Statistical Draft Report for Wind Relic & Arcus

Fronteer

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This report has been prepared for Wind Relic and Arcus Consulting who requested a statistical analysis of the bat acoustic data for the Fronteer Development footprint. This report is based on the report provided to Wind Relic in September 2020 but using only a subset of monitoring sites which are in or near the Fronteer Development footprint. The following sites were included in the analysis: C8, C10, C13, C14 and C25. Four of these sites (C8, C10, C13 and C14) are short masts, while C25 is a meteorological mast. All predictions using height were done up to 150m. These predictions need to be interpreted with caution since recordings were only made at 12m, 50m and 80m so these predictions are well beyond the range of the observed data.

The dataset contained 355 507 records, with a total of 144 317 bat passes. Ten bat species were recorded at these sites. The associated climatic data were only available for one monitoring site (C25) and no humidity data were available for this site.

Summary of Available Data

Table 1 provides a summary of the total number of bat passes and average bat passes per night. The average number of bat passes per night at the lower level (12m) recording sites is higher compared to the meteorological mast which recorded at 50m and 80m (Figure 1). The average number of passes at site C25 has much more activity at the higher recording height (Table 2). This substantial increase in activity at the 80m level compared to the 50m is unusual compared to other monitoring sites in the greater development area (see previous reports). Site C14 has more than double the average activity compared to the next most active site (C10). C14 is approximately 0.5km from the development footprint.

Table 1 - Summary statistics of recording sites

Site	**Heights**	**Total Bat passes**	**Number of Nights**	**Average bat passes per night**
C8	12m	25 757	429	60.04
C10	12m	32 861	433	75.89
C13	12m	9 056	422	21.46
C14	12m	69 385	415	167.19
C25	50m and 80m	7 258	359	10.11

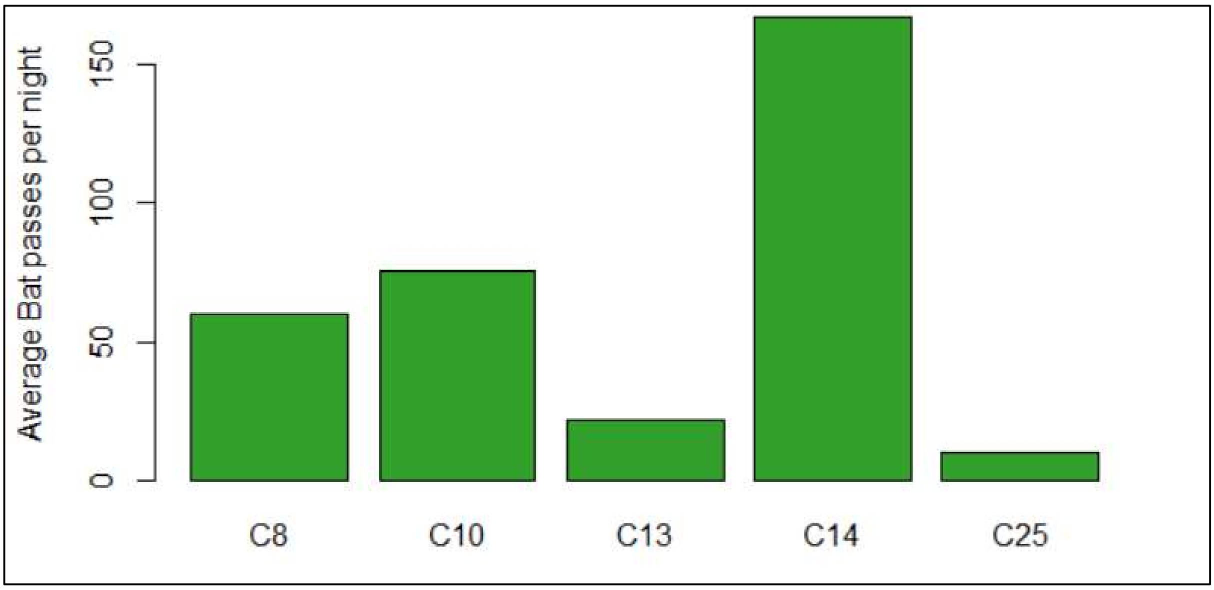

Figure 1 - Average number of bat passes per night plotted by site

Table 2 - Summary of recording sites split by height

Site	**Height**	**Total Bat passes**	**Average bat passes per night**
C25	50m	1045	2.91
	80m	6213	17.31

