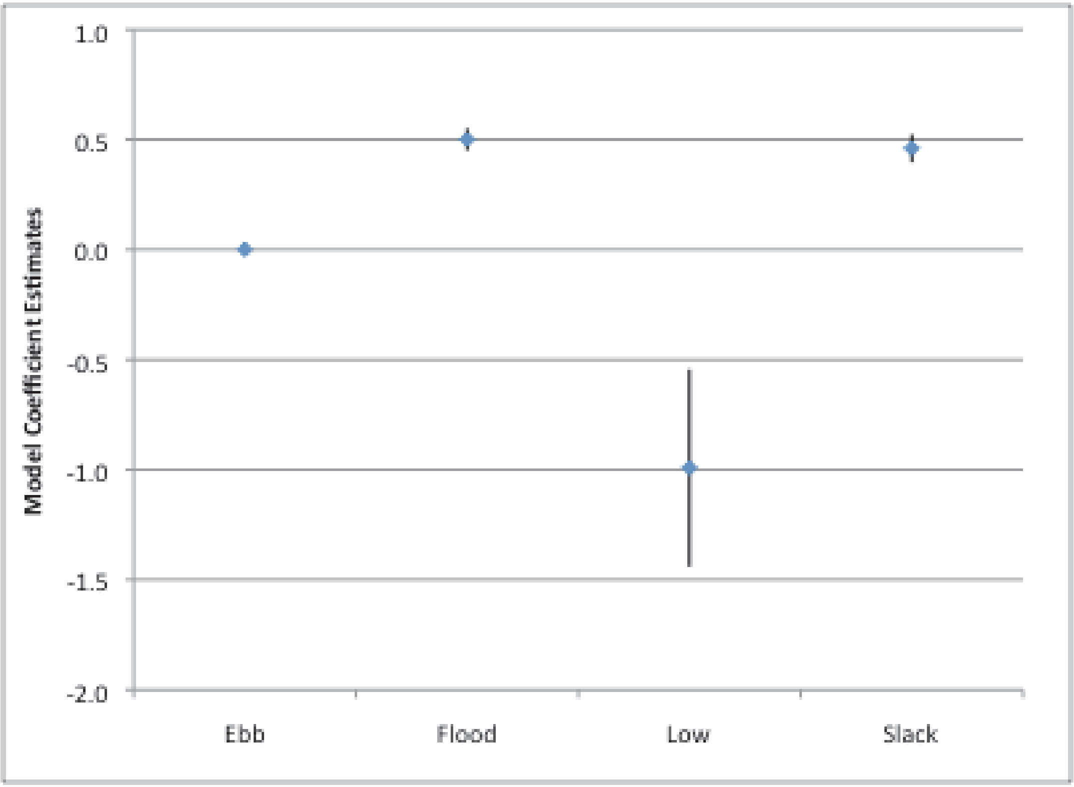


Figure 3: Mean number of eider observed per hour, throughout the day at the Fall of Warness.

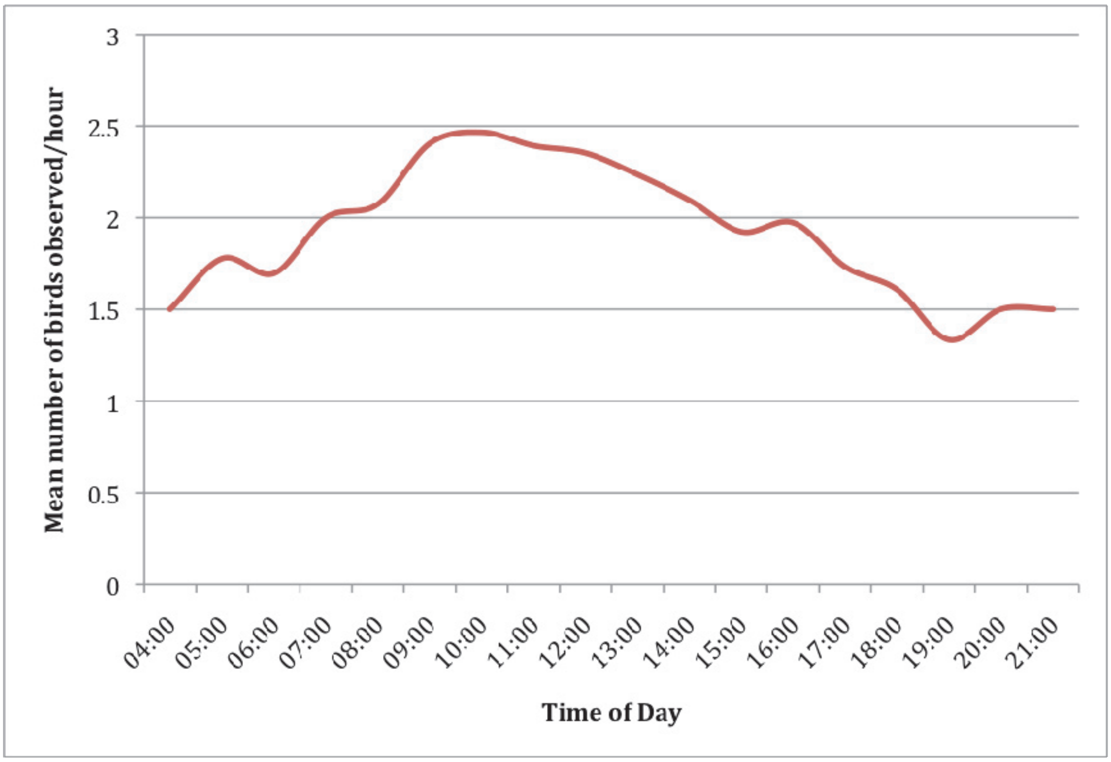


Figure 4: The proportion of observations eider were observed at different depths, at the Fall of Warness.

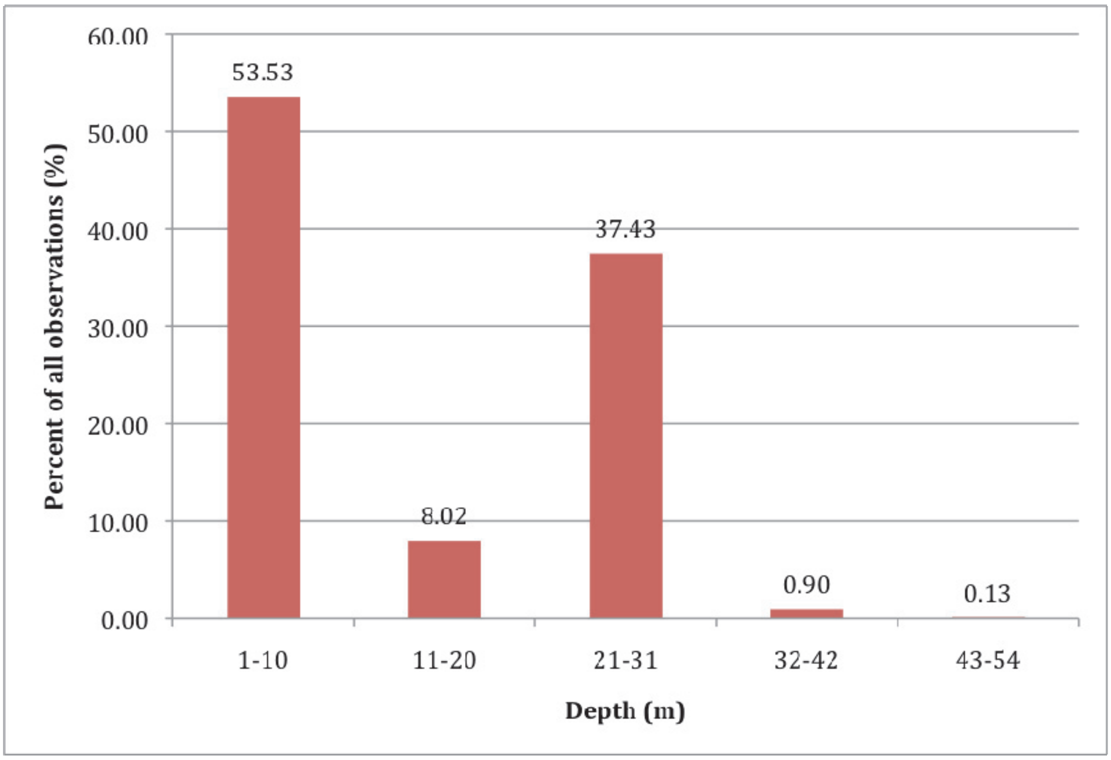


Figure 5: Mean number of eider observed per hour during different wind strengths, using the Beaufort Scale, at the Fall of Warness.

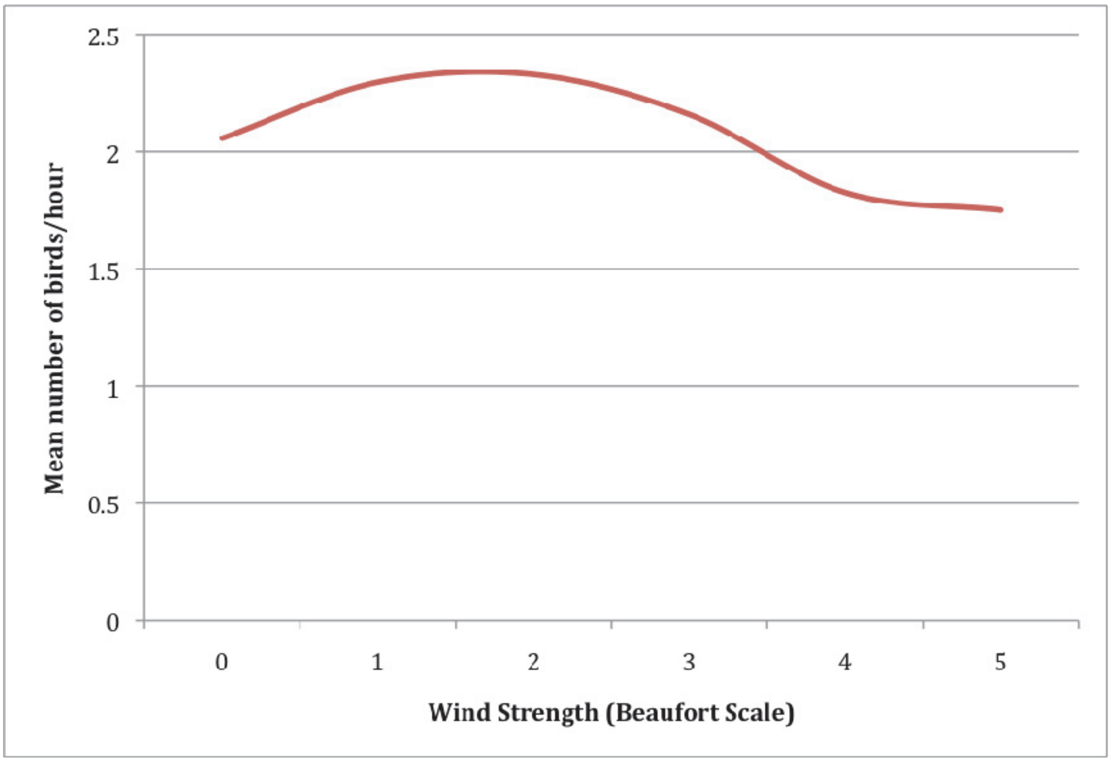
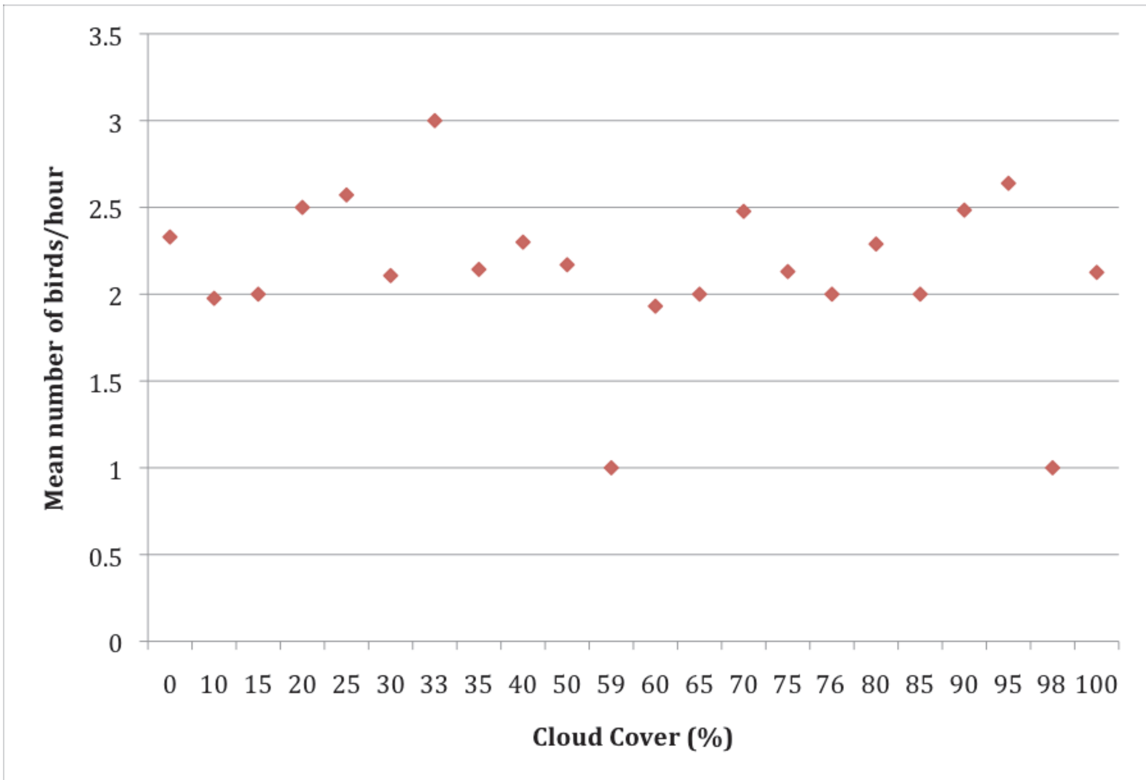


Figure 6: Mean number of eider observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Divers

Table 4: The top 5 GLMM models, as selected by AIC values, for modelling diver use of the Fall of Warness.

Model	Df	AIC
Season + time of day + depth + wind strength + tide state	10	1239
Season + depth + wind strength + tide state	9	1242
Season + time of day + depth + habitat type + wind strength +tide state + cloud cover	12	1242
Season + depth + wind strength	7	1243
Season + time of day + depth + habitat type + wind strength +tide state + cloud cover + precipitation	13	1243

Table 5: Parameter estimates, standard errors, probability values for GEE investigating diver counts as a function of season, time of day, depth, wind strength and tide state.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.363679	0.067786	28.78	8.10E-08	***
Spring	0.046002	0.028213	2.66	0.103	
Summer	0.137771	0.040708	11.45	0.00071	***
Autumn	0.085281	0.02753	9.6	0.00195	**
Time of day	0.013138	0.004761	7.62	0.00579	**
Depth	-0.004374	0.000948	21.28	4.00E-06	***
Wind strength	-0.045514	0.012141	14.05	0.00018	***
Flood	-0.038923	0.023694	2.7	0.10044	
Slack	0.041555	0.030931	1.8	0.17912	

Figure 7: Proportion of all diver sightings by species at the Fall of Warness.

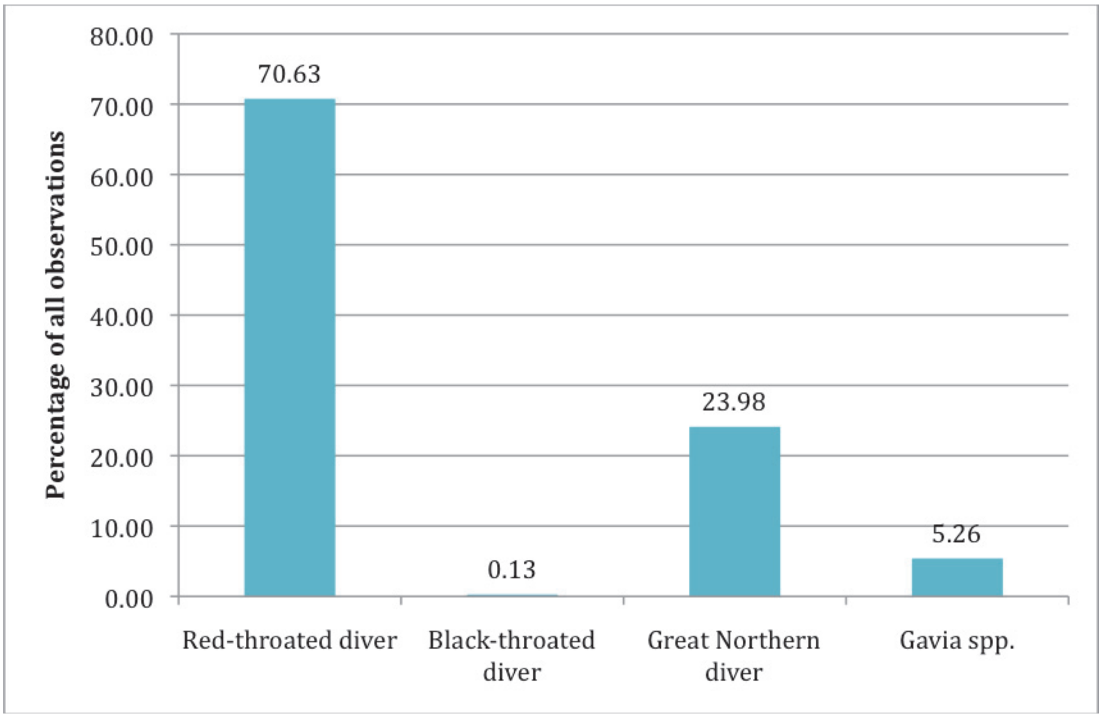


Figure 8: GEE coefficient estimates (and standard errors) for divers observed by season at the Fall of Warness.

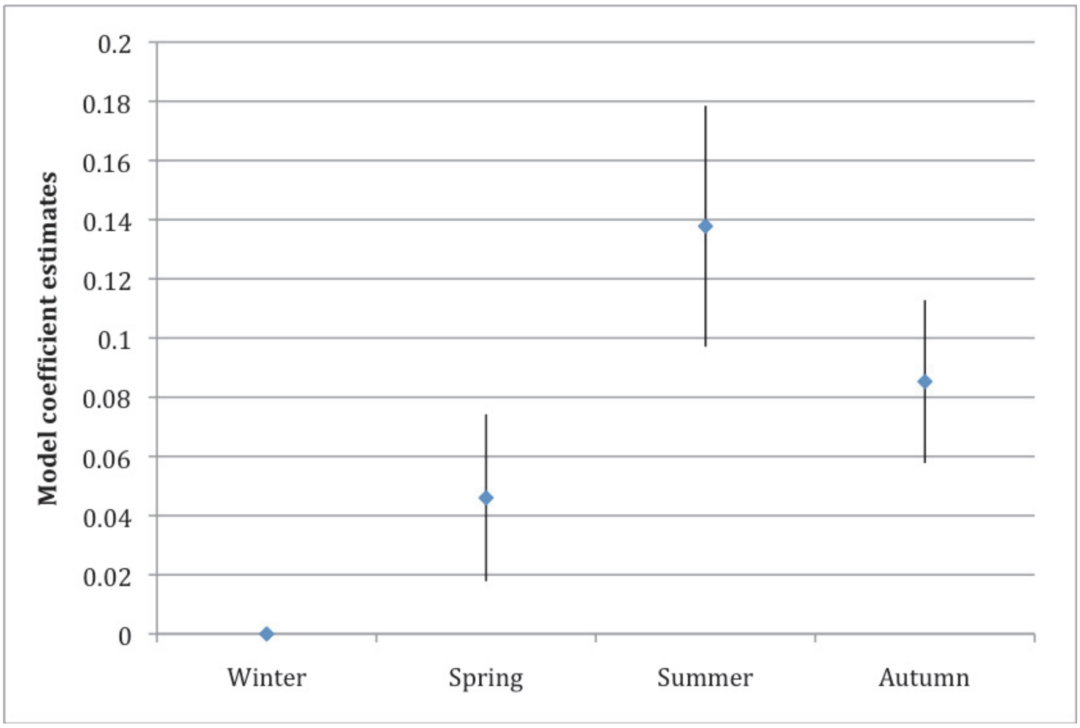


Figure 9: The proportion of divers observed by season at the Fall of Warness.

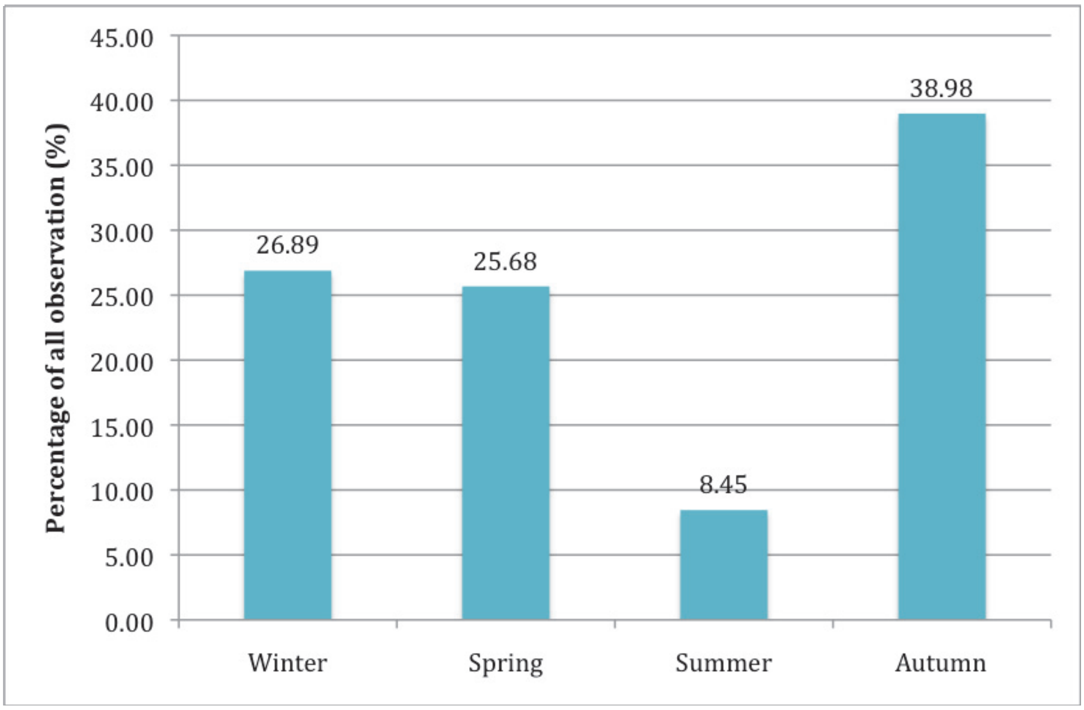


Figure 10: GEE coefficient estimates (and standard errors) for divers observed by tidal state at the Fall of Warness.