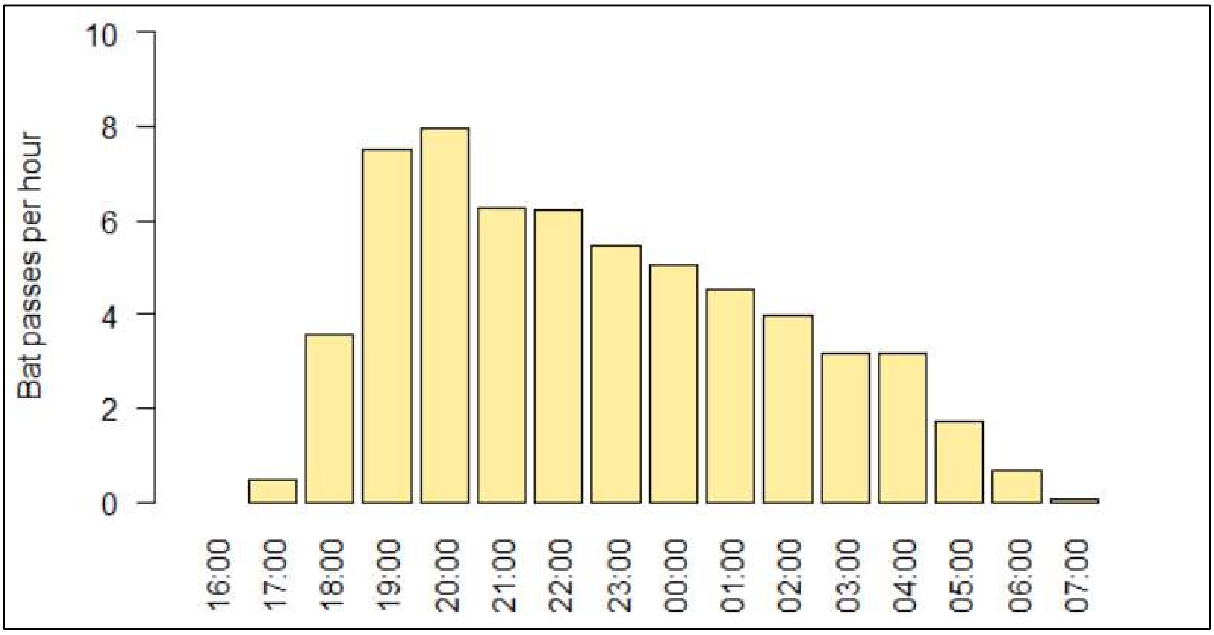

Figure 2 - Average number of bat passes per hour by time of day

The bat activity showed a peak around dusk and early night (19:00 and 20:00) and declined steadily through the night until 04:00 after which there was a substantial decrease in activity, see Figure 2. This pattern was consistent during autumn and spring although activity increased earlier in autumn, from 18:00. In winter, the activity declined much earlier in the evening, and in summer the peak occurred later at 20:00 corresponding to a later sunset time and activity levels remained far more consistent through the night, not showing the declining pattern (see Figure 3).

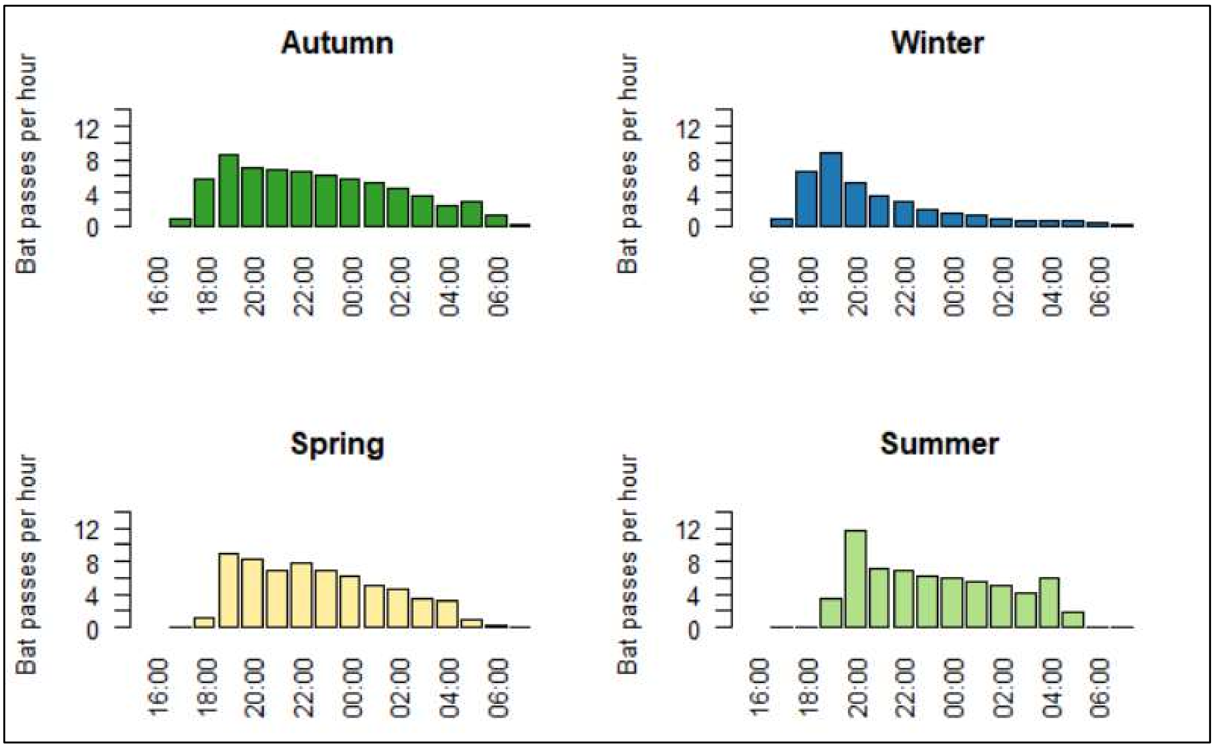

Figure 3 - Seasonal split showing average number of bat passes per hour by time of day

Vertical Activity Profiles

To build bat activity profiles, I first used the number of bat passes per hour at each height considering all recorded species pooled. At ground level, most of the activity was recorded at site C14, which is approximately 0.5km north-east of the development footprint. C8 and C10 have lower activity compared to C14. These sites are both approximately 4km from the Fronteer footprint to the north and south respectively. C25, which falls approximately 1km to the west of the footprint, shows considerably higher activity levels at 80m height compared to 50m (see Table 2).