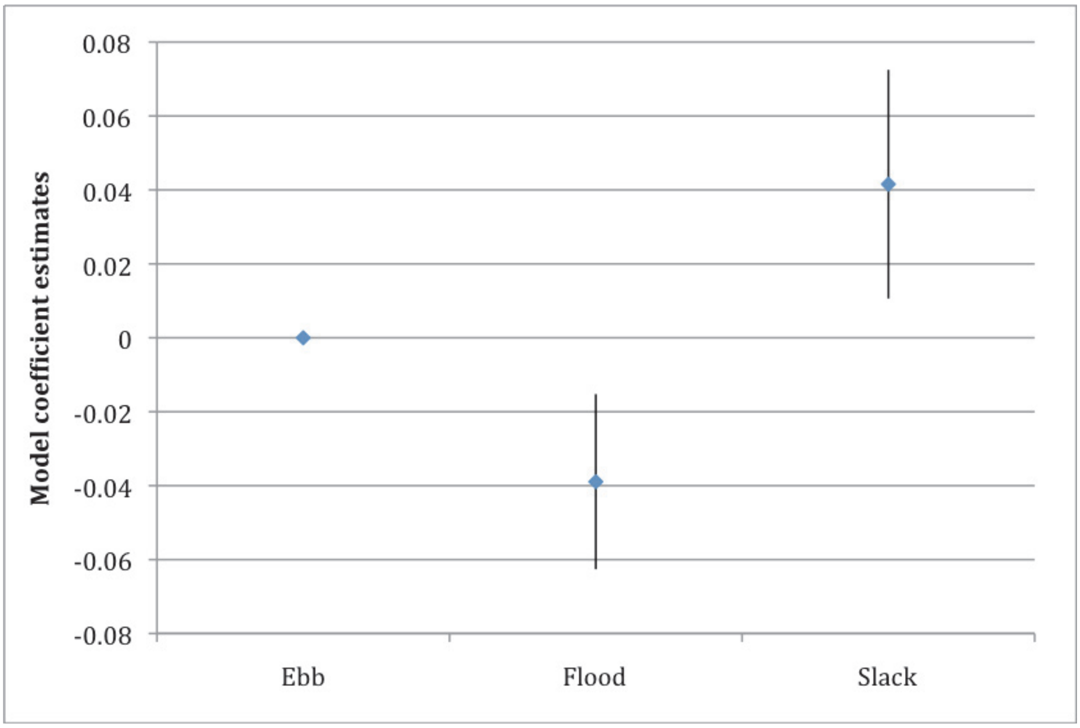


Figure 11: The proportion of divers observed by tidal state at the Fall of Warness.

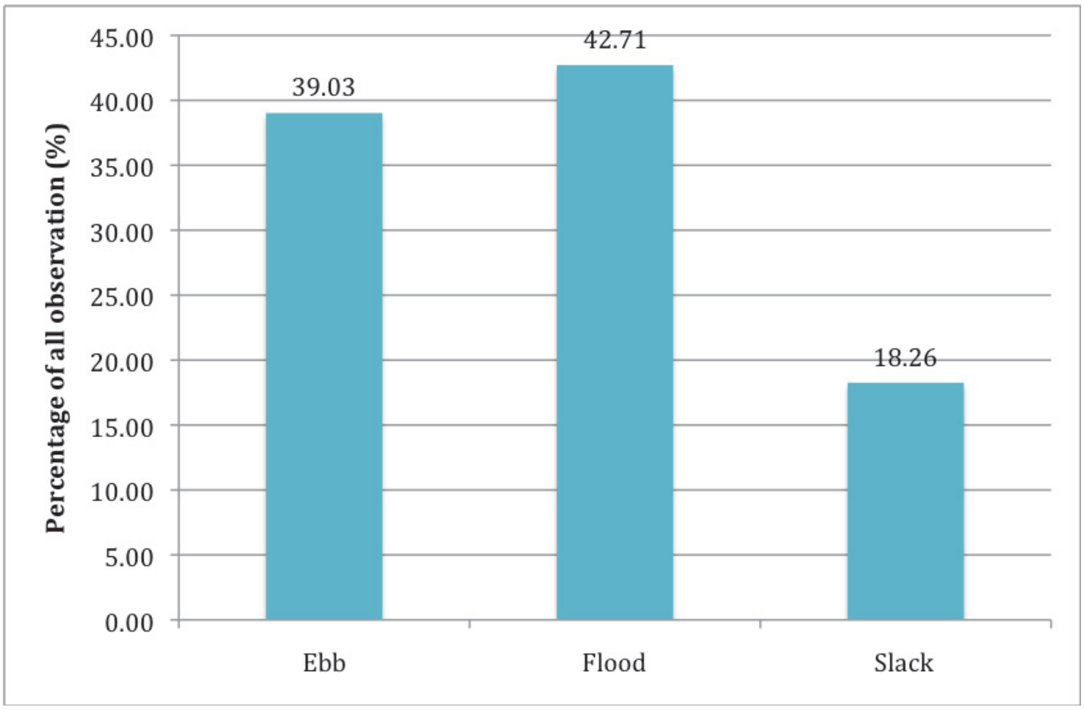


Figure 12: Mean number of divers observed per hour throughout the day at the Fall of Warness.

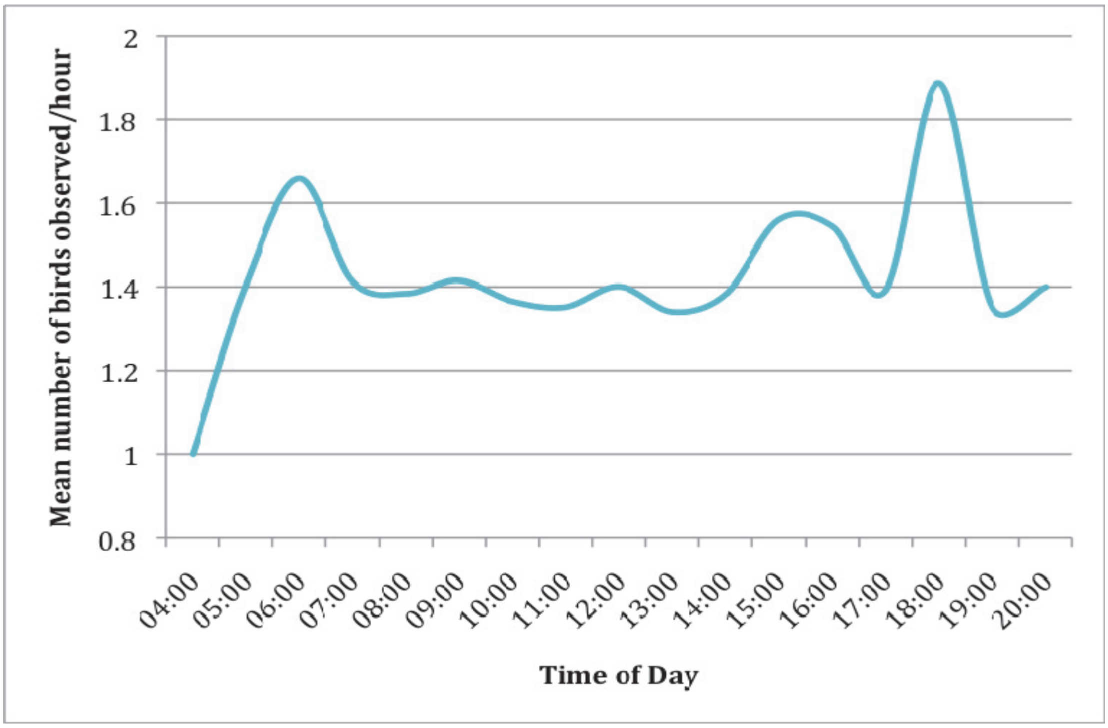


Figure 13: The proportion of observations diver were observed at different depths at the Fall of Warness.

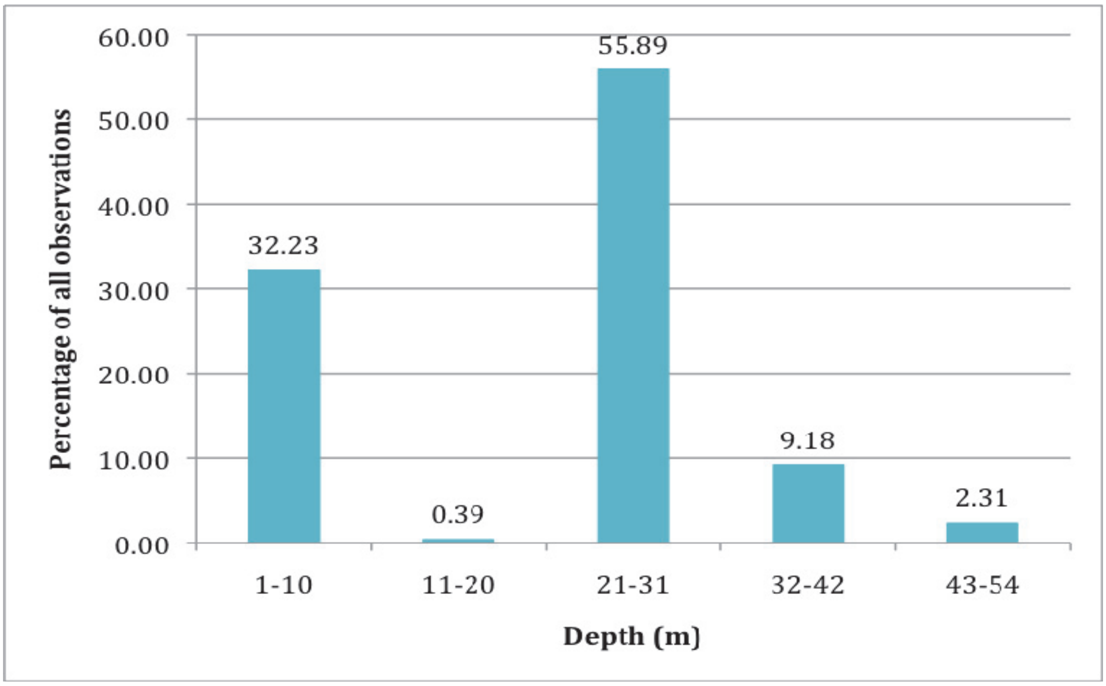
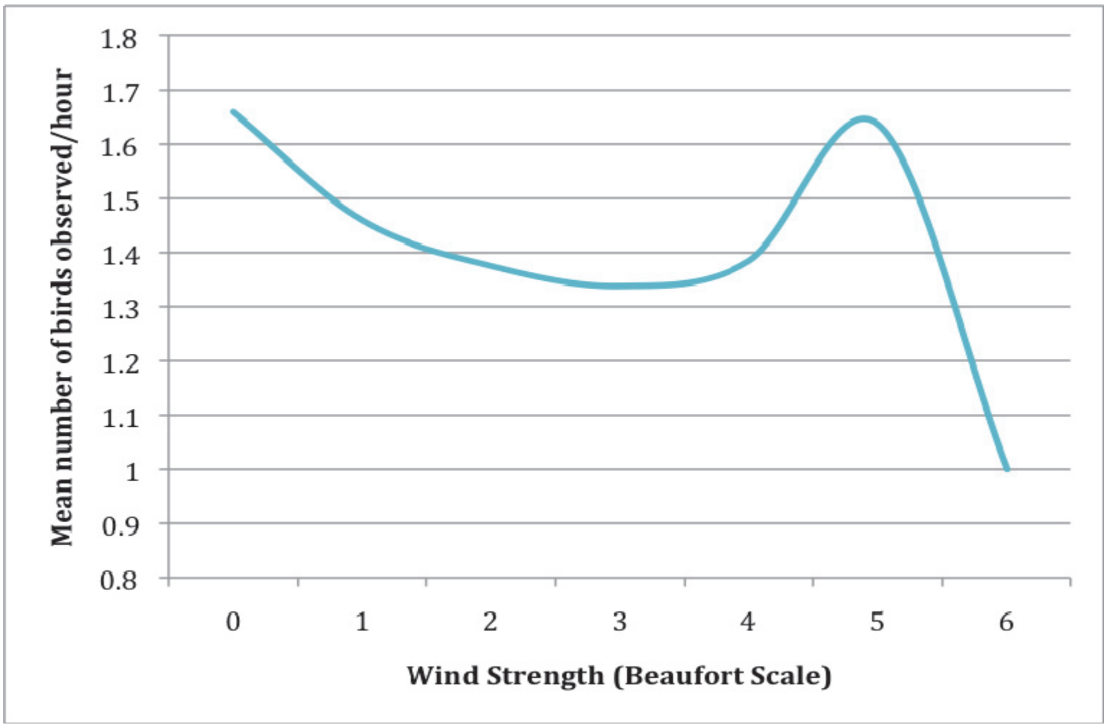


Figure 14: Mean number of diver observed per hour during different wind strengths, using the Beaufort Scale, at the Fall of Warness.



Northern Gannet

Table 6: The top 5 GLMM models, as selected by AIC values, for modelling gannet use of the Fall of Warness.

Model	Df	AIC
Season + habitat type + tide state	8	6026
Season + habitat type + tide state + cloud cover	9	6027
Season + habitat type + depth + tide state + cloud cover	10	6028
Season + time of day + habitat type + depth + tide state + cloud cover	11	6030
Season + time of day + habitat type + depth + wind strength + tide state + cloud cover	12	6031

Table 7: Parameter estimates, standard errors, probability values for GEE investigating gannet counts as a function of season, habitat type and tide state.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.22111	0.03312	44.57	2.50E-11	***
Spring	0.00877	0.05241	0.03	0.867	
Summer	0.51166	0.05503	86.46	<2.00E-16	***
Autumn	0.44116	0.03756	137.92	<2.00E-16	***
Pelagic	0.28083	0.05795	23.48	1.30E-06	***
Flood	0.0075	0.04446	0.03	0.8661	
Slack	-0.12617	0.04685	7.25	0.0071	**

Figure 15: GEE coefficient estimates (and standard errors) for gannets observed by season at the Fall of Warness.

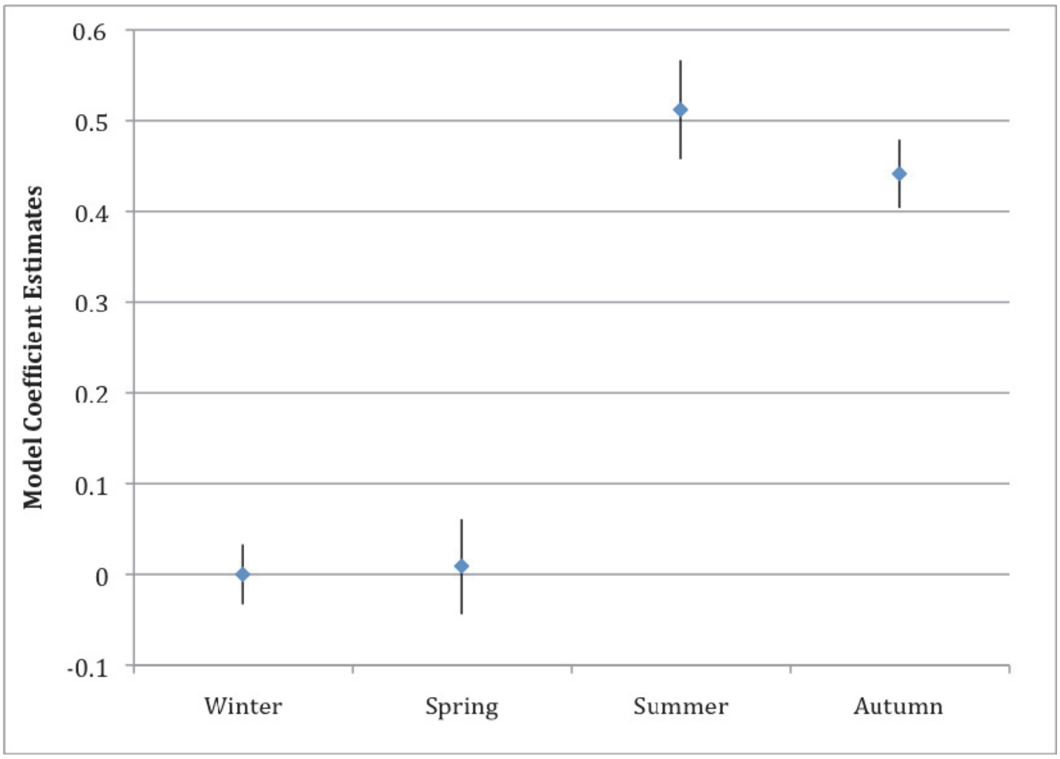


Figure 16: GEE coefficient estimates (and standard errors) for gannets observed by tidal state at the Fall of Warness.

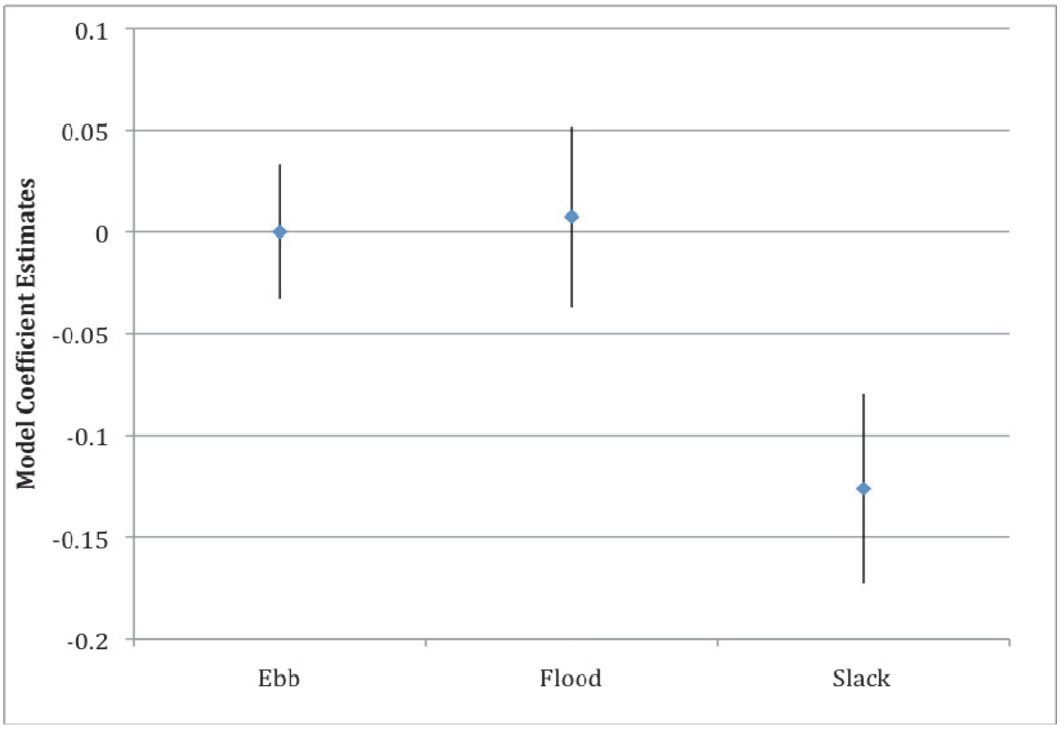


Figure 17: The proportion of gannets observed by tidal state at the Fall of Warness.

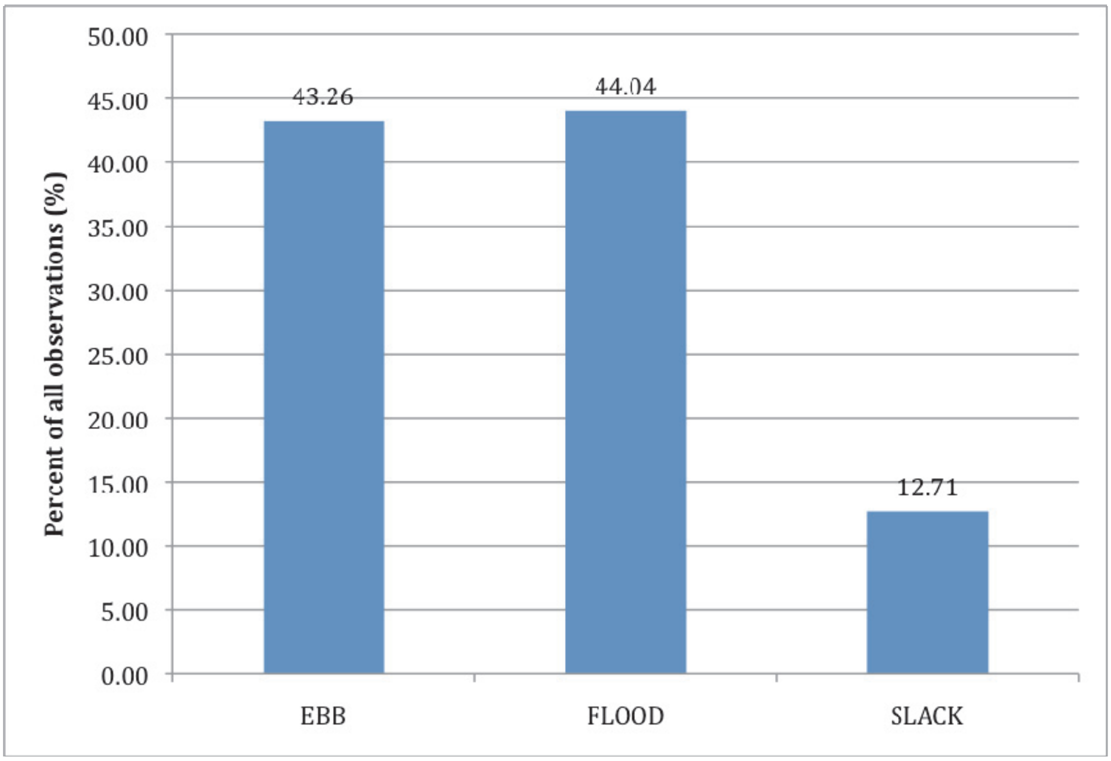


Figure 18: Mean number of gannets observed per hour throughout the day at the Fall of Warness (excluding 04:00, 21:00 and 22:00 as gannets had only been seen in single observations).