The vertical activity for all sites pooled shows that most activity took place at a lower height (below 50m), see Figure 4, with more activity at 80m than at 50m.

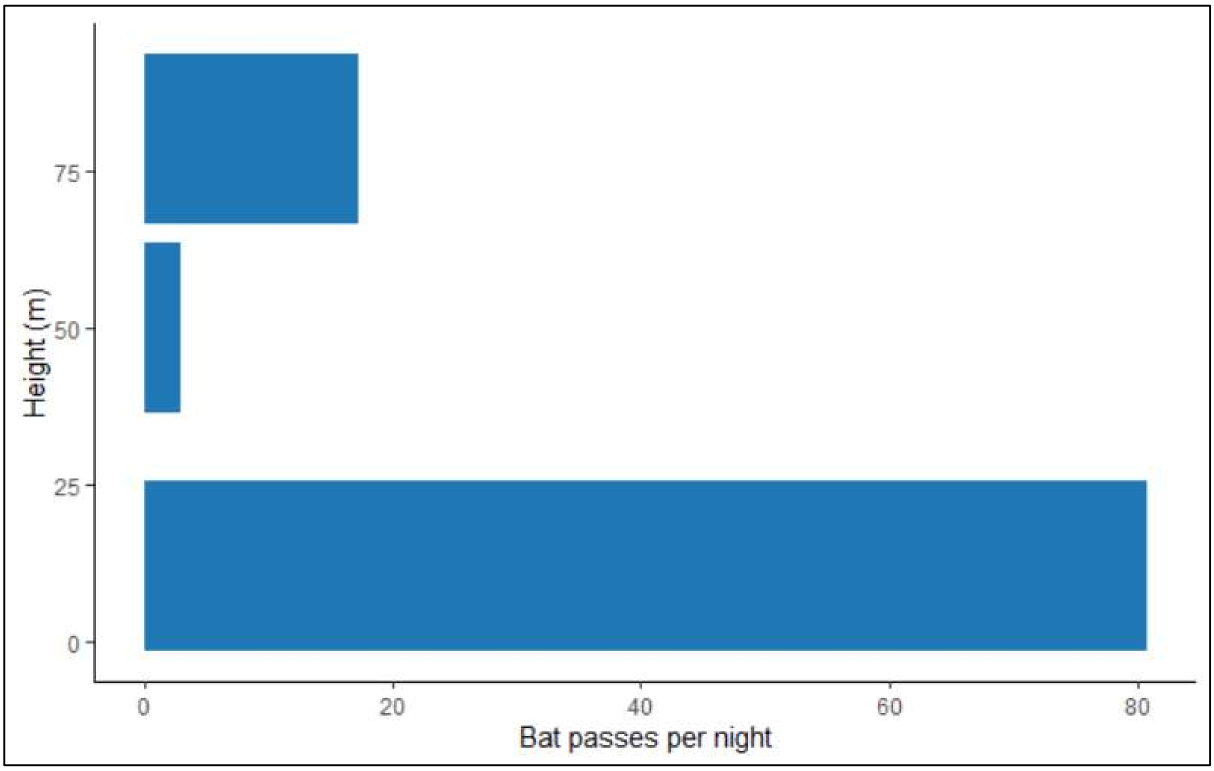

Figure 4 - Observed vertical bat activity profile

To model vertical activity profiles up to 150m above ground level, I used a linear model describing the mean number of bat passes per recording night as a function of the natural logarithm of height. The model found no significant linear relationship between the natural logarithm of height and the mean number of bat passes per night ($t = -2.269, p = 0.264$).

Similar models were then run for the Egyptian free-tailed bat and the Little free-tailed bat, split by season, and modelling the mean number of bat passes per hour as a function of the logarithm of height. The results are shown in Figure 5. For the Egyptian free-tailed bat, the mean number of bat passes per hour decreases exponentially with increasing height and the pattern is consistent across all seasons. However, for the Little free-tailed bat in winter, there is an increasing predicted number of bat passes with increasing height. However, none of these seasonal models were significant for either species.

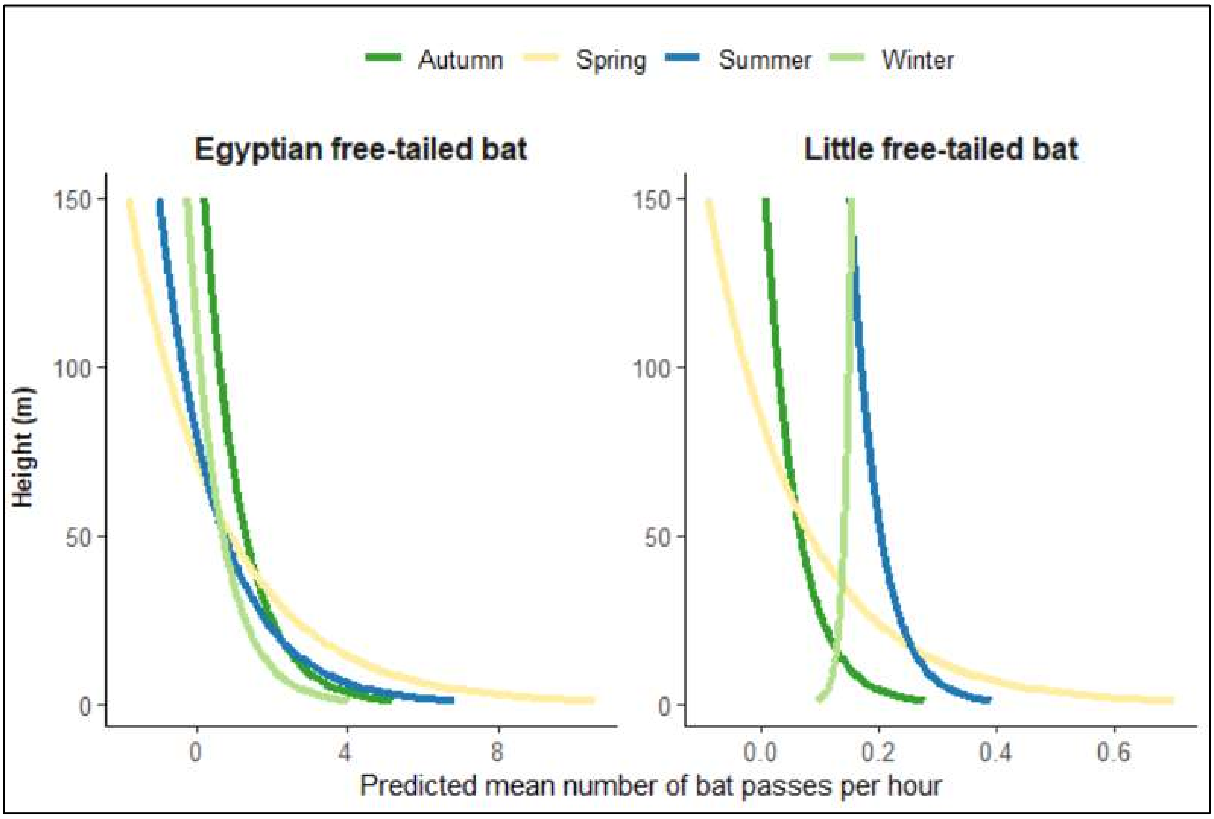

Figure 5 - Predicted mean number of bat passes per hour with height

Effect of wind speed on bat activity

In order to investigate the relationship between bat activity and wind speed, I calculated a *probability of activity occurrence per hour (p)* using a logistic regression. For this, I transformed the raw activity data (number of bat passes per hour) into simple presence/absence (binomial distribution) per hour. The probability of activity occurrence per hour was modelled as a logistic regression using average wind speed or maximum wind speed as the predictor variable. The results of the logistic regression showed that both the average and maximum wind speed were significant predictors of the probability of bat occurrence. The fit of the full and the null (excluding the predictor variable) was compared using a likelihood ratio test statistic. The results are given in Table 3.

Table 3 - Results of logistic regression models of probability of bat occurrence against wind speed

Height	Variable	Test Statistic	Degrees of Freedom	*p*-value
50m	Average wind speed	11.334	1	0.0008
50	Maximum wind speed	13.355	1	0.0003
80	Average wind speed	128.33	1	<0.0001
80	Maximum wind speed	140.59	1	<0.0001

Plots of the fitted models are shown in Figure 6. At 50m, the probability of bats being present is low, at any wind speed. At 80m the effect of wind speed is more pronounced, with a 42% probability of occurrence at very low wind speeds and this decreases exponentially, dropping to below 5% from 21m/s. The effect of the average or the maximum wind speed is very similar.

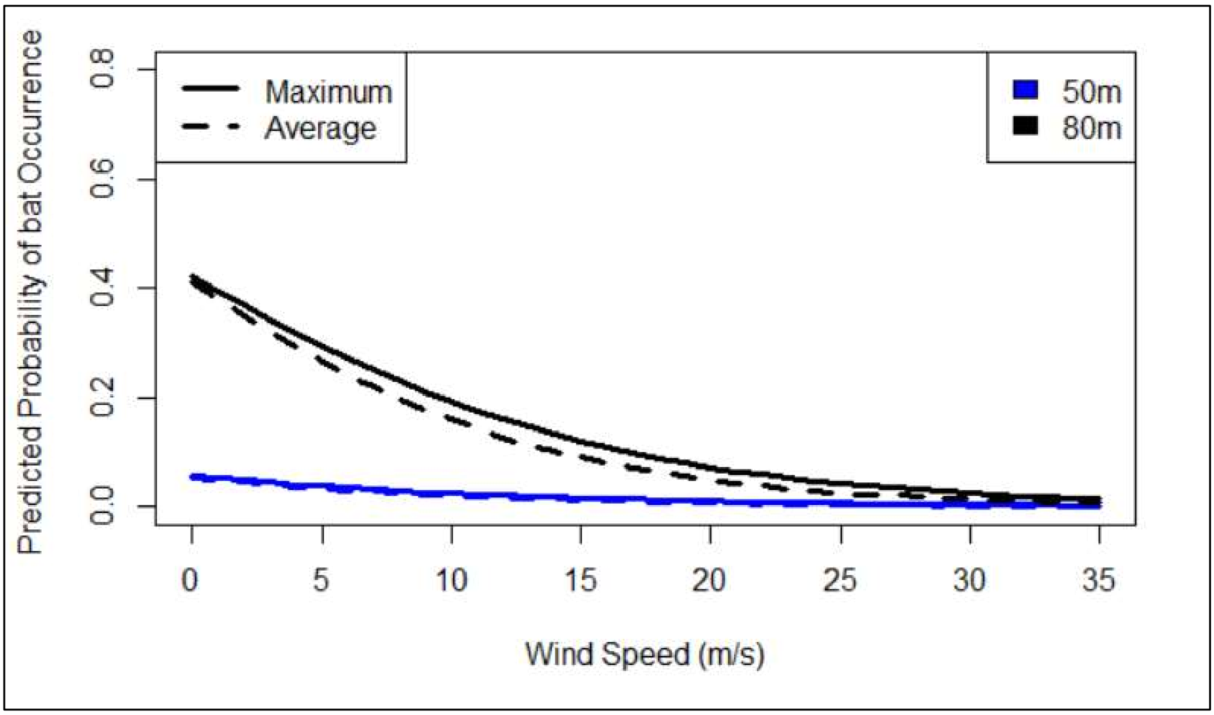

Figure 6 - Predicted probability of bat occurrence from logistic regression models