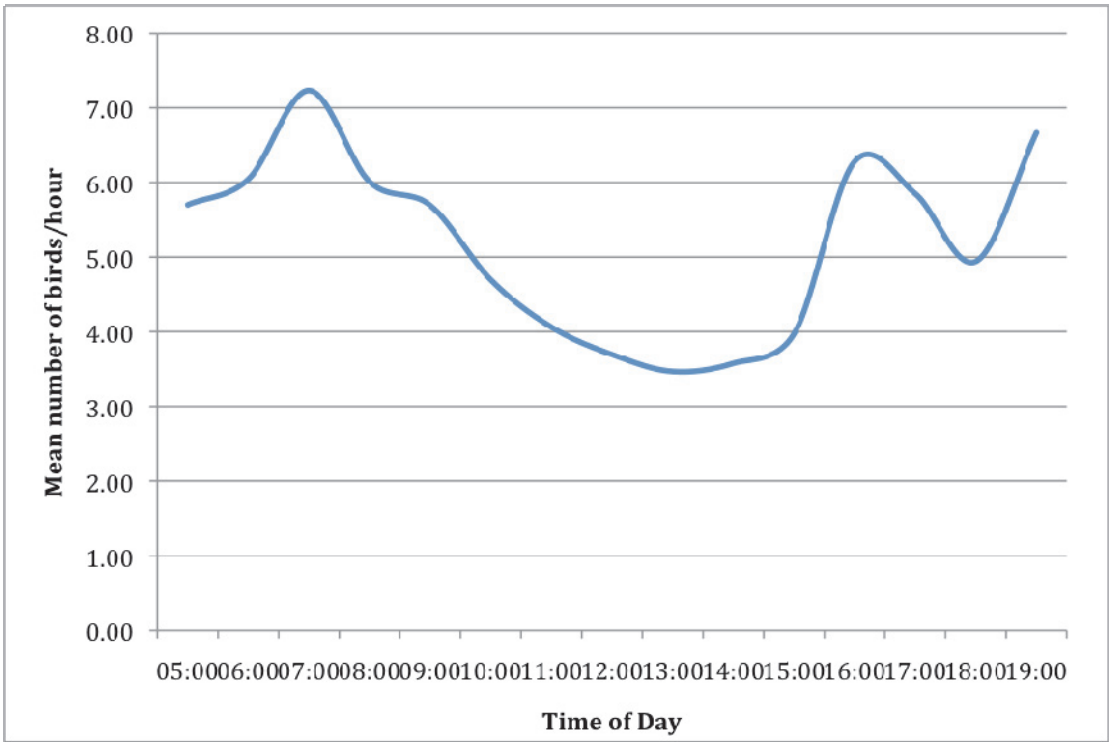
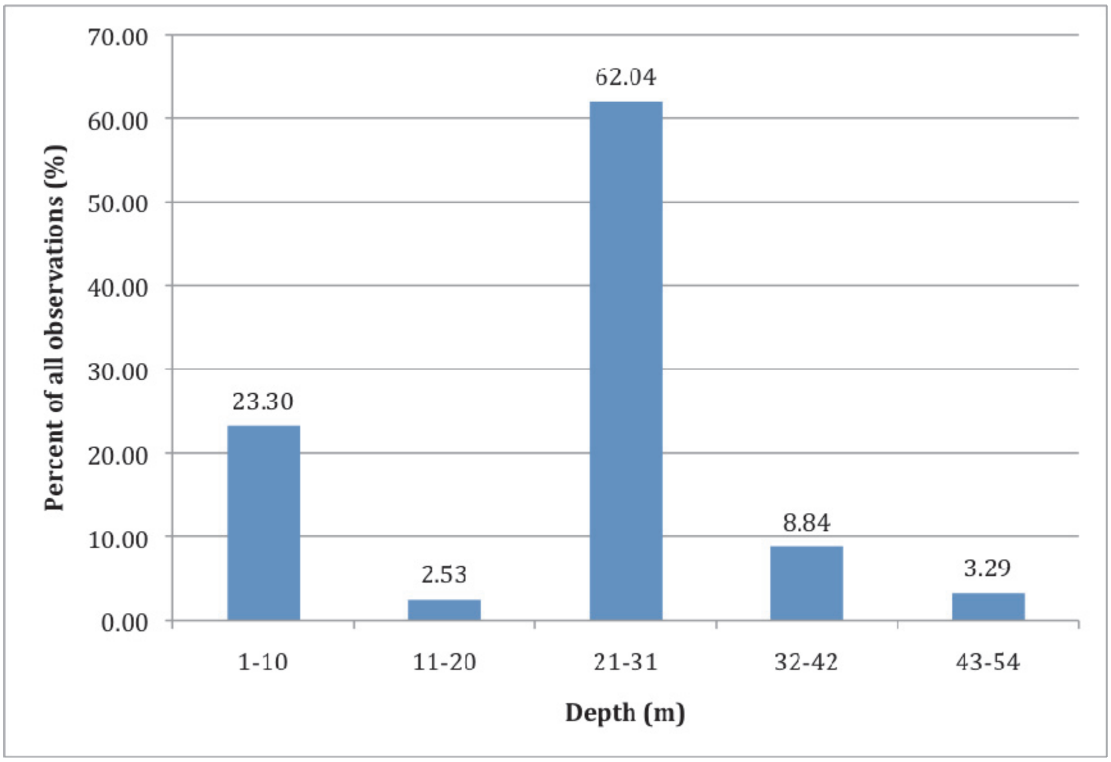


Figure 19: The proportion of observations gannet observed at different depths at the Fall of Warness.



Cormorants

Table 8: The top 5 GLMM models, as selected by AIC values, for modelling *Phalacrocorax spp.* use of the Fall of Warness.

Model	Df	AIC
*Season + time of day*tide state + depth + habitat type + wind strength + cloud cover*	14	132881
*Season + time of day*tide state + depth + habitat type + wind strength + precipitation + cloud cover*	15	132882
Season + time of day + depth + habitat type + tide state + wind direction + precipitation + cloud cover	17	132920
Season + time of day + depth + habitat type + tide state + wind strength + cloud cover	12	132983
Season + time of day + depth + habitat type + tide state + wind strength + precipitation + cloud cover	13	132984

Table 9: Parameter estimates, standard errors, probability values for GEE investigating *Phalacrocorax spp.* counts as a function of season, time of day*tidal state, depth, habitat type, wind strength and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	3.23055	0.12499	668.03	<2.00E-16	***
Spring	-1.03995	0.04698	489.91	<2.00E-16	***
Summer	-1.43267	0.05081	794.94	<2.00E-16	***
Autumn	0.07514	0.05067	2.2	0.1381	*
Time of Day	-0.05051	0.00841	36.08	1.90E-09	***
Flood	-0.09722	0.15366	0.4	0.5269	
Slack	-0.21697	0.20434	1.13	0.2883	
Depth	-0.0213	0.00203	110.26	<2.00E-16	***
Pelagic	-0.06708	0.07167	0.88	0.3493	
Wind Strength	-0.04697	0.01894	6.15	0.0132	**
Cloud Cover	0.00222	0.0007	10.04	0.0015	***
Time of Day*Flood	-0.01456	0.01282	1.29	0.256	
Time of Day*Slack	0.00101	0.01632	0	0.9504	

Figure 20: GEE coefficient estimates (and standard errors) for *Phalacrocorax spp.* observed by season at the Fall of Warness.

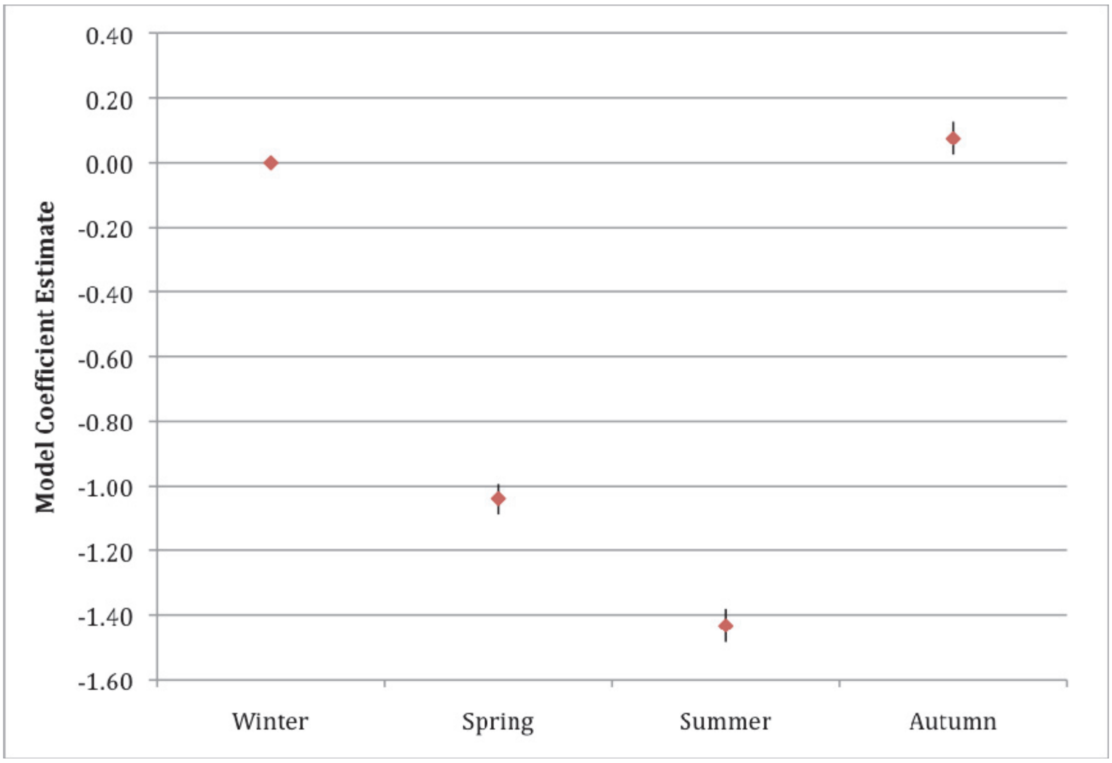


Figure 21: GEE coefficient estimates (and standard errors) for *Phalacrocorax spp.* observed by tidal state at the Fall of Warness.

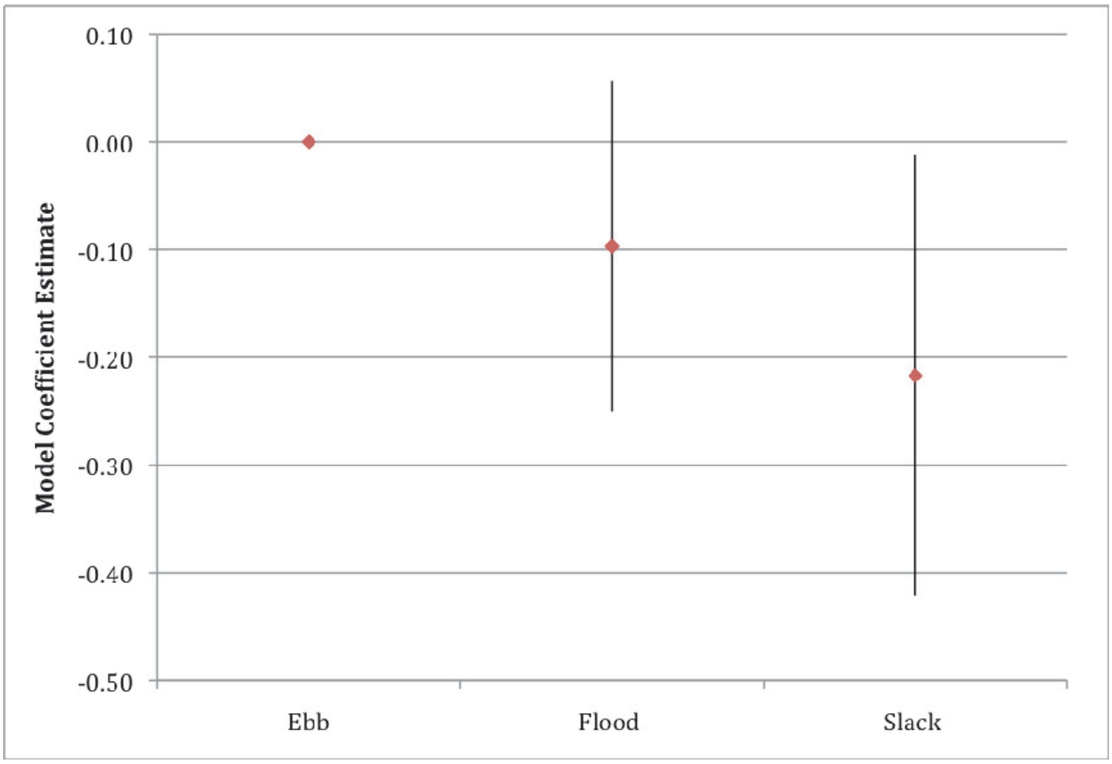


Figure 22: Mean number of *Phalacrocorax spp.* observed per hour, throughout the day at the Fall of Warness by ebb, flood and slack tidal states.

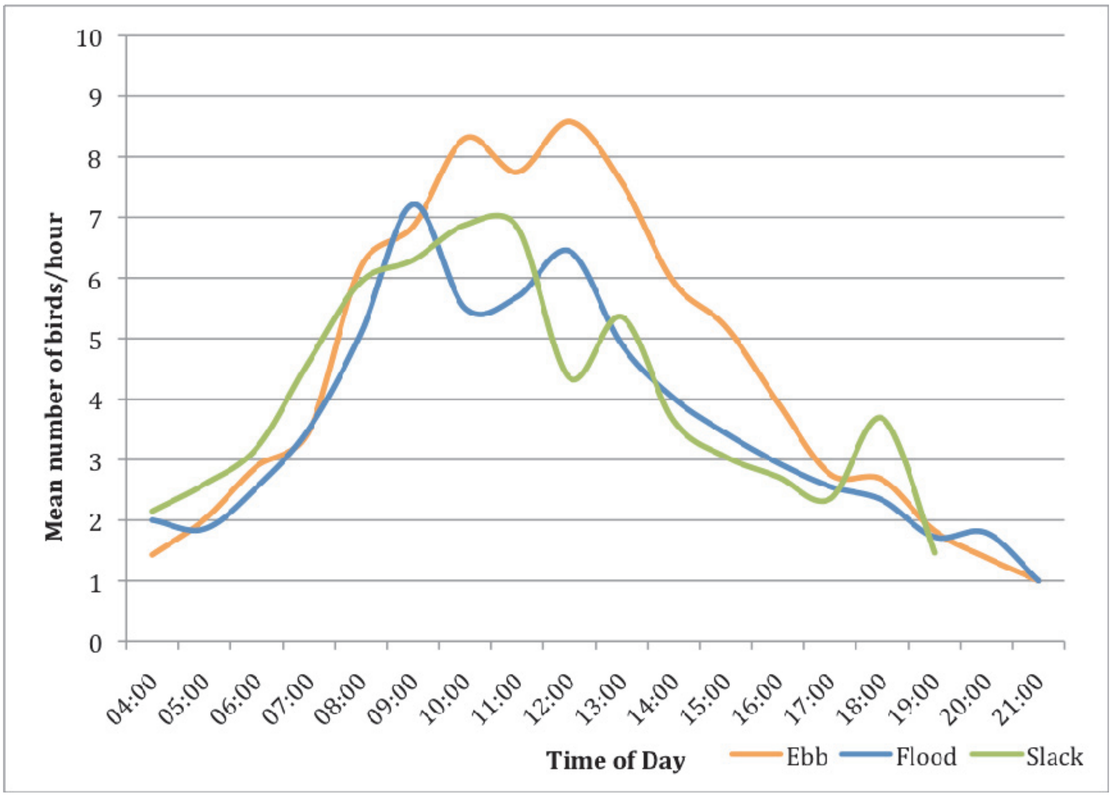


Figure 23: The proportion of observations *Phalacrocorax spp.* observed at different depths at the Fall of Warness.

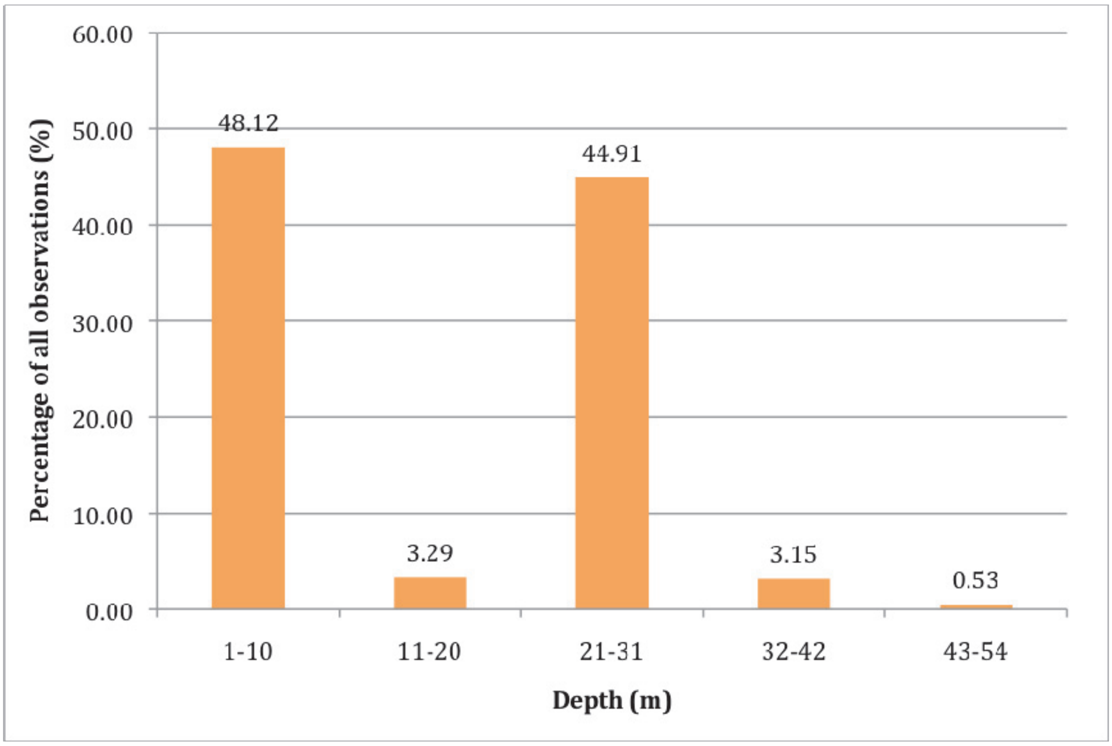


Figure 24: Mean number of *Phalacrocorax spp.* observed per hour during different wind strengths, using the Beaufort Scale, at the Fall of Warness.

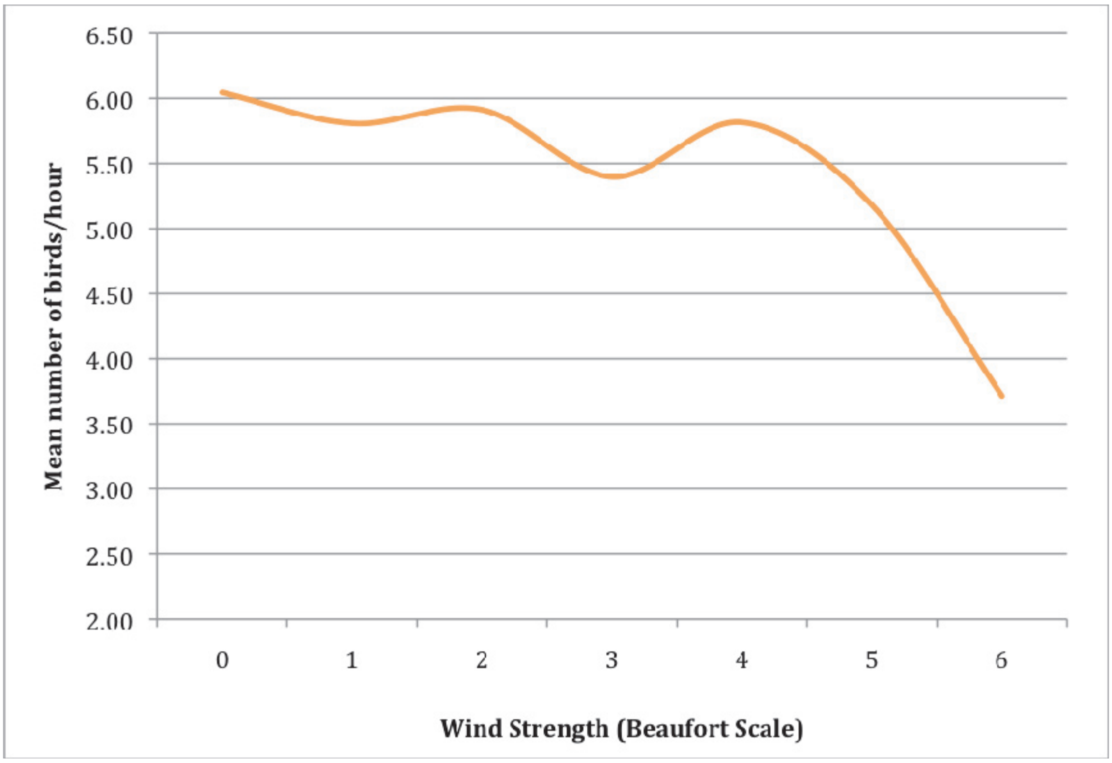
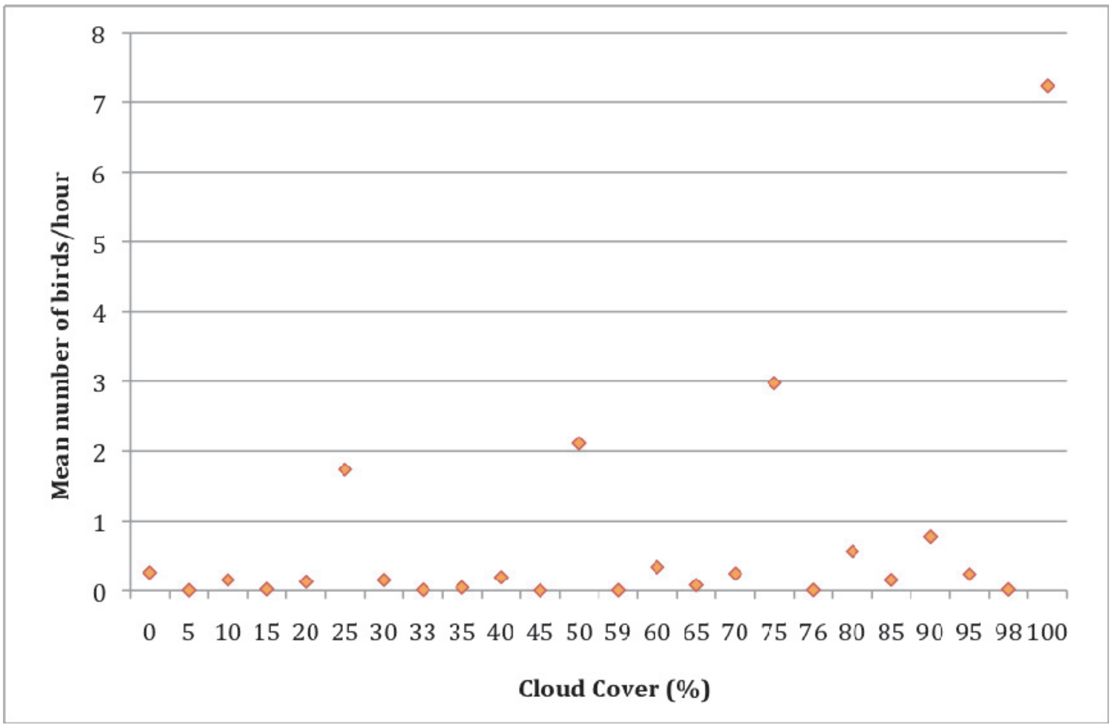


Figure 25: Mean number of *Phalacrocorax spp.* observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Guillemot

Table 10: The top 5 GLMM models, as selected by AIC values, for modelling guillemot use of the Fall of Warness.