I also fitted multiple logistic regression models using the average wind speed and the time of day as predictor variables. I used 20:00 as the reference time, since this time period had the highest number of bat passes per night (Figure 2). For the 50m height, the following time periods were significant compared to 20:00, midnight through to 06:00, 18:00 and 23:00. At 80m, all time periods were significant compared to 20:00 except for 07:00. Figure 7 provides a plot of the adjusted odds ratios. For 80m, all times show lower odds of bats being present compared to 20:00. For the 50m height, the odds of bat presence were lower for all time periods compared to 20:00, except for 19:00 which had higher odds of a bet being present compared to 20:00.

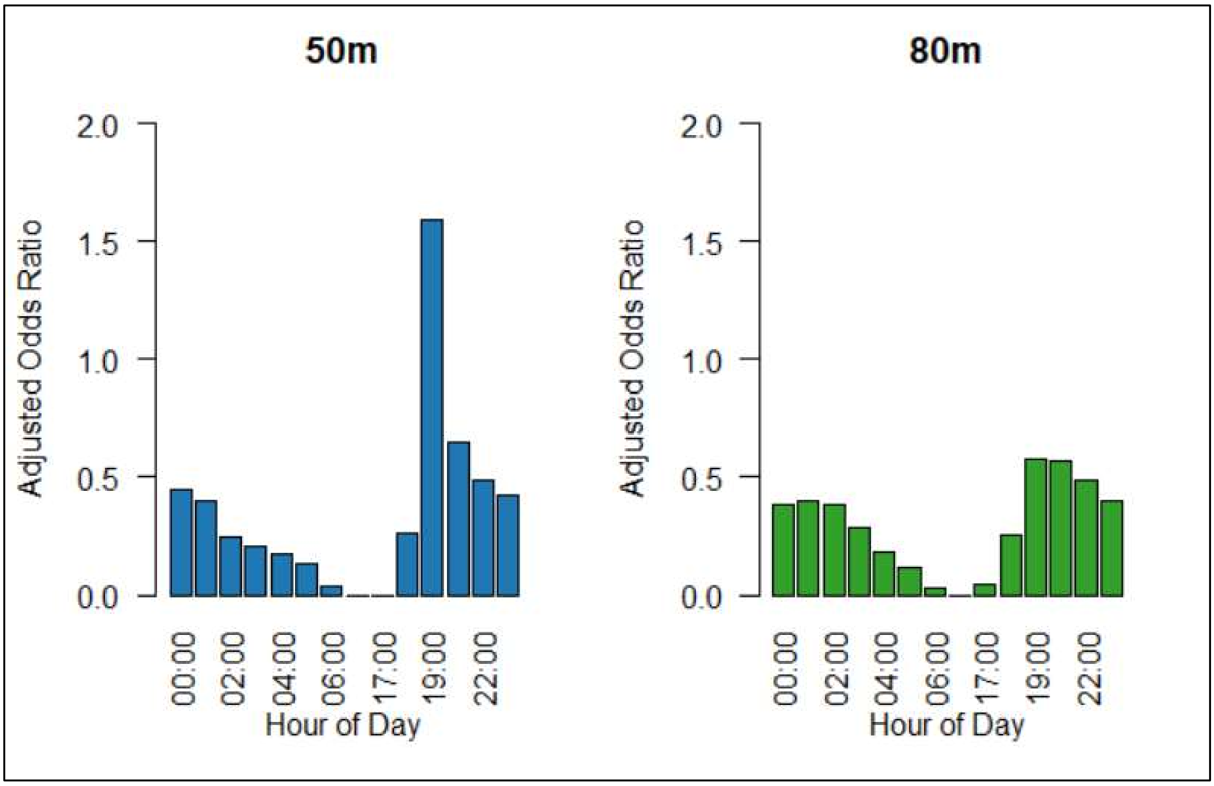

Figure 7 - Adjusted odds ratio of logistic regression models of bat probability against time and wind speed for 50m (left) and 80m (right)

I then fitted a multiple logistic regression model using average wind speed and season as predictor variables, as well as a multiple logistic regression model using average wind speed and month as predictor variables. The models including month rather than season were selected as the "best" according to the Akaike Information Criteria. The results of the seasonal model are shown in Figure 8 and of the monthly model in Figure 9.