Model	Df	AIC
Season + time of day + habitat type + wind direction + tide state + precipitation + cloud cover	16	34975
Season + time of day + depth + habitat type + wind direction + tide state + precipitation + cloud cover	17	34975
Season + time of day + habitat type + tide state + precipitation + wind direction	15	34992
*Season + time of day*tide state + depth + habitat type + wind strength + precipitation + cloud cover*	15	35985
Season + time of day + habitat type + tide state + wind direction	14	35472

Table 11: Parameter estimates, standard errors, probability values for GEE investigating guillemot counts as a function of season, time of day, habitat type, wind direction, tidal state, precipitation and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	-0.4524	0.43828	1.07	0.302	
Spring	1.97919	0.15543	162.14	<2e-16	***
Summer	1.94014	0.13549	205.05	<2e-16	***
Autumn	-0.12489	0.10986	1.29	0.256	
Time of Day	-0.01099	0.01932	0.32	0.57	
Pelagic	1.38857	0.14841	87.54	<2e-16	***
Wind Dir None	-0.67984	0.28525	5.68	0.017	*
Wind Dir North	-0.32021	0.21244	2.27	0.132	
Wind Dir South	0.3448	0.21848	2.49	0.115	
Wind Dir Variable	0.52023	0.31009	2.81	0.093	.
Wind Dir West	-0.61842	0.24004	6.64	0.01	**
Flood	0.2966	0.16072	3.41	0.065	.
Slack	-0.36078	0.15707	5.28	0.022	*
Precipitation	0.03005	0.2187	0.02	0.891	
Cloud Cover	0.00342	0.00213	2.58	0.108	

Figure 25: GEE coefficient estimates (and standard errors) for guillemots observed by season at the Fall of Warness.

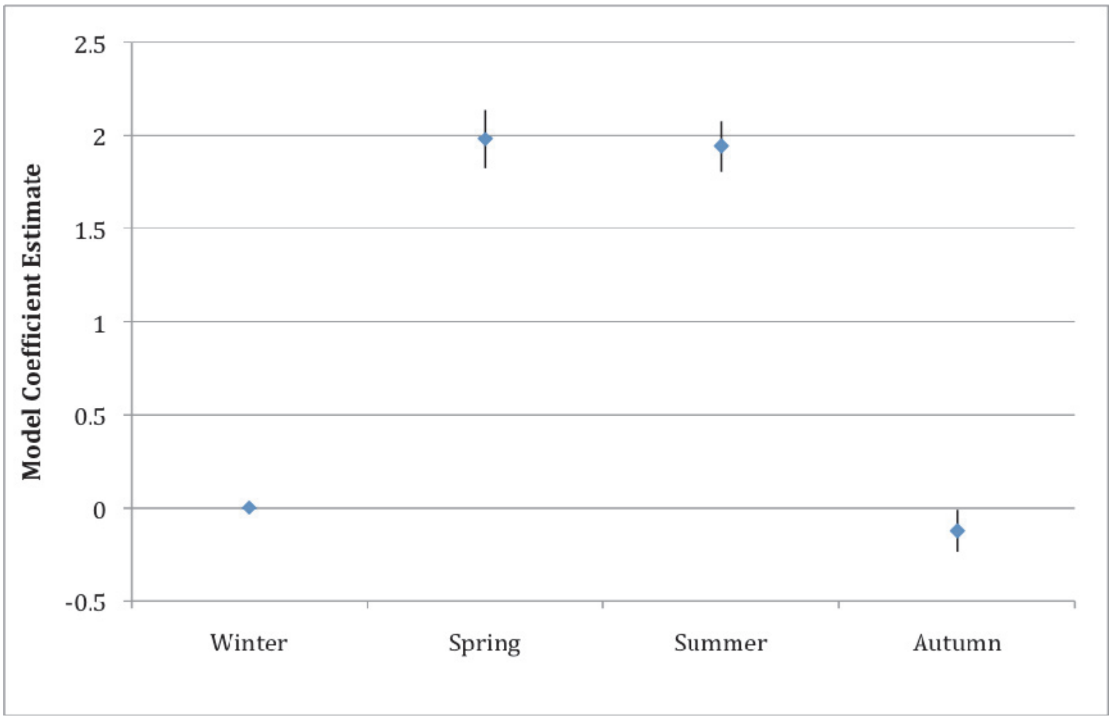


Figure 26: Mean number of guillemots observed per hour throughout the day at the Fall of Warness.

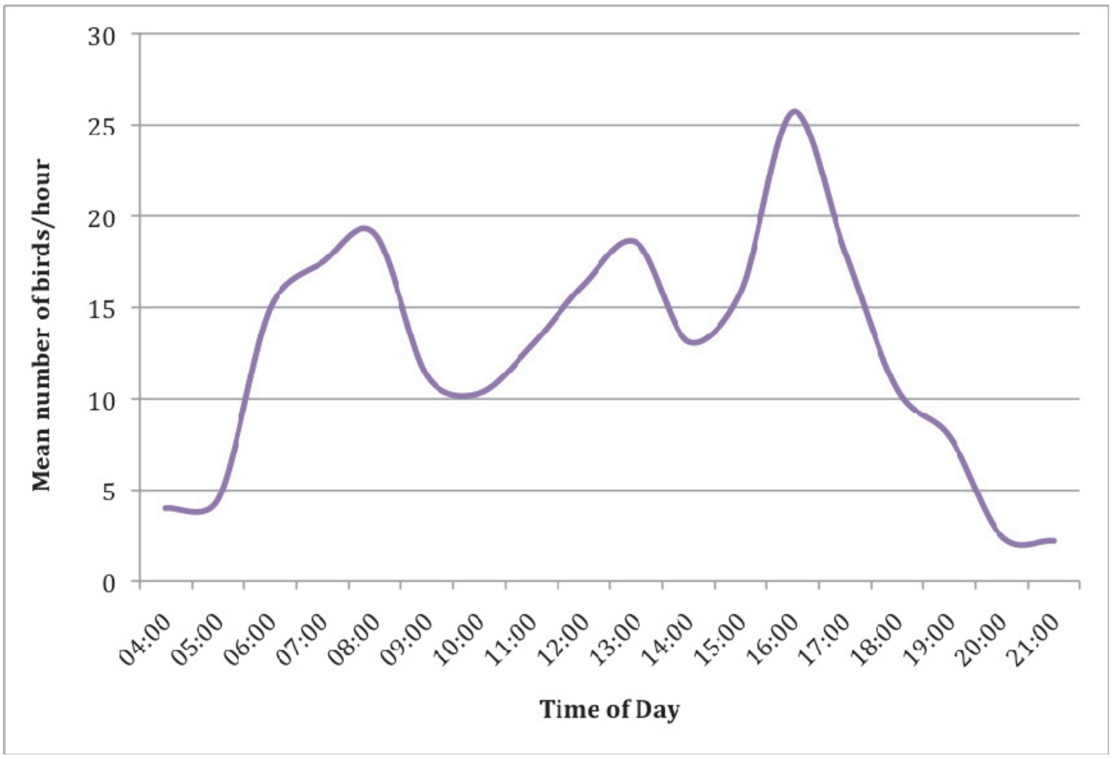


Figure 27: The proportion of observations guillemots observed in different pelagic and coastal habitats at the Fall of Warness.

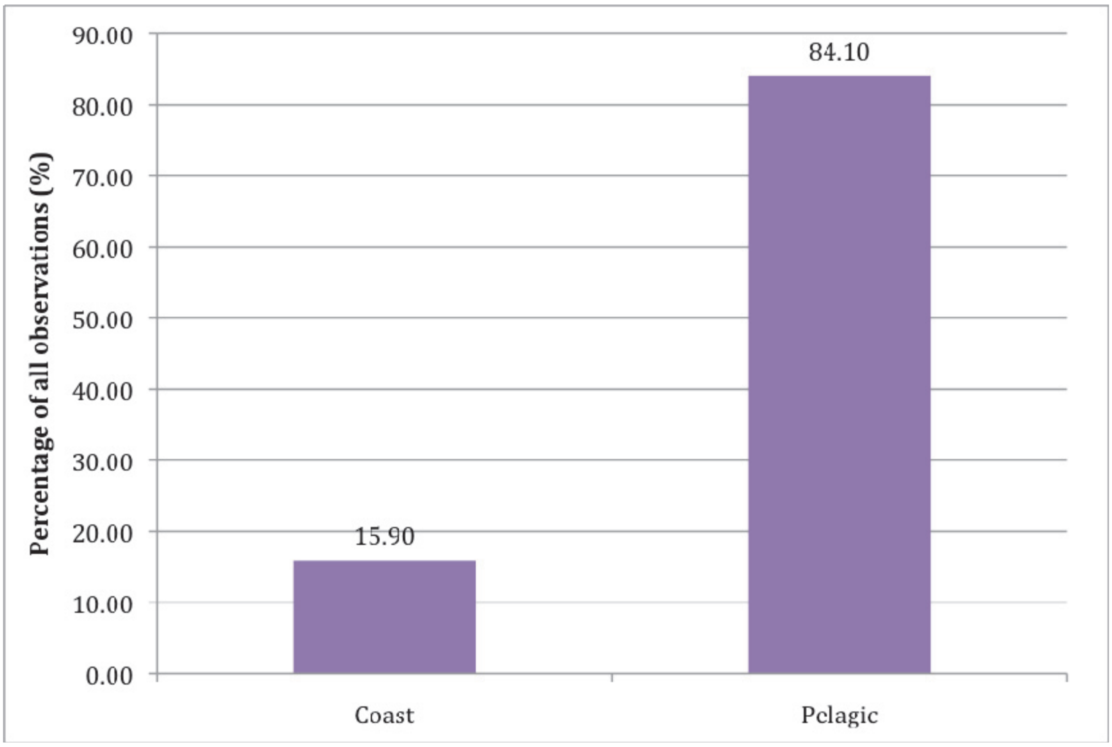


Figure 28: GEE coefficient estimates (and standard errors) for guillemots observed with different wind directions at the Fall of Warness.

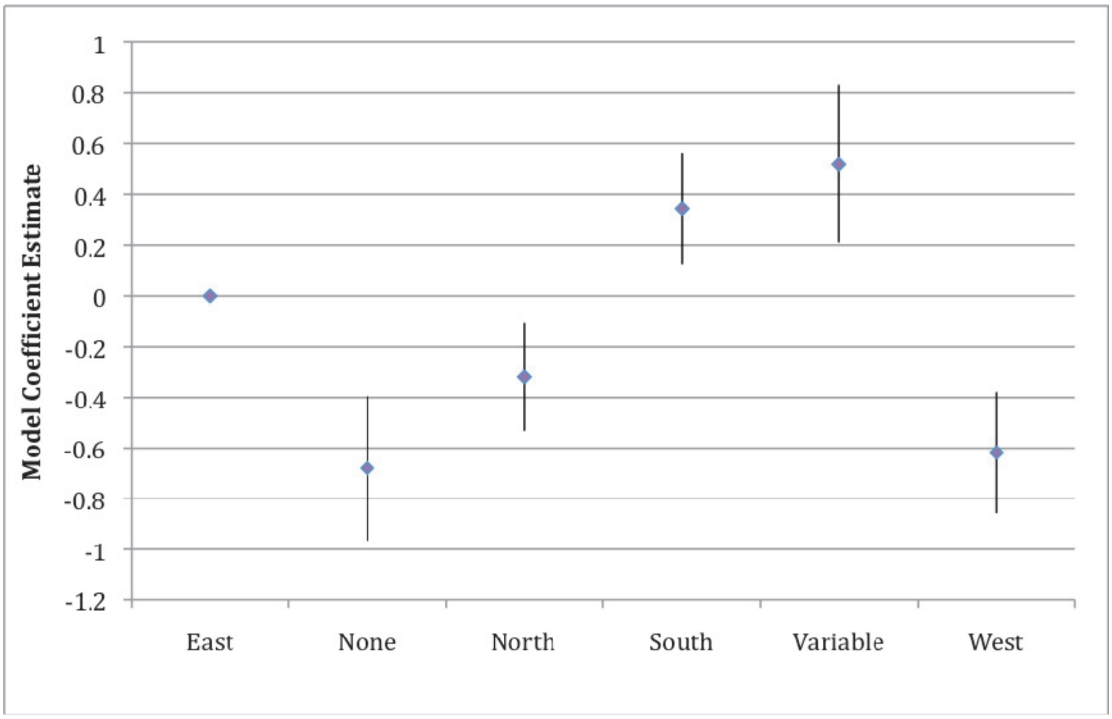


Figure 29: GEE coefficient estimates (and standard errors) for guillemots observed by tidal state at the Fall of Warness.

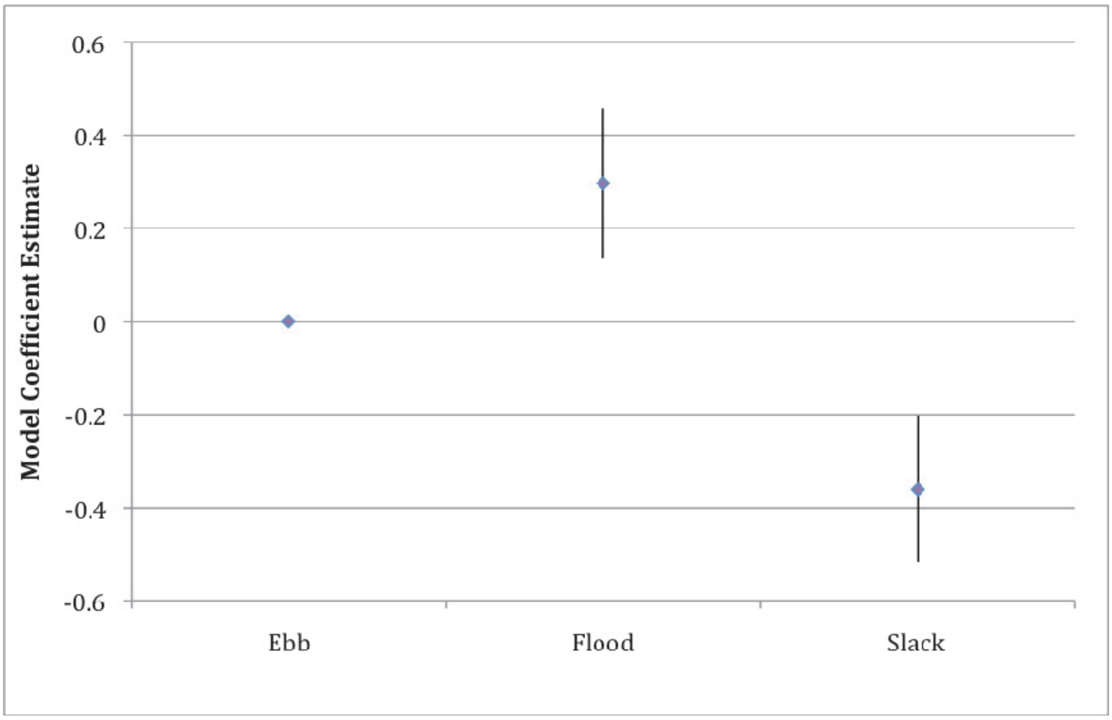
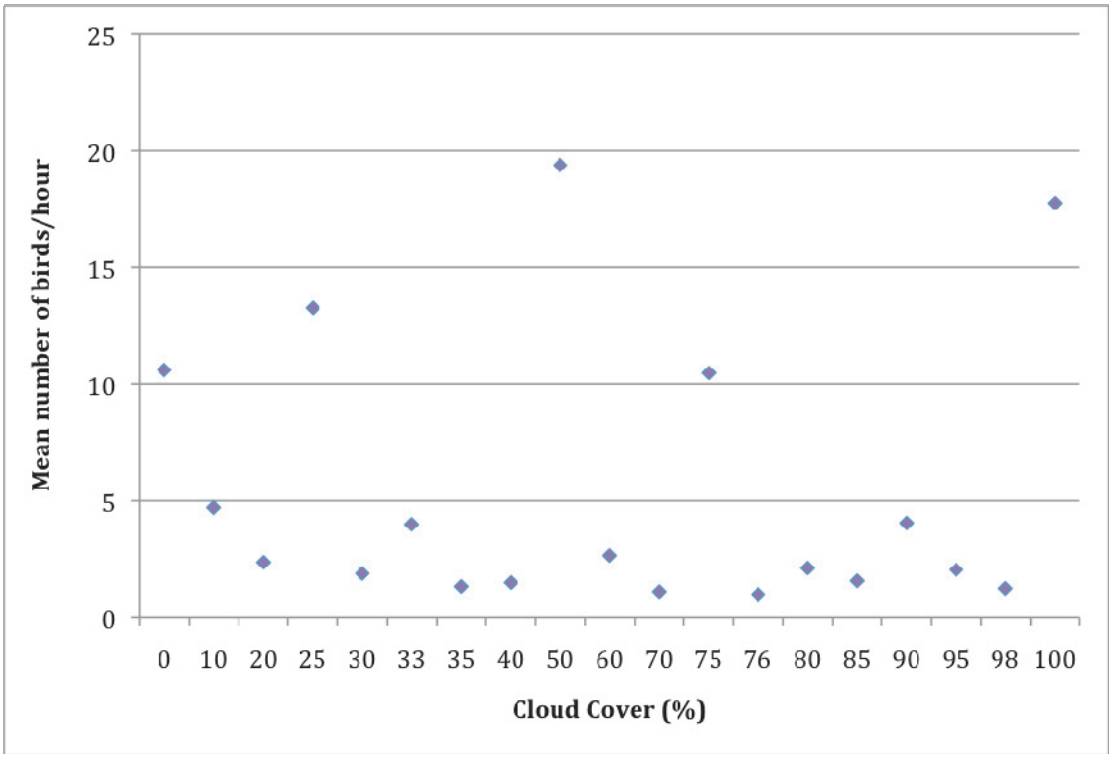


Figure 30: Mean number of guillemots observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Razorbill

Table 12: The top 5 GLMM models, as selected by AIC values for modelling razorbills use of the Fall of Warness.

Model	Df	AIC
Season + time of day + depth + habitat type + wind direction + tide state + precipitation + cloud cover	17	750
Season + time of day + habitat type + wind direction + tide state + precipitation + cloud cover	16	751
Season + time of day + habitat type + wind direction + tide state	14	755
Season + time of day + habitat type + wind direction + precipitation	15	757
Season + time of day + depth + wind direction + tide state + precipitation + cloud cover	16	765

Table 13: Parameter estimates, standard errors, probability values for GEE investigating razorbills counts as a function of season, time of day, habitat type, wind direction, tidal state, precipitation and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	-2.7454	1.0299	7.11	0.00768	**
Spring	0.9363	0.4055	5.33	0.02093	*
Summer	0.0372	0.4537	0.01	0.93463	
Autumn	-0.3689	0.4816	0.59	0.44362	
Time of Day	0.0659	0.0535	1.52	0.21826	
Pelagic	1.2334	0.203	36.91	1.20E-09	***
Wind Dir None	1.4526	0.4412	10.84	0.00099	***
Wind Dir North	-0.7294	0.3462	4.44	0.03515	*
Wind Dir South	-0.7111	0.3338	4.54	0.03314	*
Wind Dir Variable	-0.4395	0.5374	0.67	0.41345	
Wind Dir West	-1.12	0.4758	5.54	0.01858	*
Flood	1.0937	0.2847	14.76	0.00012	***
Slack	0.3681	0.2857	1.66	0.19759	
Precipitation	0.3396	0.3088	1.21	0.27154	
Cloud Cover	0.0209	0.0048	18.99	1.30E-05	***

Figure 31: GEE coefficient estimates (and standard errors) for razorbills observed by season at the Fall of Warness.

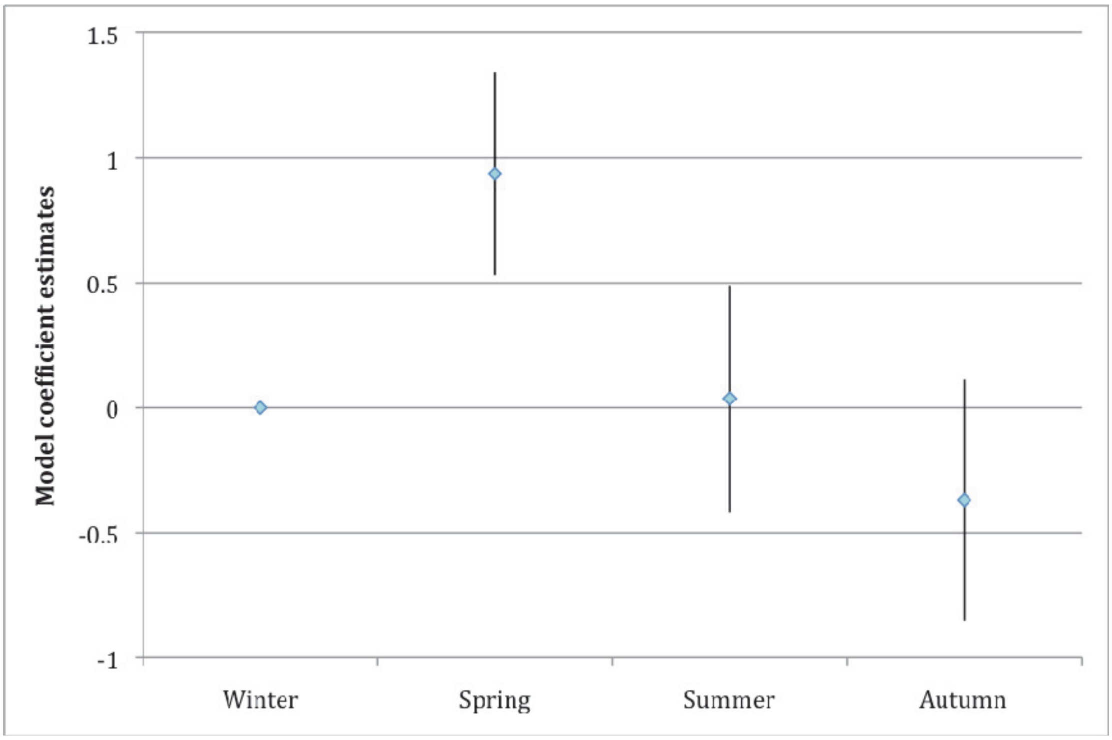


Figure 32: Mean number of razorbills observed per hour, throughout the day at the Fall of Warness.

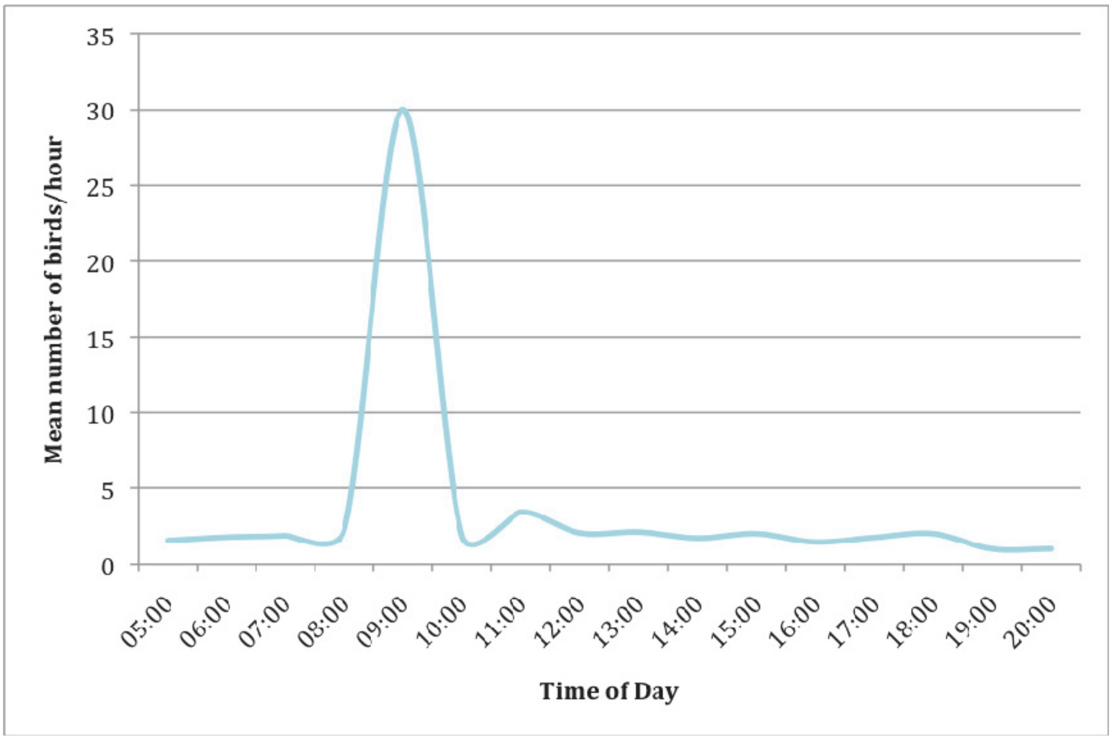


Figure 33: GEE coefficient estimates (and standard errors) for razorbills observed in coastal and pelagic habitats, at the Fall of Warness.

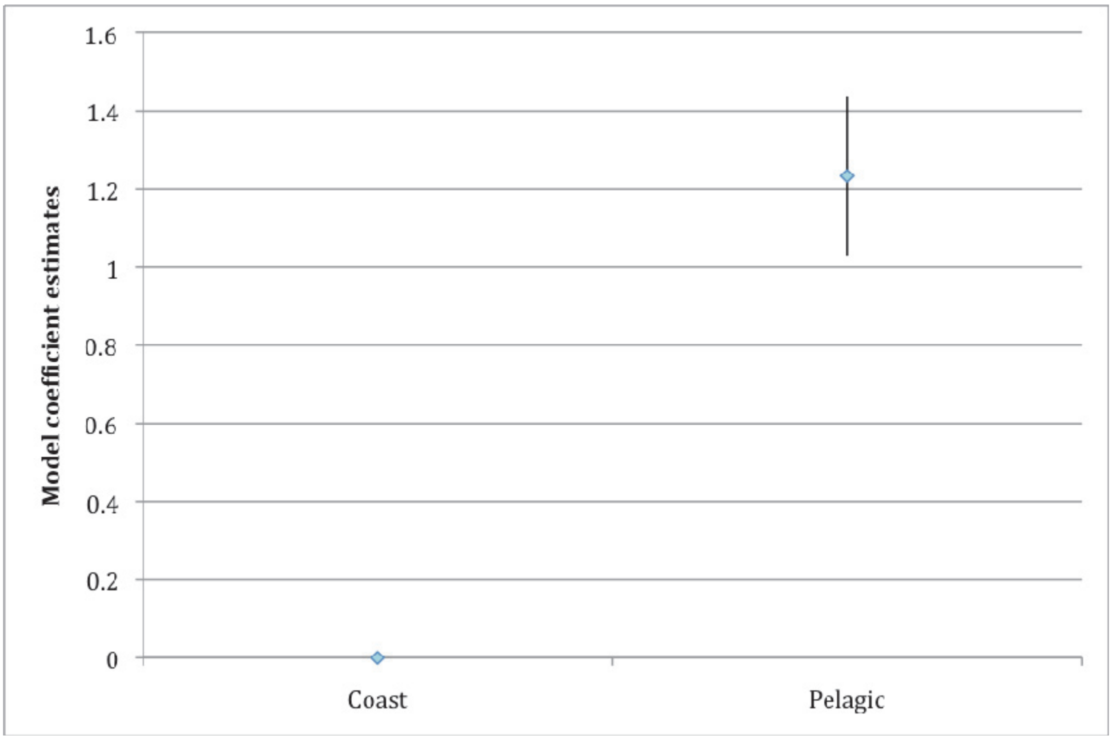


Figure 34: GEE coefficient estimates (and standard errors) for razorbills observed with different wind directions at the Fall of Warness.

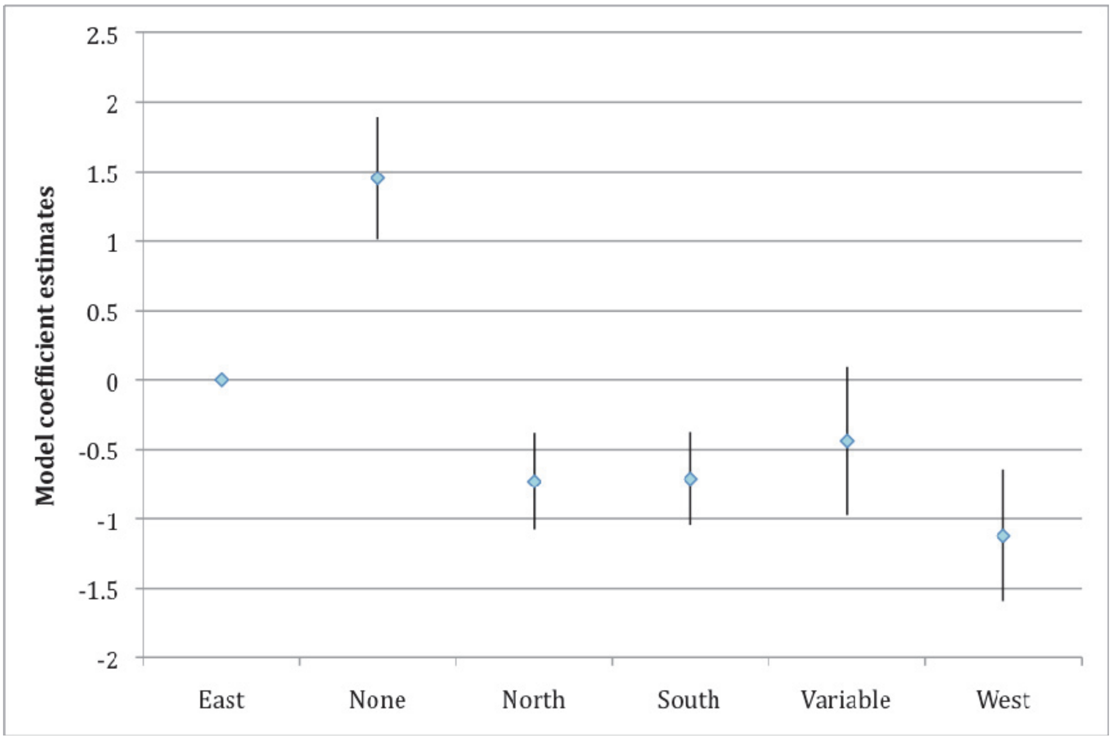
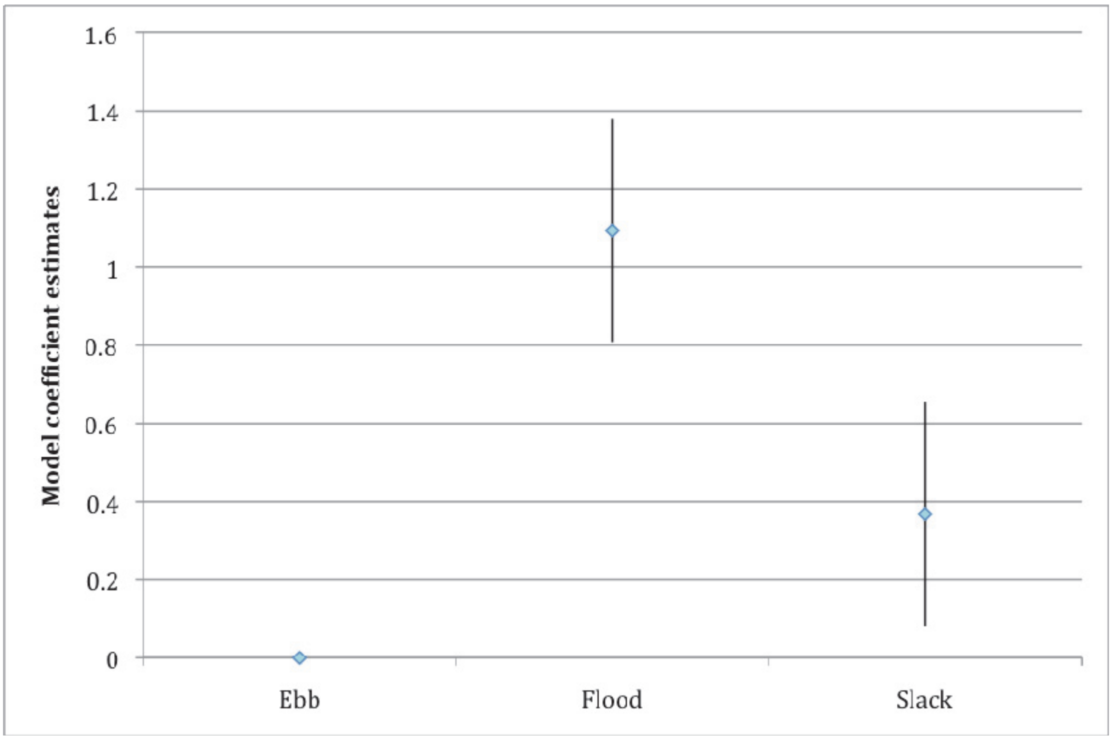


Figure 35: GEE coefficient estimates (and standard errors) for razorbills observed by tidal state, at the Fall of Warness.



Black Guillemot

Table 14: The top 5 GLMM models, as selected by AIC values, for modelling black guillemots use of the Fall of Warness.

Model	Df	AIC
*Season + time of day*tide state + depth + habitat type + wind strength + precipitation + cloud cover*	15	39720
Season + time of day + tide state + depth + habitat type + wind strength + precipitation + cloud cover	13	39770
Season + time of day + tide state + depth + habitat type + wind strength + cloud cover	12	39771
Season + time of day + tide state + depth + habitat type + wind direction + precipitation + cloud cover	17	39929
Season + time of day + habitat type + tide state + precipitation + wind strength	11	39935

Table 15: Parameter estimates, standard errors, probability values for GEE investigating black guillemot counts as a function of season, time of day*tidal state, depth, habitat type, wind strength, precipitation and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	3.021314	0.085964	1235.27	<2.00E-16	***
Spring	0.474125	0.047848	98.19	<2.00E-16	***
Summer	0.117568	0.04888	5.79	0.01616	*
Autumn	-0.166884	0.057867	8.32	0.00393	**
Time of Day	-0.119139	0.005556	459.84	<2.00E-16	***
Flood	-0.445485	0.079263	31.59	1.90E-08	***
Slack	0.030022	0.096358	0.1	0.75537	
Depth	-0.012933	0.001417	83.29	<2.00E-16	***
Pelagic	-0.274787	0.038852	50.02	1.50E-12	***
Wind Strength	-0.09639	0.014489	44.26	2.90E-11	***
Precipitation	0.029342	0.028613	1.05	0.30513	
Cloud Cover	0.001464	0.000399	13.44	0.00025	***
Time of Day*Flood	0.038906	0.007624	26.04	3.30E-07	***
Time of Day*Slack	-0.009054	0.009494	0.91	0.34026	

Figure 36: GEE coefficient estimates (and standard errors) for black guillemots observed by season at the Fall of Warness.

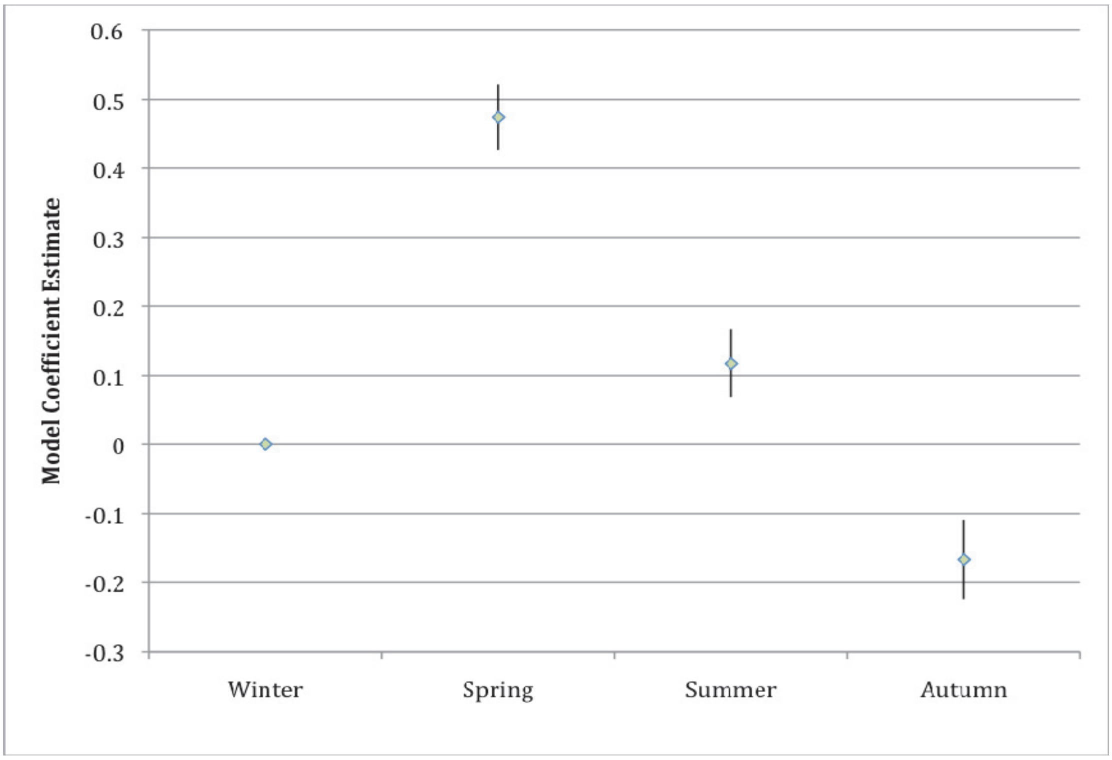


Figure 37: Mean number of black guillemots observed per hour throughout the day at the Fall of Warness.

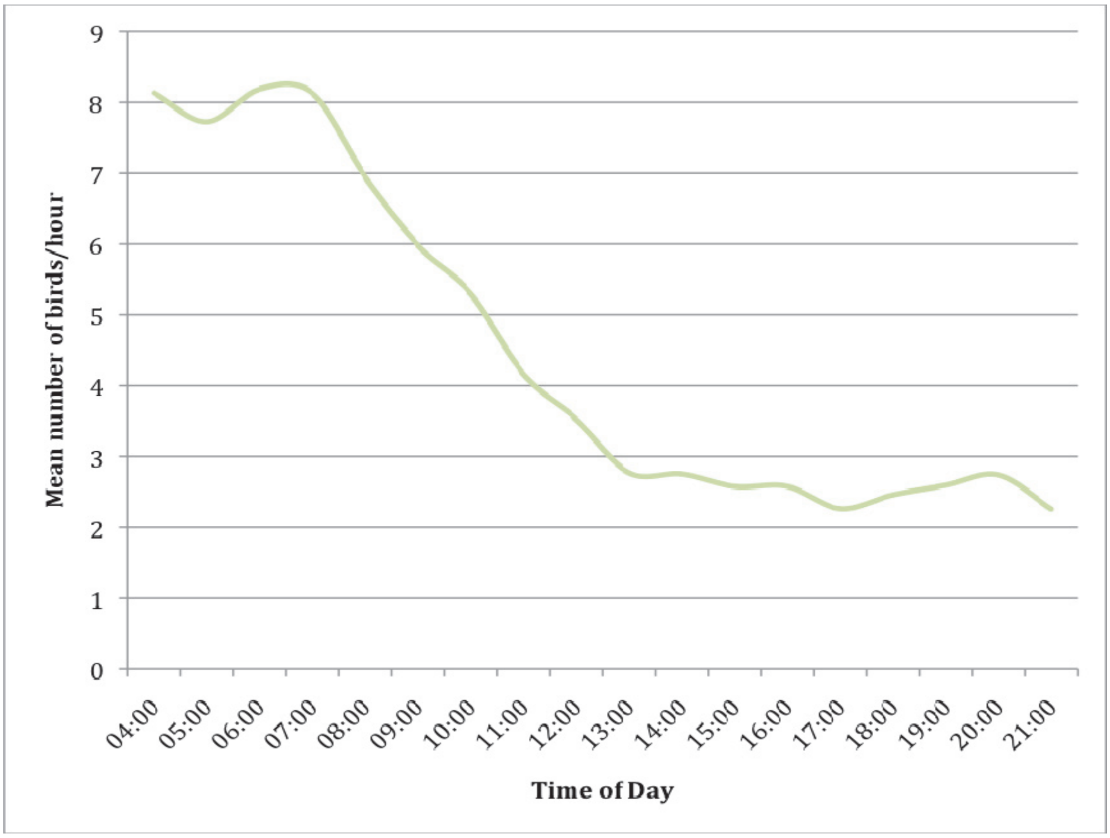


Figure 38: Mean number of black guillemots observed per hour, throughout the day at the Fall of Warness by ebb, flood and slack tidal states.

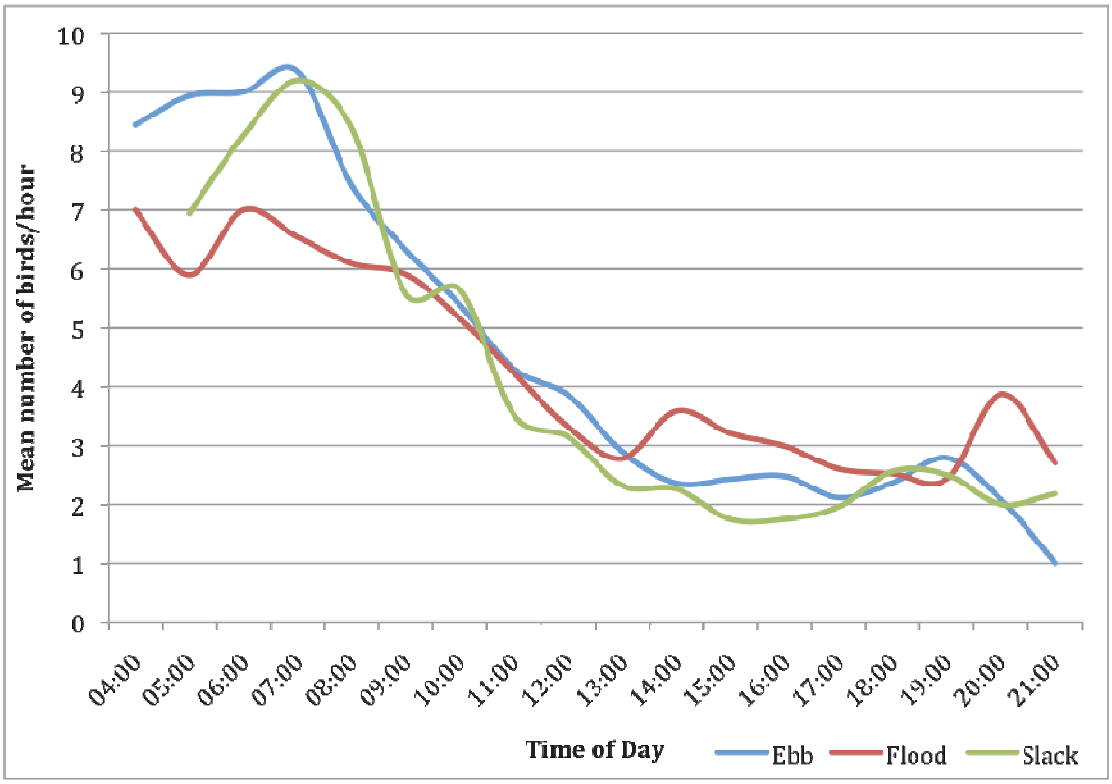


Figure 39: GEE coefficient estimates (and standard errors) for black guillemots observed in coastal and pelagic habitats at the Fall of Warness.

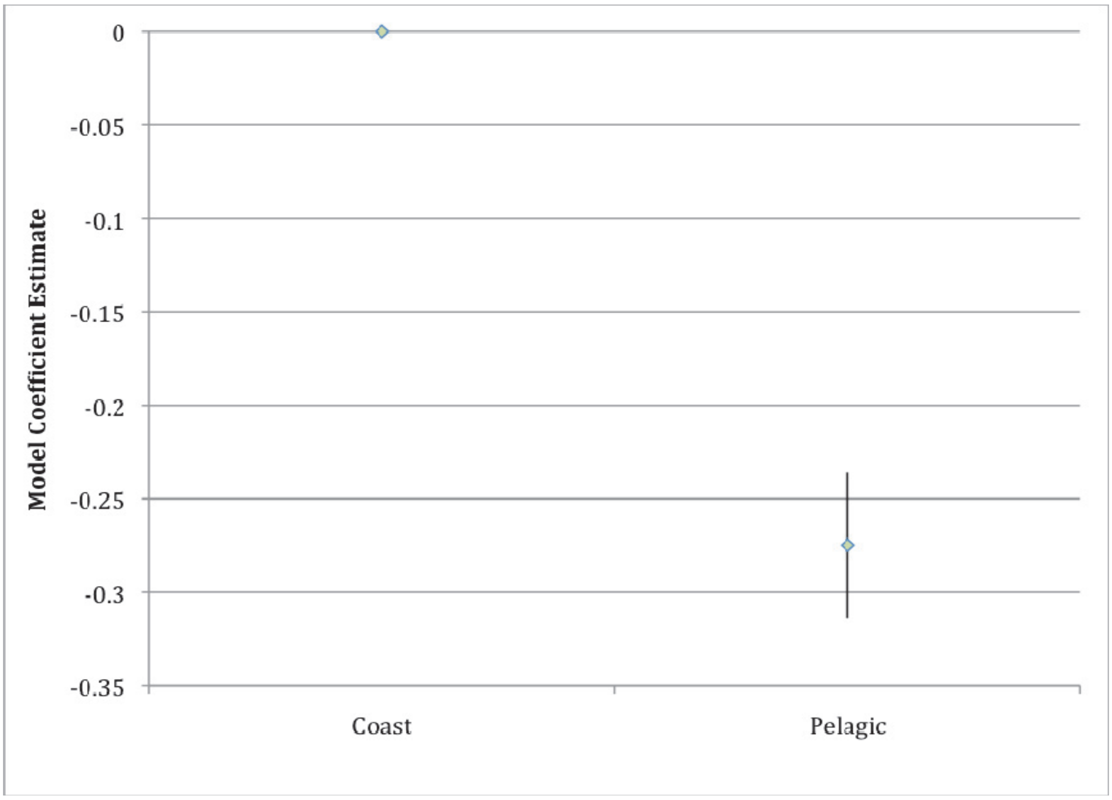


Figure 40: The proportion of observations black guillemots were observed at different depths at the Fall of Warness.