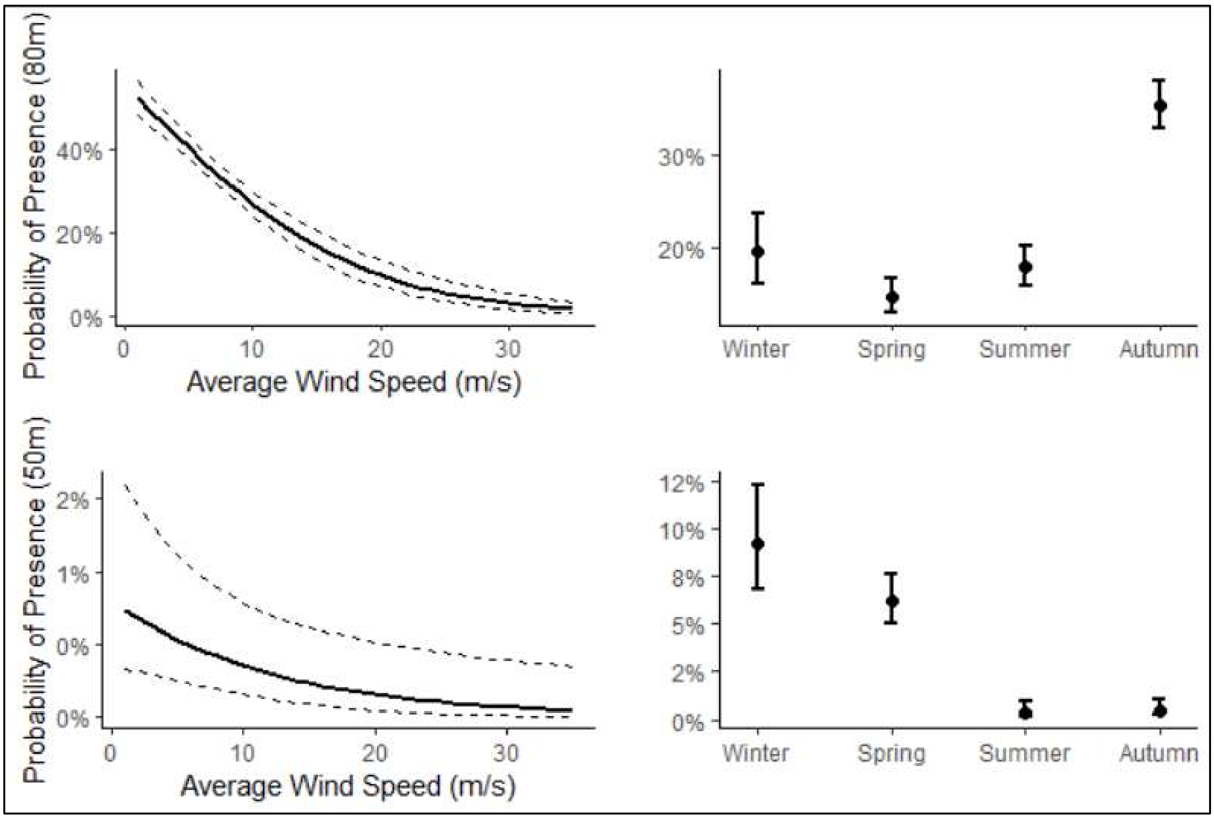

Figure 8 - Logistic regression with wind data with height and season

There is a different seasonal pattern of probability of presence at the two heights with autumn having the highest probability of presence at 80m but the lowest probability at 50m. Winter has the highest probability of presence at 50m, although the probabilities of presence are very low at 50m at any speed and season. This can be seen through the monthly model (Figure 9) where at 80m, the higher probabilities of presence occur in March, April and May. At 50m the monthly pattern is not particularly informative due to the lack of bat presence at this height. The effect of the wind speed to predict the probability of presence is reduced once the month of the year has been considered.

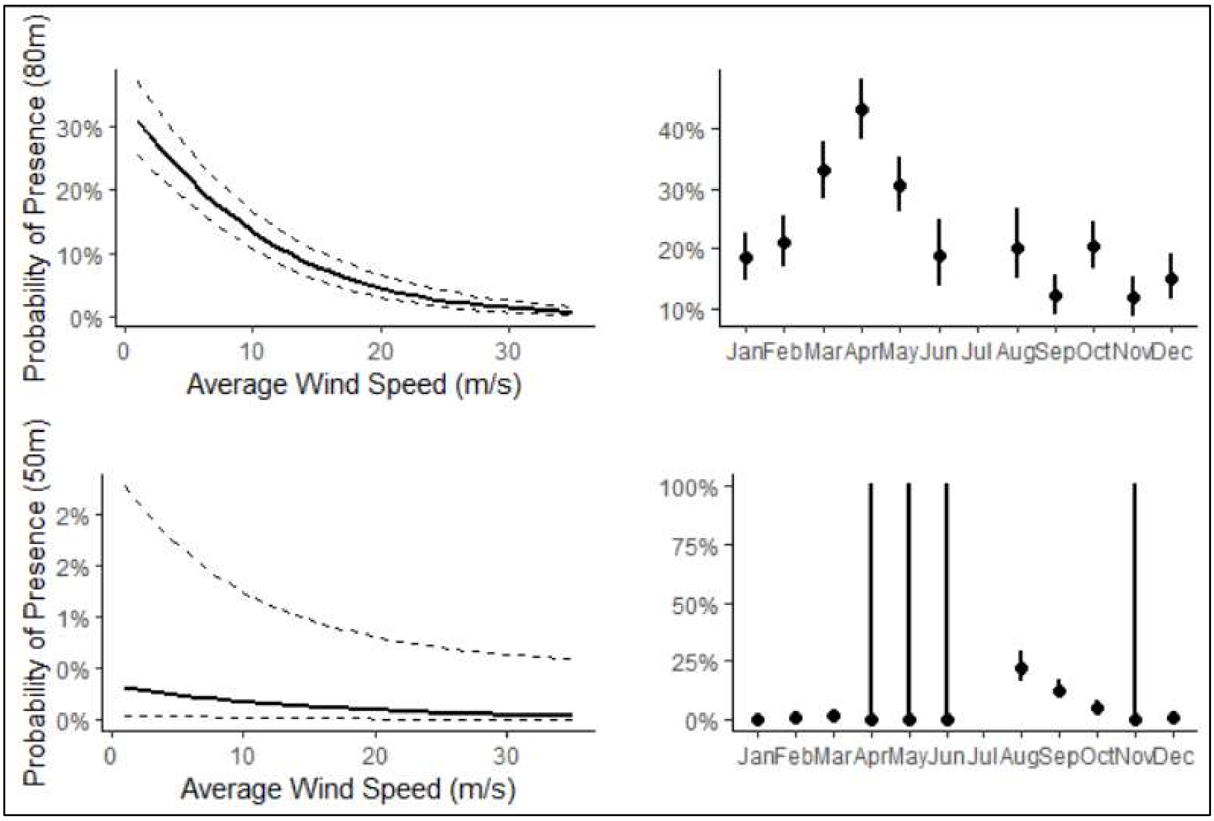

Figure 9 - Logistic regression using sites with wind data (random effect) with height and month at 80m (top) and 50m (bottom)

<u>Effect of height on bat presence</u>

I then used the data from all sites to model the probability of bat presence using a logistic regression model, with site as a random effect. The results of the model of height and month are shown Figure 10. The predicted probability of a bat being present increases at 5% per unit increase in height. The probability of a bat being present is predicted to be highest in March although the confidence intervals are very wide. The model shows an increasing probability of presence with increasing height. As mentioned before, this unusual pattern is due to the increased activity at site C25 at 80m.

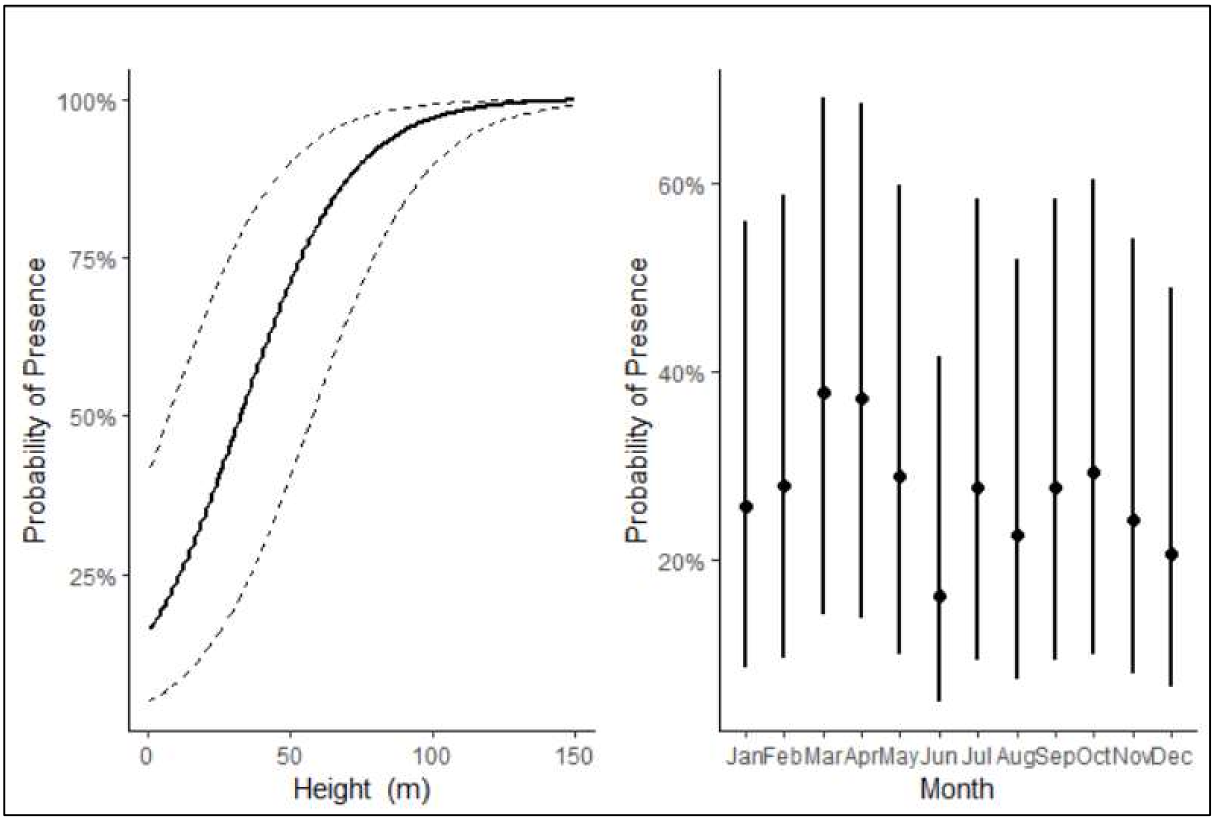

Figure 10 - Logistic regression using all sites (random effect) with height and month

A model of presence/absence against height and time of day also showed the unusual pattern of increasing probability of bat presence with increasing height. The plot for time of day is shown in Figure 11. The predicted probability of bat presence peaks at 20:00 and declines consistently through the night.

Figure 12 shows the relationship between the predicted probability of bat presence and height for the two most common species at the meteorological recording site. This plot once again shows the unusual increased probability of presence at higher heights at site C25.