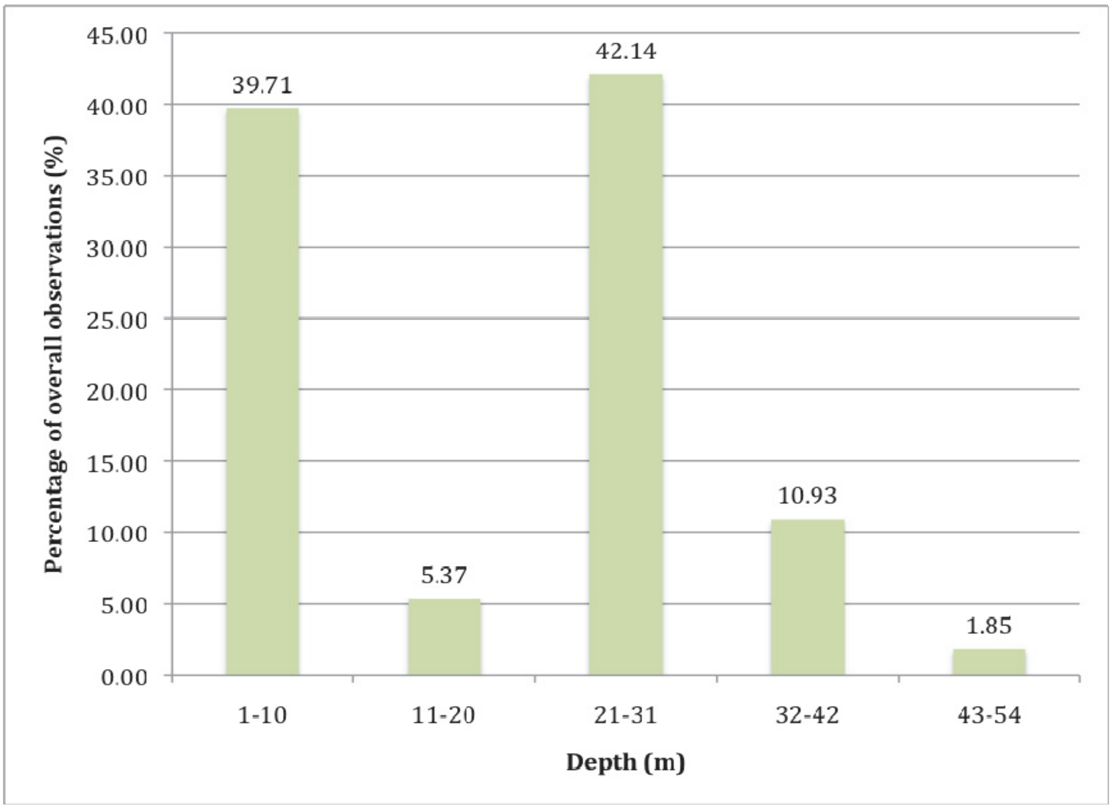


Figure 41: GEE coefficient estimates (and standard errors) for black guillemots observed by tidal state, at the Fall of Warness.

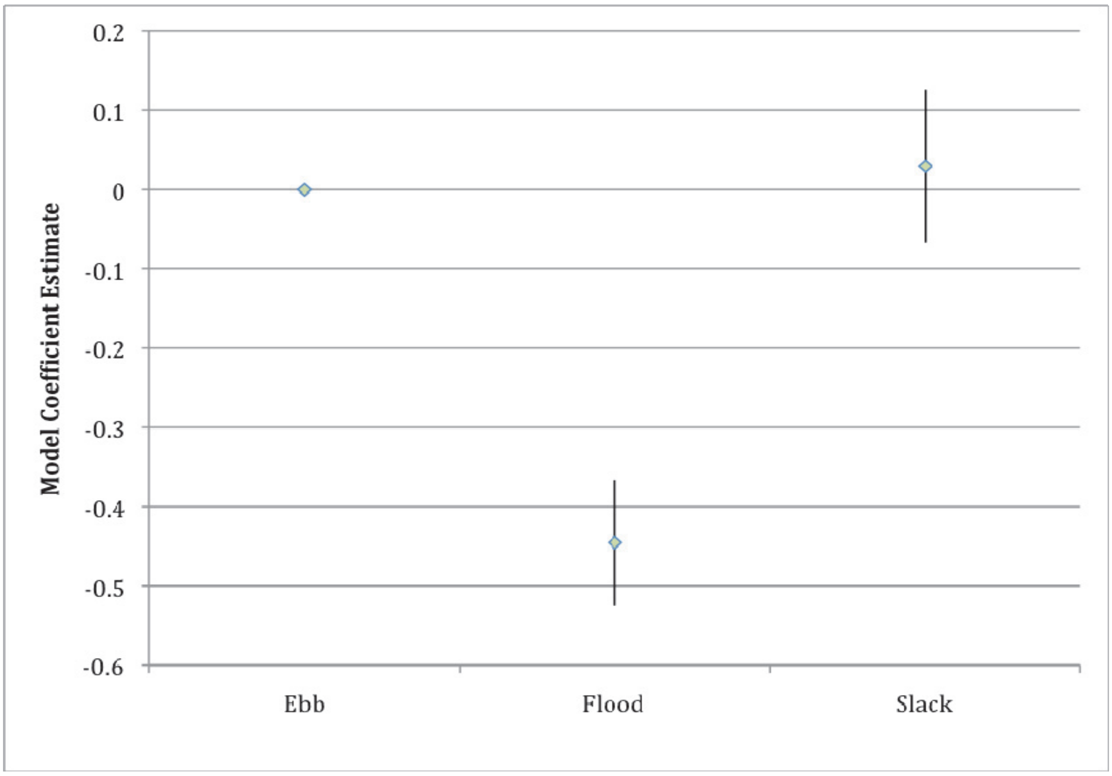


Figure 42: Mean number of black guillemots observed per hour during different wind strengths, using the Beaufort Scale, at the Fall of Warness.

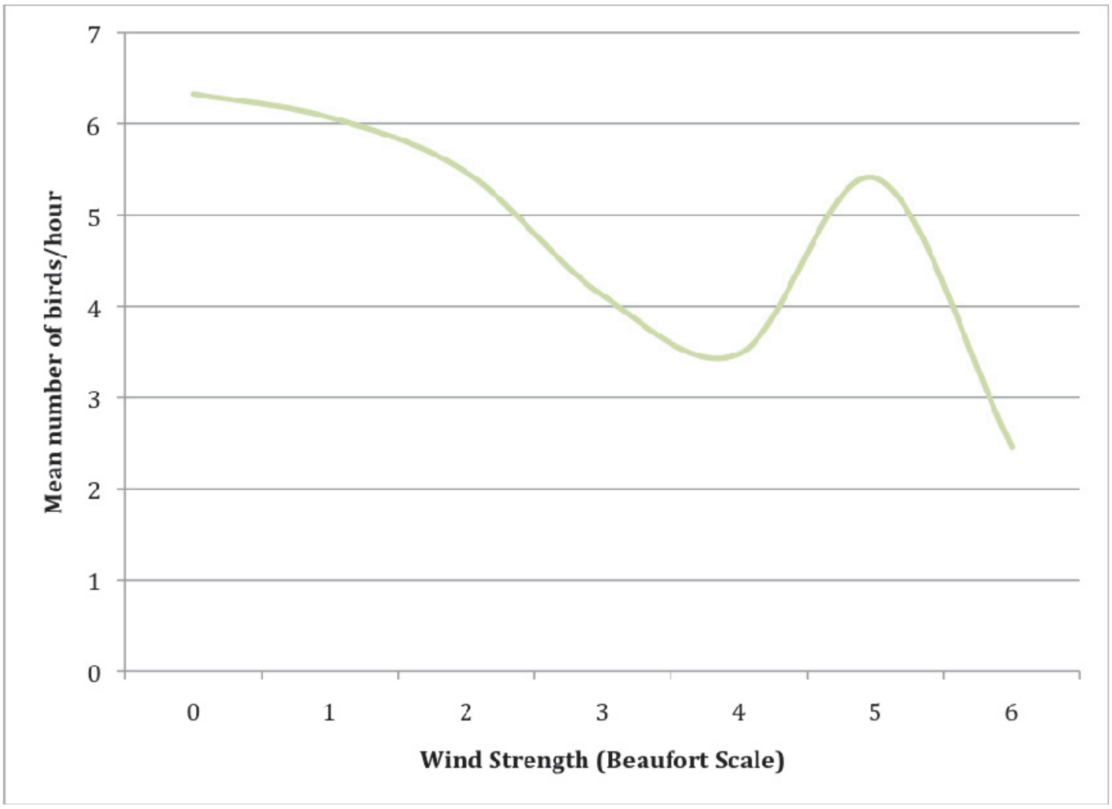
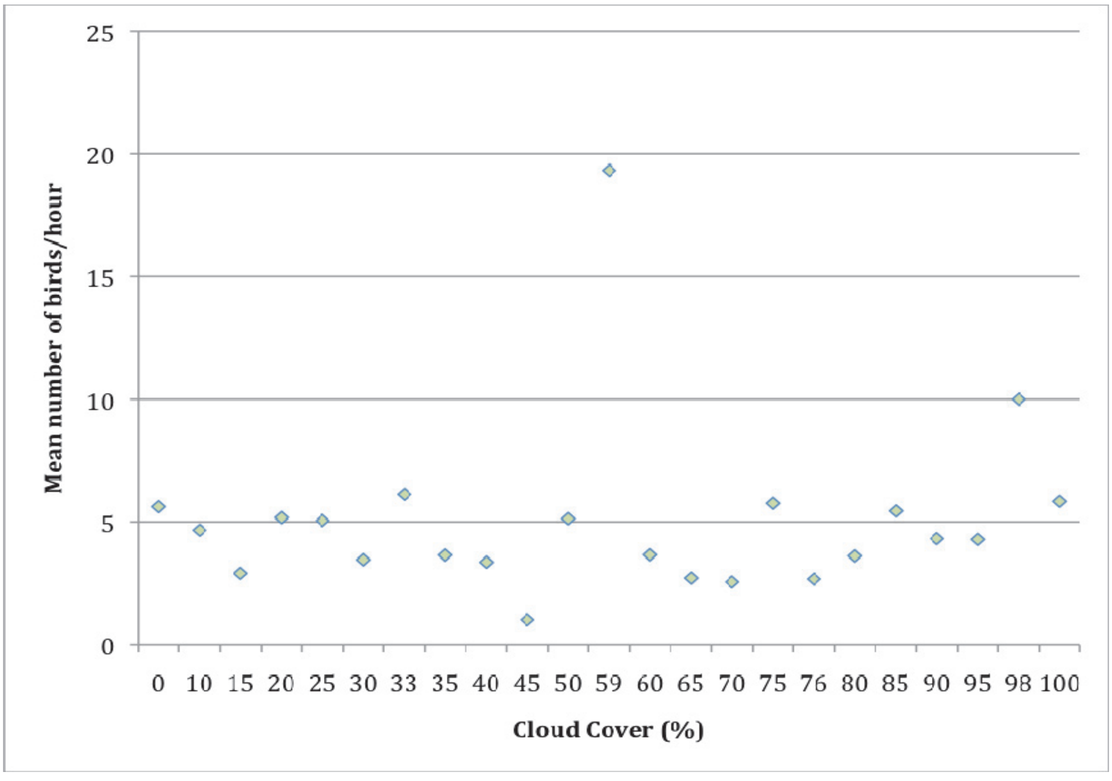


Figure 43: Mean number of black guillemots observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Atlantic Puffin

Table 16: The top 5 GLMM models, as selected by AIC values, for modelling puffin use of the Fall of Warness.

Model	Df	AIC
Season + time of day + depth + habitat type	8	3194
Time of day + depth + habitat type	5	3198
Season + time of day + tide state + depth + habitat type + cloud cover	11	3199
Season + time of day + depth + habitat type + wind strength + tide state + cloud cover	12	3200
Season + time of day + depth + habitat type + wind strength + tide state + precipitation + cloud cover	13	3200

Table 17: Parameter estimates, standard errors, probability values for GEE investigating puffin counts as a function of season, time of day, tidal state, habitat type and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.438367	0.08944	24.02	9.50E-07	***
Spring	0.74193	0.05815	162.79	<2.00E-16	***
Summer	0.790093	0.058671	181.35	<2.00E-16	***
Autumn	0.180963	0.113705	2.53	0.11	
Time of Day	0.02141	0.00395	29.38	5.90E-08	***
Flood	0.019126	0.033163	0.33	0.56	
Slack	0.020291	0.042516	0.23	0.63	
Depth	-0.022173	0.001776	155.92	<2.00E-16	***
Pelagic	0.183599	0.039742	21.34	3.80E-06	***
Cloud Cover	-0.000315	0.00049	0.41	0.52	

Figure 44: GEE coefficient estimates (and standard errors) for puffins observed by season at the Fall of Warness.

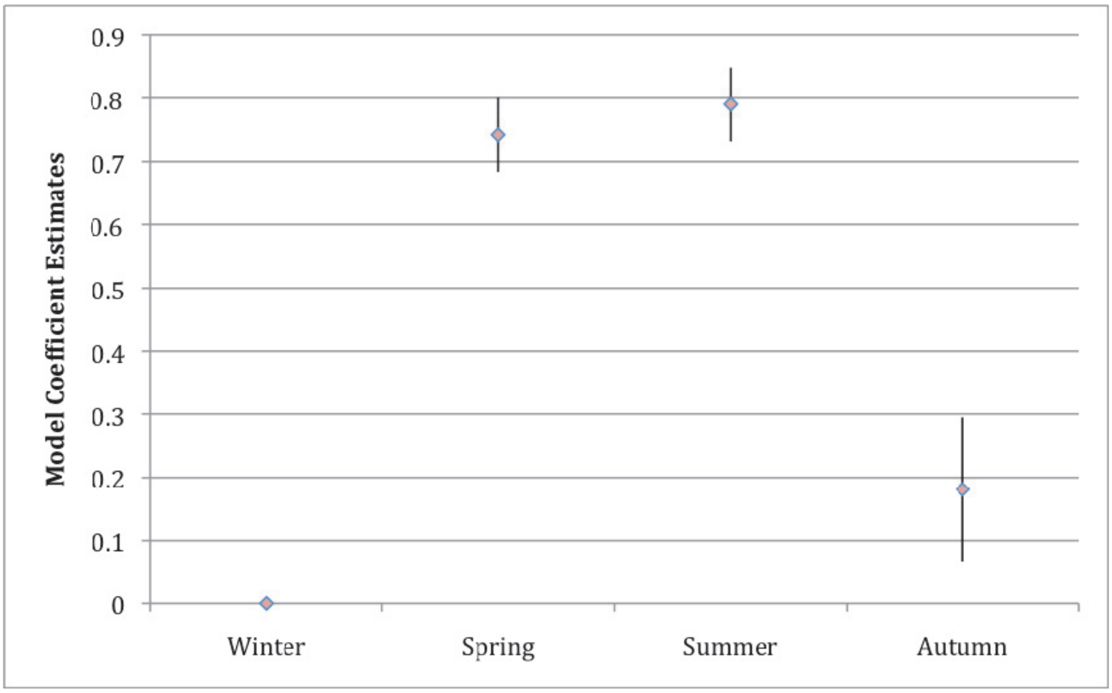


Figure 45: Mean number of puffins observed per hour throughout the day at the Fall of Warness.

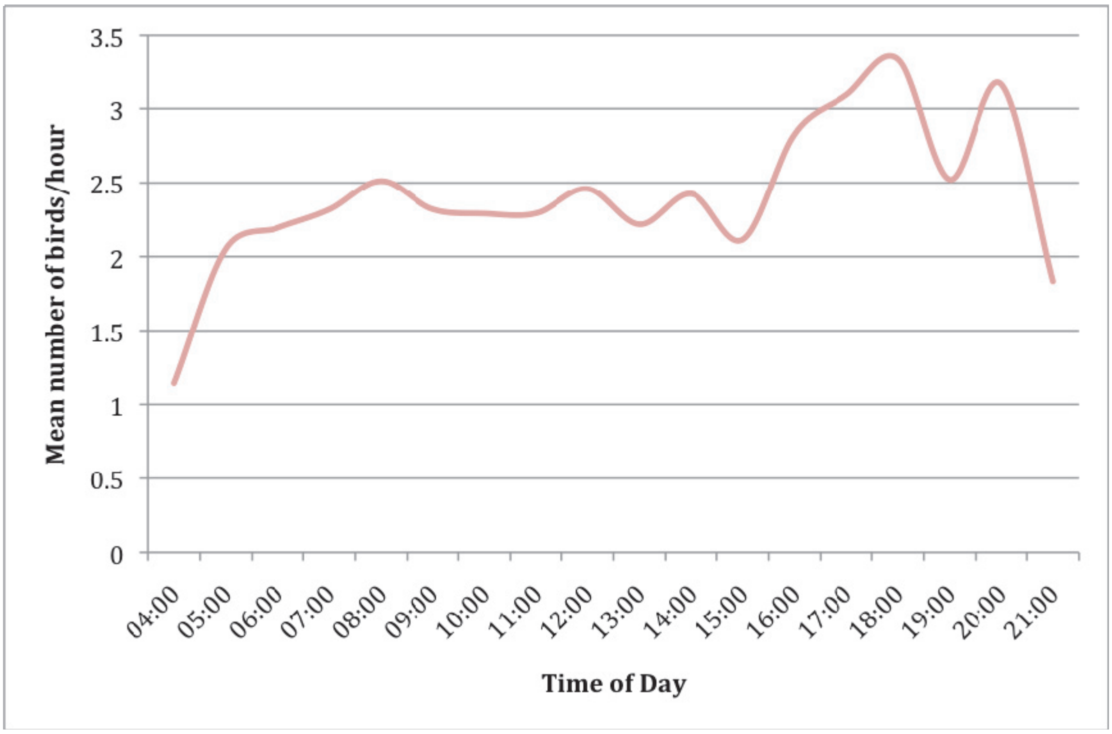


Figure 46: GEE coefficient estimates (and standard errors) for puffins observed by tidal state at the Fall of Warness.

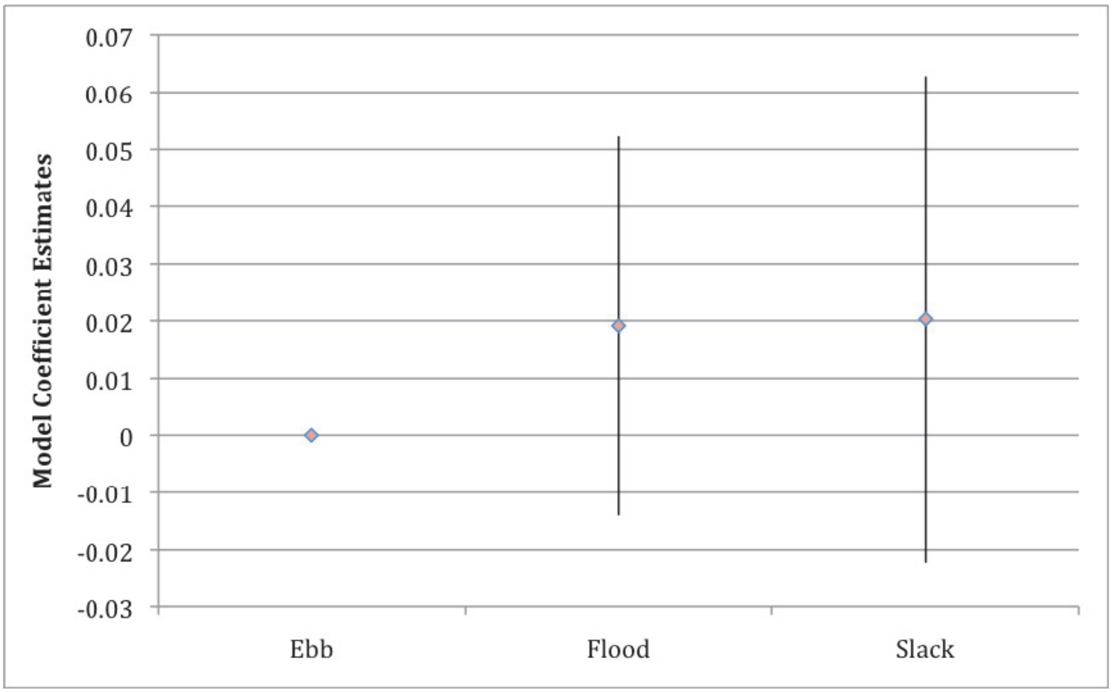


Figure 47: GEE coefficient estimates (and standard errors) for puffins observed in coastal and pelagic habitats at the Fall of Warness.

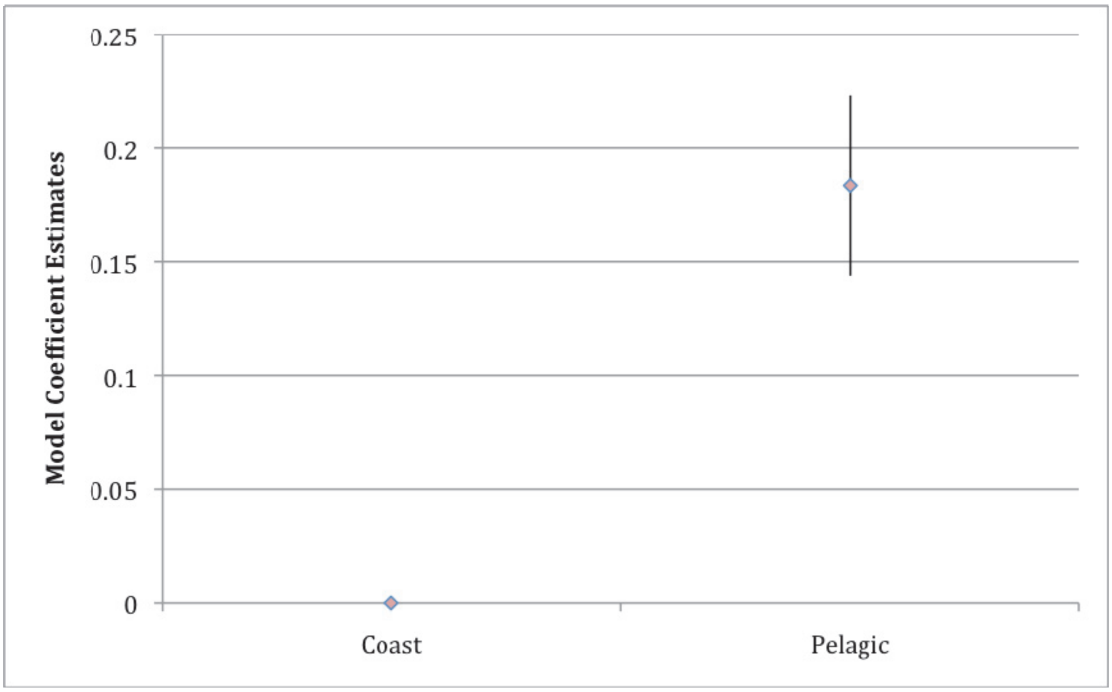


Figure 48: The proportion of observations puffins were observed at different depths at the Fall of Warness.