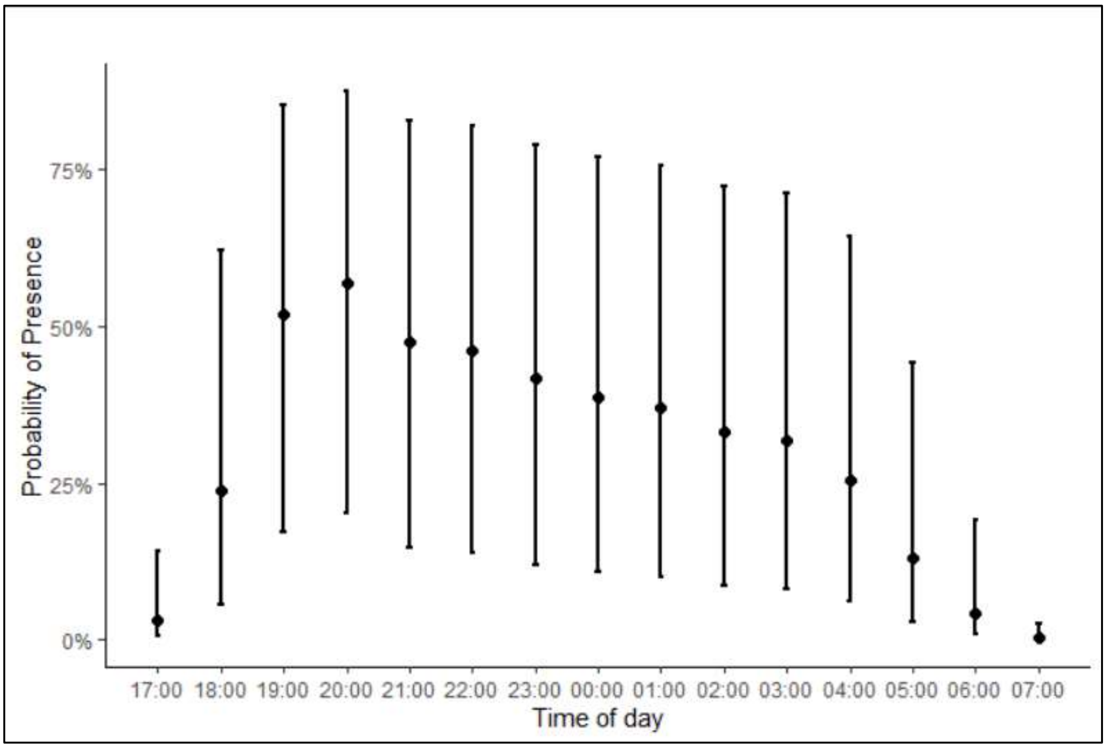

Figure 11 - Logistic regression using all sites (random effect) with height and time of day

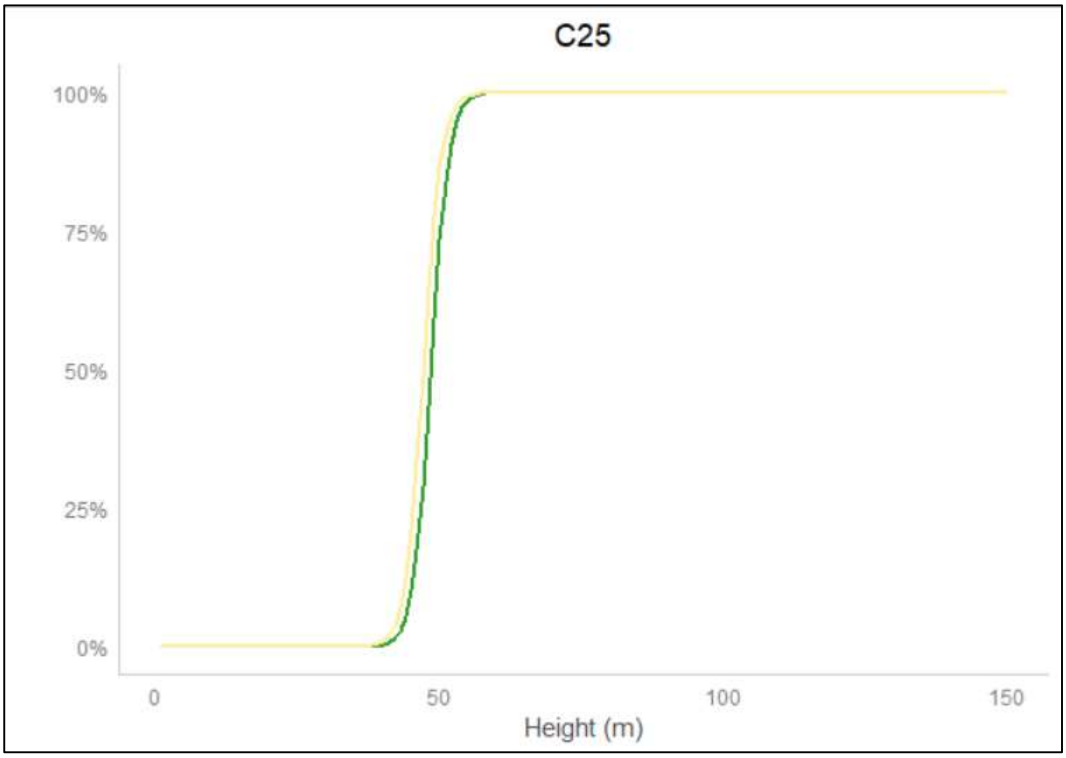

Figure 12 - Probability of presence of Egyptian (yellow) and Little (green) free-tailed bats with height