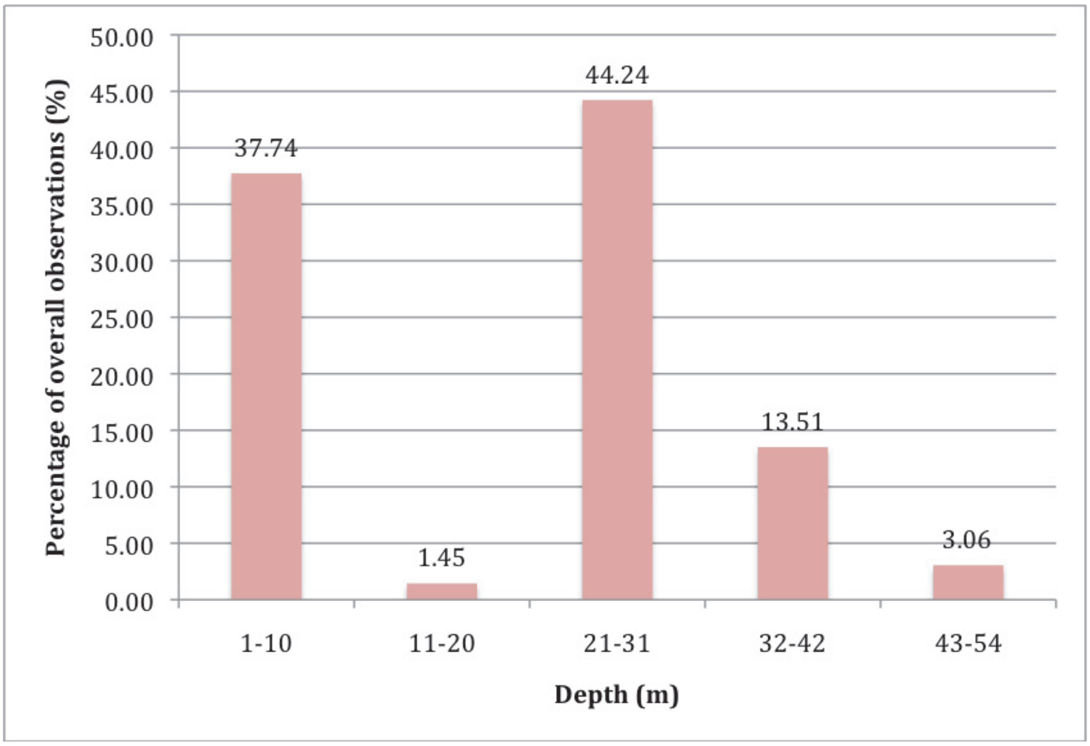
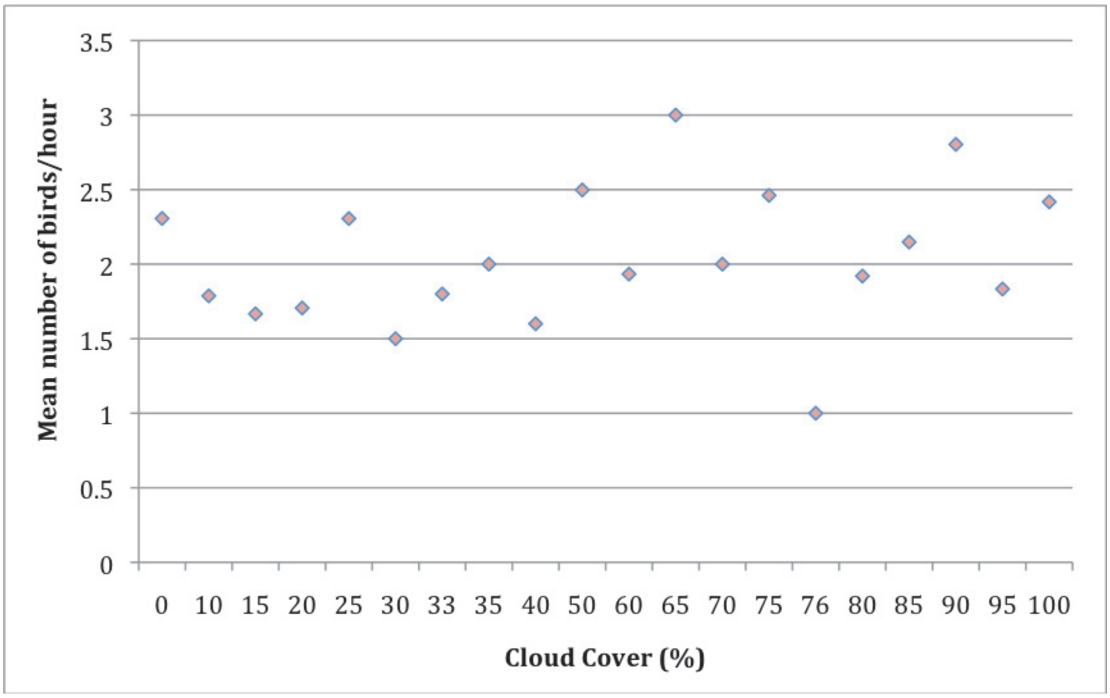


Figure 49: Mean number of puffins observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Harbour seal

Table 18: The top 5 GLMM models, as selected by AIC values, for modelling harbour seal use of the Fall of Warness.

Model	Df	AIC
Season + depth	6	531
Season + tide state + depth	8	532
Season + tide state + depth + cloud cover	9	534
Season + tide state + depth + habitat type + cloud cover	10	535
Season + time of day + tide state + depth + habitat type	10	535

Table 19: Parameter estimates, standard errors, probability values for GEE investigating harbour seal counts as a function of season, tidal state and depth.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.45939	0.0971	22.38	2.20E-06	***
Spring	0.19728	0.08067	5.98	0.0145	*
Summer	0.16696	0.07329	5.19	0.0227	*
Autumn	0.31289	0.09566	10.7	0.0011	**
Flood	-0.07977	0.05167	2.38	0.1226	
Slack	0.05718	0.11737	0.24	0.6261	
Depth	-0.01193	0.00212	31.8	1.70E-08	***

Figure 50: GEE coefficient estimates (and standard errors) for harbour seals observed by season at the Fall of Warness.

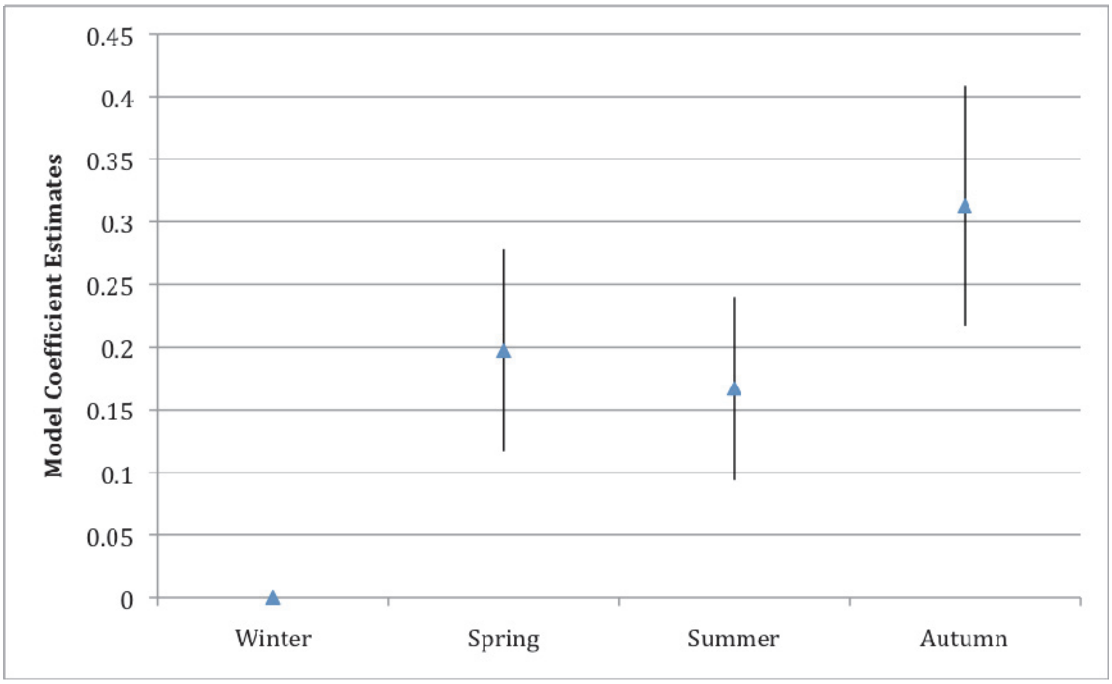


Figure 51: Proportion of all harbour seal observations that occurred during each season at the Fall of Warness.

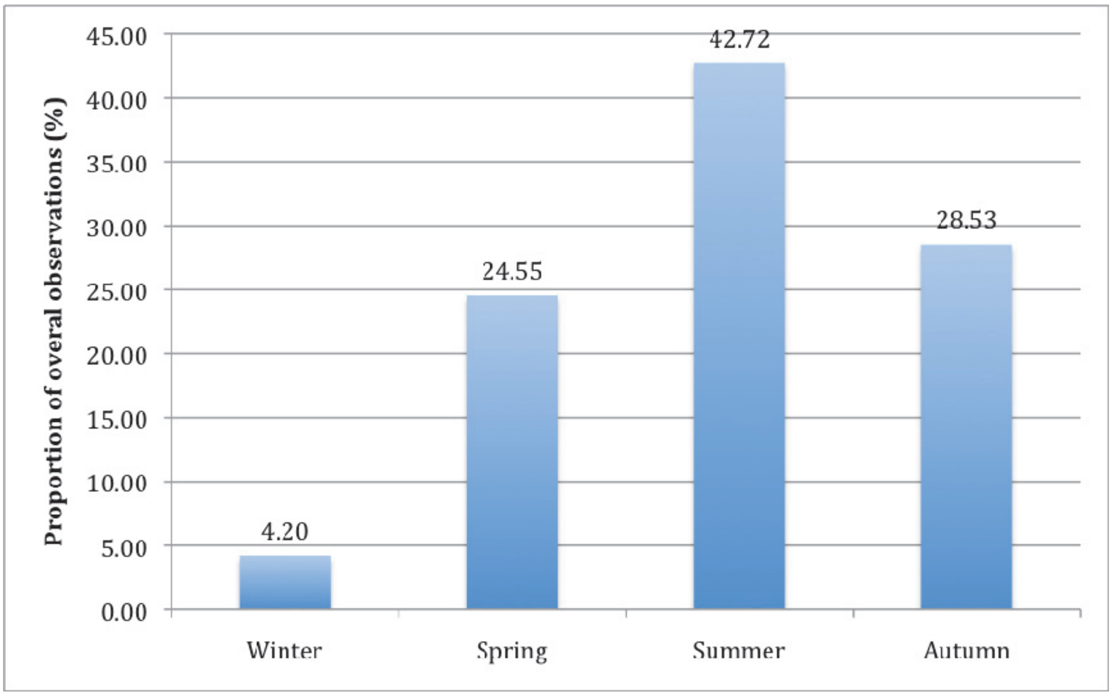


Figure 52: GEE coefficient estimates (and standard errors) for harbour seals observed by tidal state at the Fall of Warness.

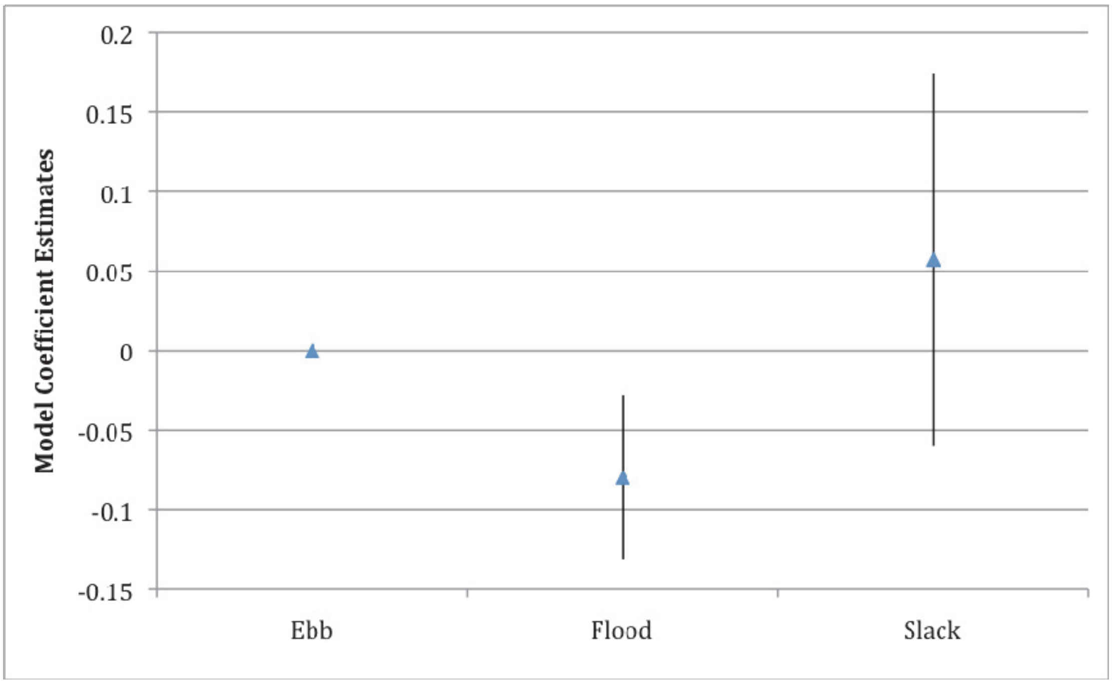
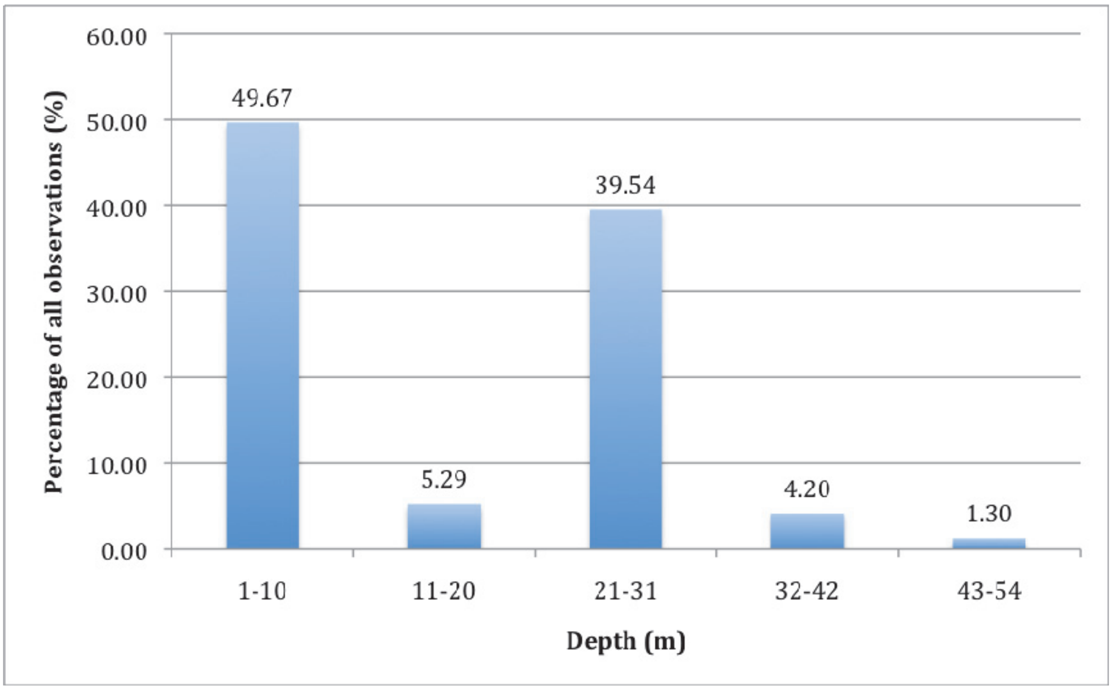


Figure 53: The proportion of observations harbour seals were observed at different depths at the Fall of Warness.



Grey seal

Table 20: The top 5 GLMM models, as selected by AIC values, for modelling grey seal use of the Fall of Warness.

Model	Df	AIC
Season + time of day + depth + habitat type + wind direction + cloud cover	14	2887
Season + time of day + depth + habitat type + wind direction + precipitation + cloud cover	18	2891
Season + time of day + depth + wind direction + precipitation + cloud cover	17	2899
Season + time of day + depth + habitat type + tide state	10	2905
Season + time of day + depth + habitat type + tide state + cloud cover	11	2907

Table 21: Parameter estimates, standard errors, probability values for GEE investigating grey seal counts as a function of season, time of day, depth, habitat type, wind direction and cloud cover.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.07565	0.26947	0.08	0.77891	
Spring	-0.197191	0.117332	2.82	0.09284	.
Summer	-0.152651	0.112657	1.84	0.17541	
Autumn	0.266755	0.112726	5.6	0.01796	*
Time of Day	0.045158	0.013493	11.2	0.00082	***
Depth	-0.019089	0.003593	28.23	1.10E-07	***
Pelagic	-0.269054	0.073554	13.38	0.00025	***
None	0.507798	0.112921	20.22	6.90E-06	***
North	0.339406	0.115295	8.67	0.00324	**
South	0.377704	0.091405	17.08	3.60E-05	***
Variable	0.527715	0.114106	21.39	3.70E-06	***
West	0.151927	0.084609	3.22	0.07255	.
Cloud Cover	0.000368	0.001316	0.08	0.77949	

Figure 54: GEE coefficient estimates (and standard errors) for grey seals observed by season at the Fall of Warness.

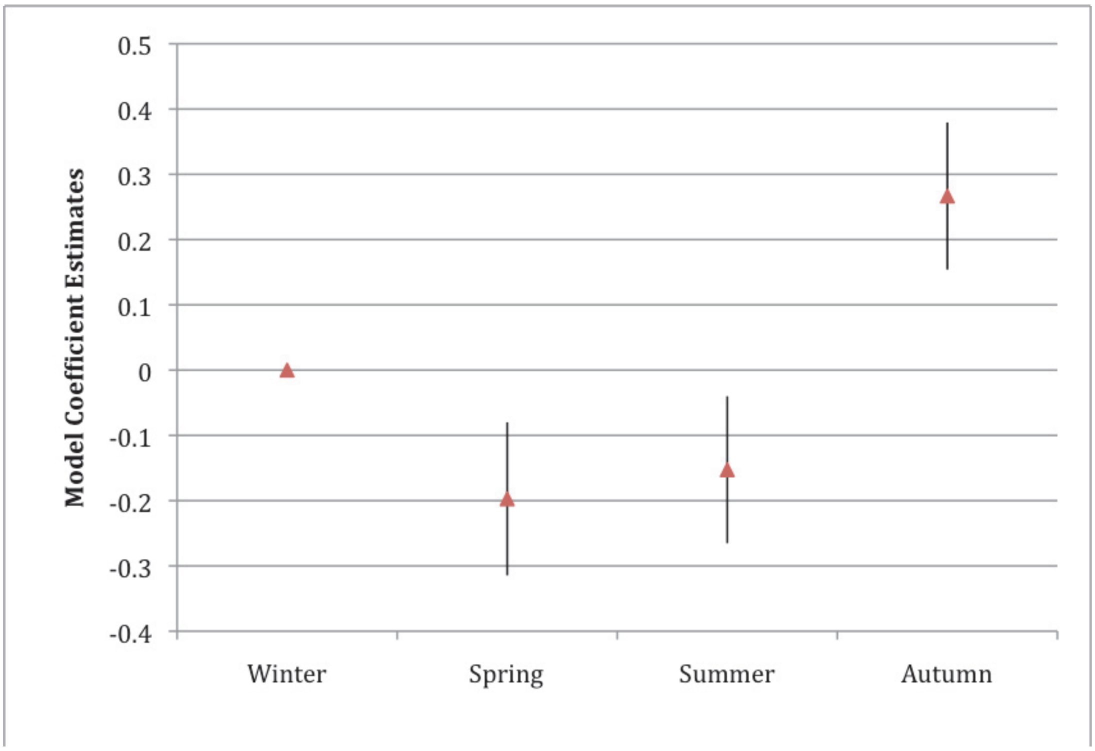


Figure 55: Proportion of all grey seal observations that occurred during each season at the Fall of Warness.

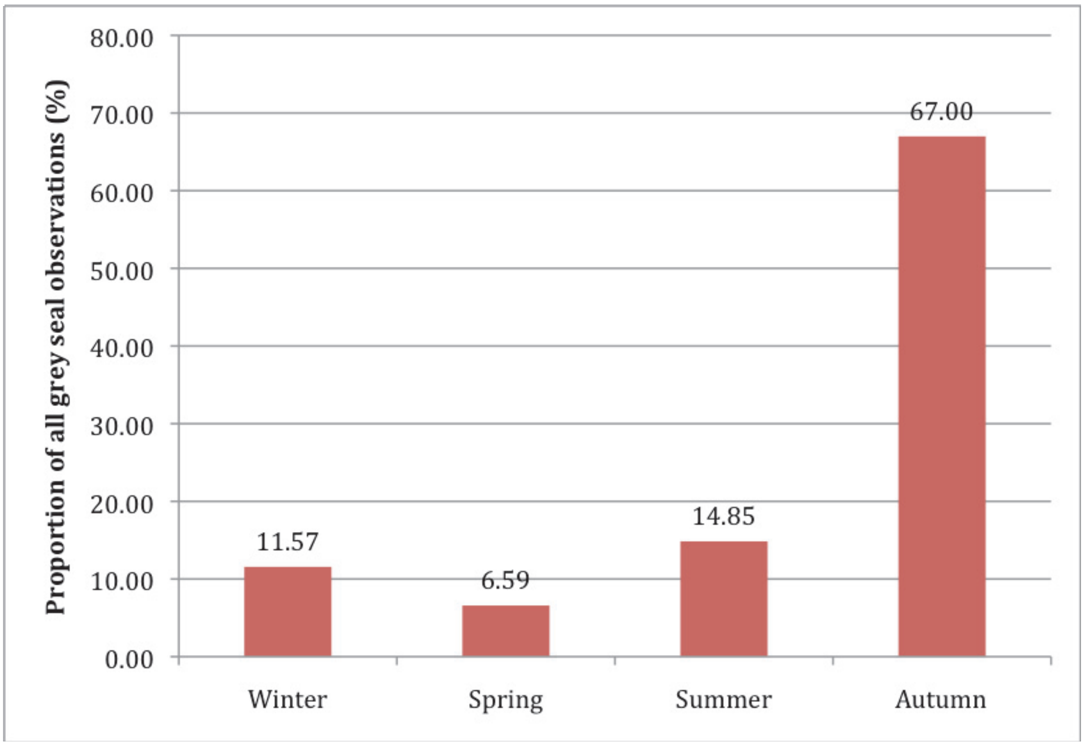


Figure 56: Mean number of grey seals observed per hour, throughout the day at the Fall of Warness.

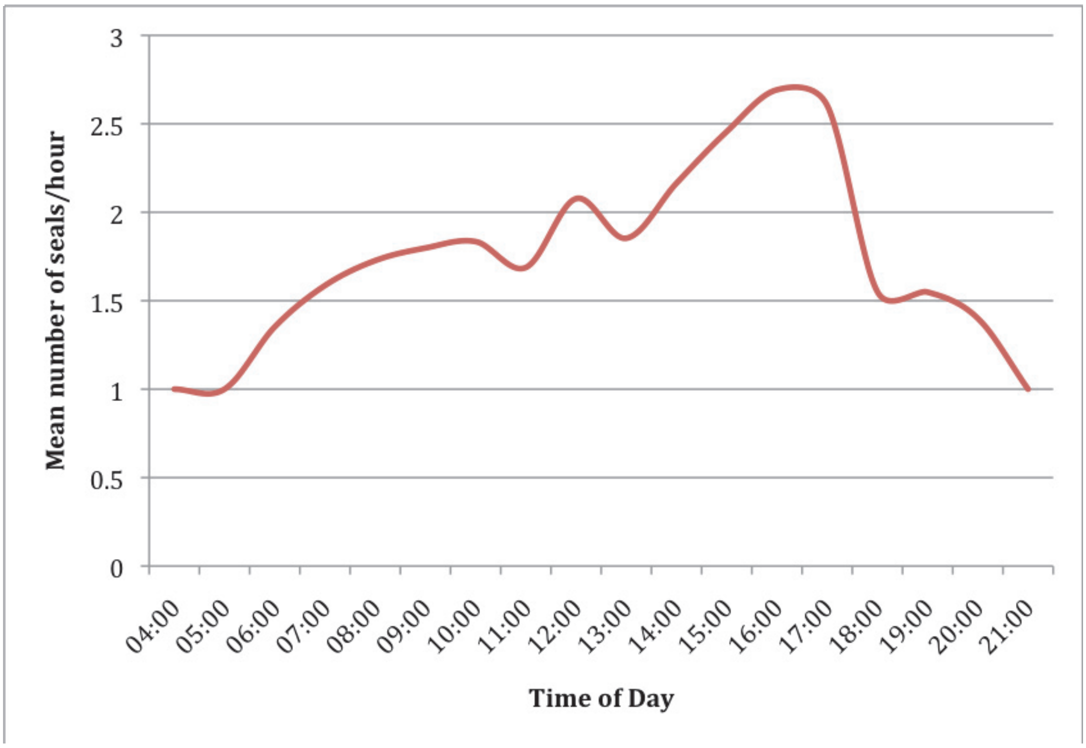


Figure 57: GEE coefficient estimates (and standard errors) for grey seals observed in costal and pelagic grid squares, at the Fall of Warness.

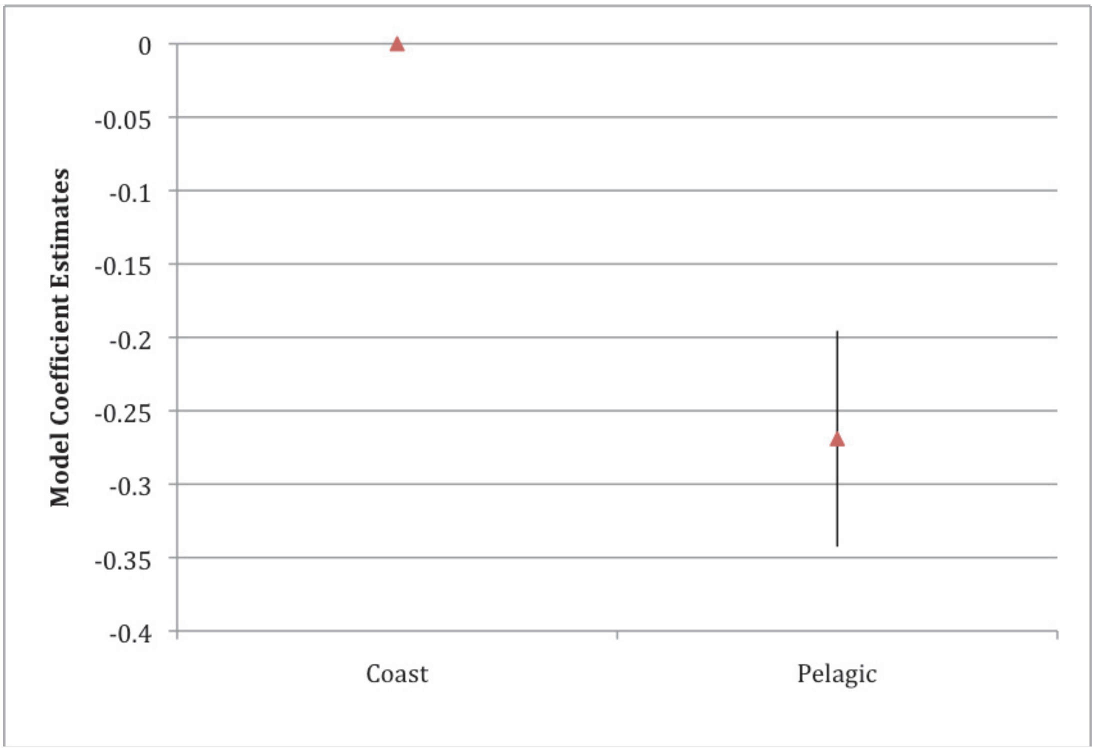


Figure 58: The proportion of observations grey seals were observed at different depths at the Fall of Warness.

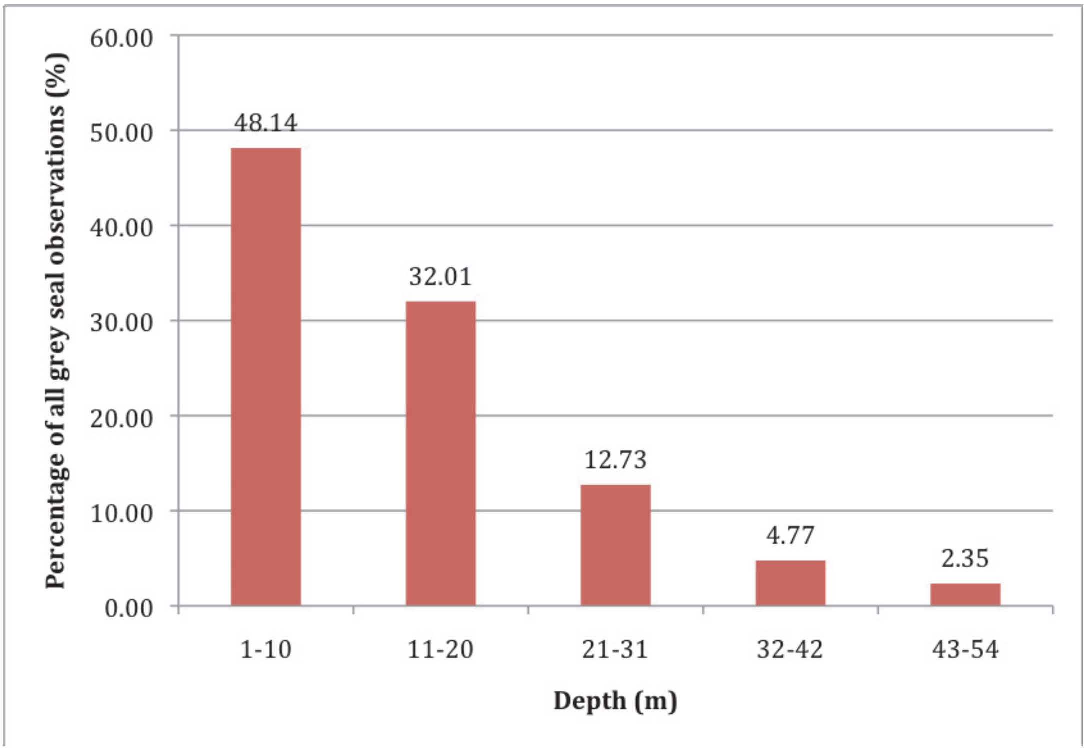


Figure 59: GEE coefficient estimates (and standard errors) for grey seals observed during different wind directions, at the Fall of Warness.

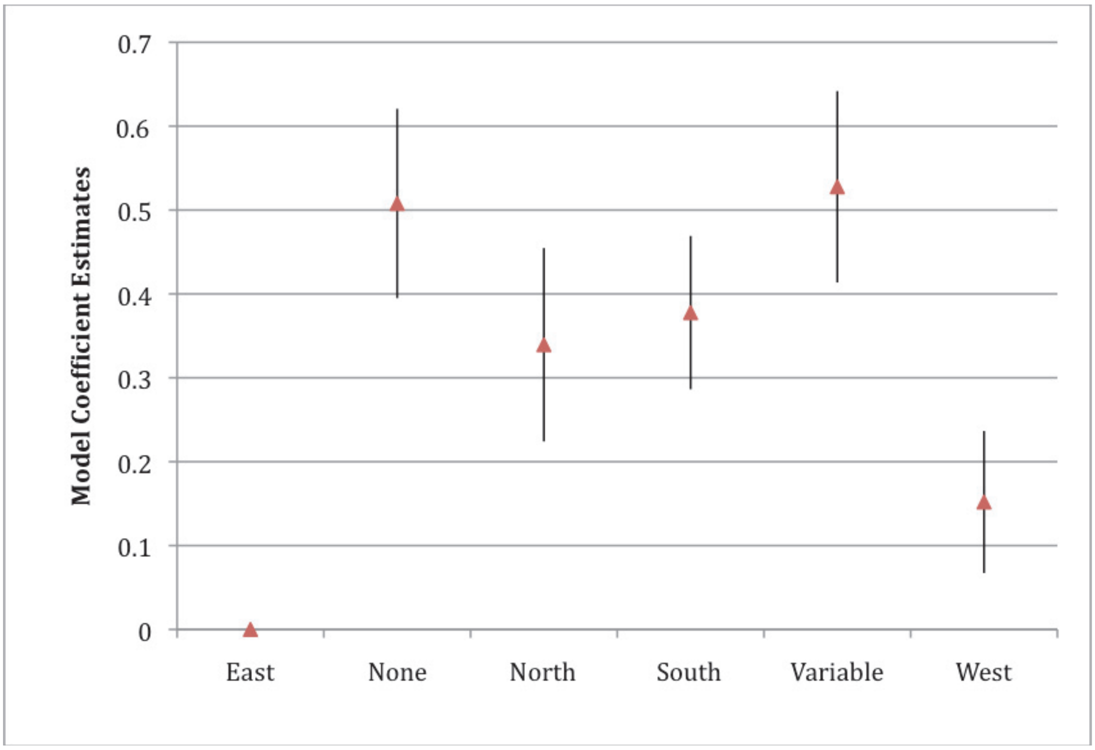
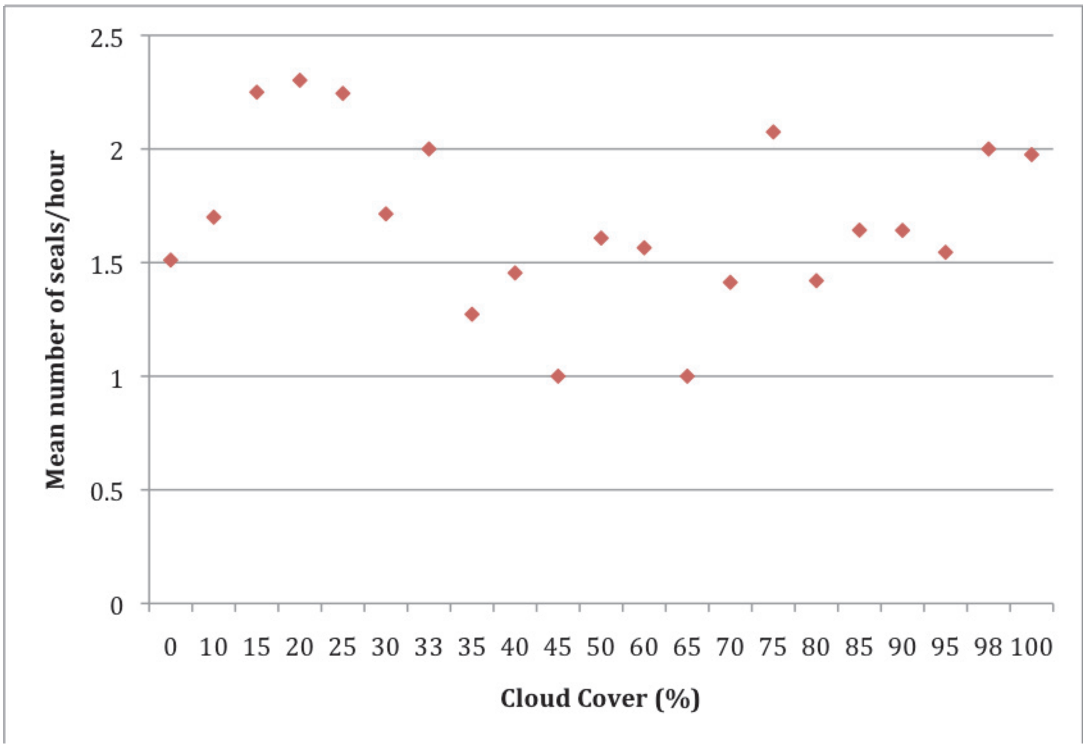


Figure 60: Mean number of grey seals observed per hour during different percentage cloud cover conditions at the Fall of Warness.



Harbour porpoise

Table 20: The top 5 GLMM models, as selected by AIC values, for modelling harbour porpoise use of the Fall of Warness.

Model	Df	AIC
Time of day + habitat type	4	199
Season + time of day + depth + habitat type + wind direction + cloud cover	14	201
Season + time of day + tide state + depth + habitat type + cloud cover	13	206
Season + time of day + habitat type + tidal state + precipitation + cloud cover	13	206
Season + time of day + habitat type + tidal state	11	207

Table 21: Parameter estimates, standard errors, probability values for GEE investigating harbour porpoise counts as a function of time of day and habitat type.

	Estimate	Std. error	Wald	Pr (>|W|)	Signif.
(Intercept)	0.53551	0.10413	26.45	2.70E-07	***
Time of Day	0.02819	0.00944	8.91	0.0028	**
Habitat Type	0.17522	0.06897	6.46	0.0111	*

Figure 61: Mean number of harbour porpoise observed per hour, throughout the day at the Fall of Warness.

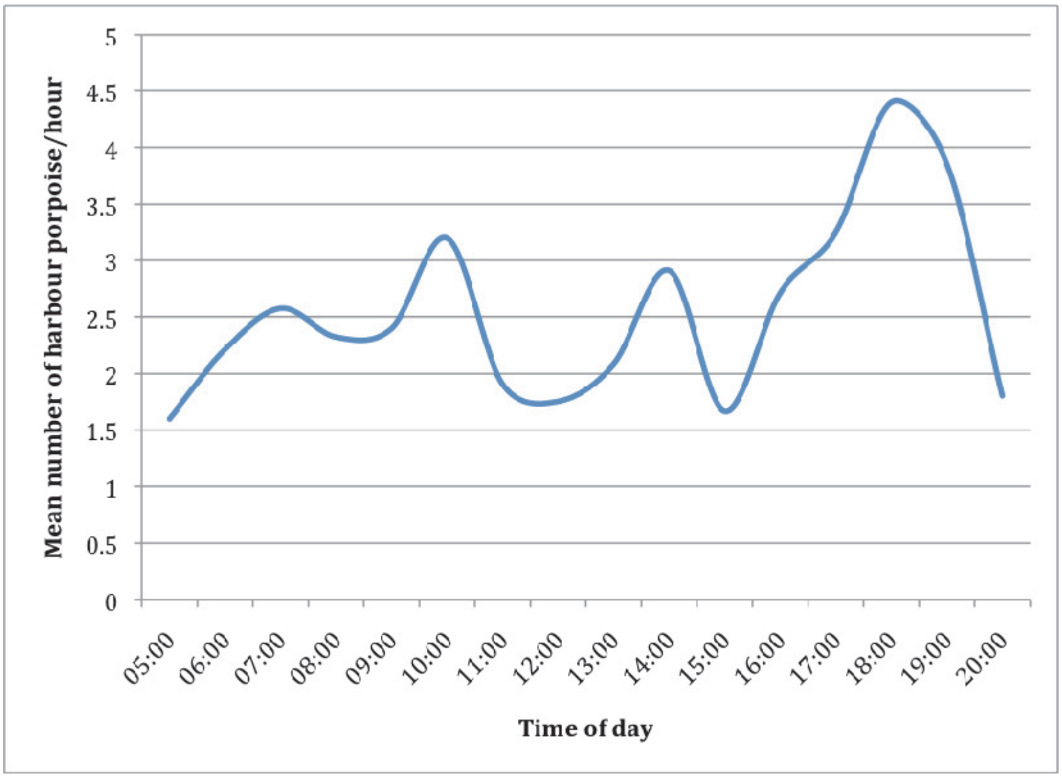
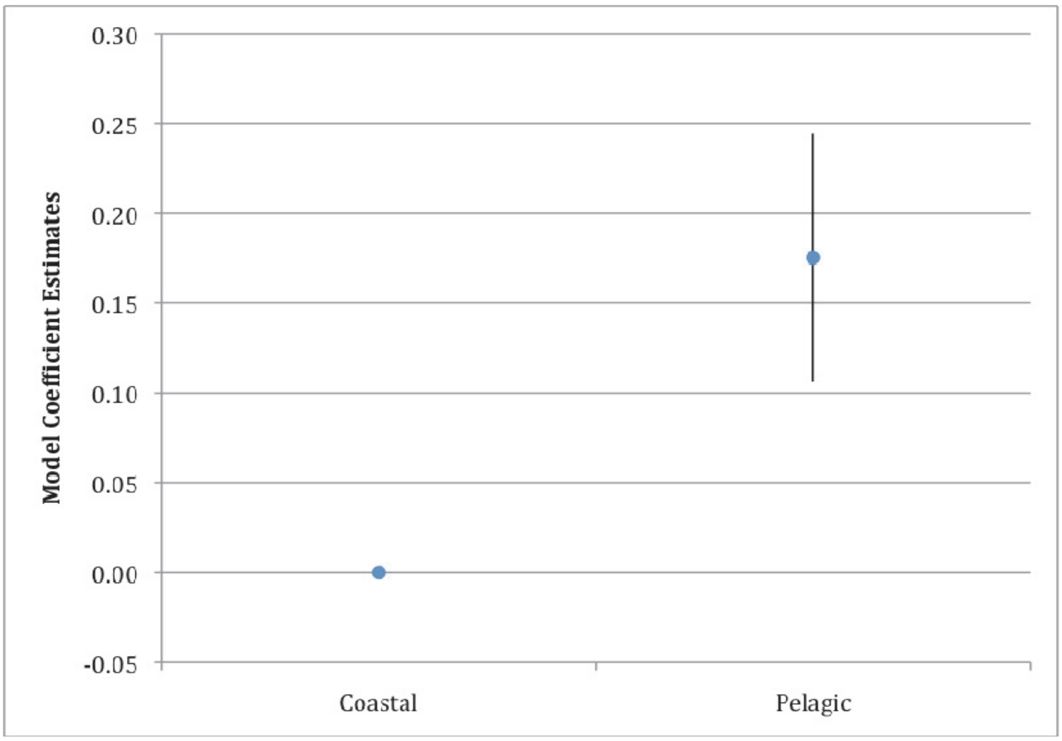


Figure 62: GEE coefficient estimates (and standard errors) for harbour porpoise observed in costal and pelagic grid squares, at the Fall of Warness.



ANNEX 2: EXAMPLE OF THE R SCRIPT USED

```
#Adding season factor
guillemot$fSeason<-guillemot$MONTH
I1<-guillemot$MONTH==1 | guillemot$MONTH==2 | guillemot$MONTH==12
I2<-guillemot$MONTH==3 | guillemot$MONTH==4 | guillemot$MONTH==5
I3<-guillemot$MONTH==6 | guillemot$MONTH==7 | guillemot$MONTH==8
I4<-guillemot$MONTH==9 | guillemot$MONTH==10 | guillemot$MONTH==11
guillemot$fSeason[I1] <- "a"
guillemot$fSeason[I2] <- "b"
guillemot$fSeason[I3] <- "c"
guillemot$fSeason[I4] <- "d"
guillemot$fSeason <- as.factor(guillemot$fSeason)

#Variance Inflation Factors - Collinearity

vif(lm (NUMBER ~ WINDDIRECTION + WINDSTRENGTH, data=guillemot))
vif(lm (NUMBER ~ TIDESTATE + FLOWDIRECTION, data=guillemot))
vif(lm (NUMBER ~ TIDESTATE + WATERFLOW, data=guillemot))
vif(lm (NUMBER ~ WATERFLOW + FLOWDIRECTION, data=guillemot))
vif(lm (NUMBER ~ DEPTH + ZONETYPE, data=guillemot))
vif(lm (NUMBER ~ CLOUDCOVER + NEWPRECIPITATION, data=guillemot))

#GLMM

guillemotglm <- glm(NUMBER ~ fSeason + TOD + Time + ZONE + ZONETYPE + DEPTH
 + TIDESTATE + WINDSTRENGTH + NEWPRECIPITATION + CLOUDCOVER, data =
 guillemot, family = poisson)
summary(guillemotglm)

drop1(guillemotglm, test=c("Chisq"))

guillemotlmer <- lmer(NUMBER ~ fSeason + Time + ZONE + TIDESTATE +
 WINDSTRENGTH + CLOUDCOVER + (1|DAYZONE), data = guillemot, family =
 poisson)
summary(guillemotlmer)

#GEE

guillemotform <- formula(NUMBER ~ fSeason + Time + ZONE + TIDESTATE +
 WINDSTRENGTH + CLOUDCOVER)

guillemotgee <- geeglm(guillemotform, data = gannet, family = poisson, id =
 DAYZONE, corstr = "ar1")
summary(guillemotgee)
```

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Policy and Advice Directorate, Great Glen House,
Leachkin Road, Inverness IV3 8NW
T: 01463 725000

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