# Statistical Draft Report for Wind Relic & Arcus

# Wind Garden

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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 Wind Garden 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 Wind Garden development footprint. The following sites were included in the analysis: C11, C13, C9, C24 and C25. Three of these sites (C9, C11 and C13) are short masts, while C24 and C25 are meteorological masts. 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 374 286 records, with a total of 63 210 bat passes. Ten bat species were recorded at these sites. The associated climatic data were only available for two of the monitoring sites (C24 and C25) and no humidity data were available for these sites.

## 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 masts which recorded at 50m and 80m (Figure 1). The average number of passes are similar at the two heights for site C24, however 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).

*Table 1 - Summary statistics of recording sites*

| Site | Heights | Total Bat passes | Number of Nights | Average bat passes per night |
|---|---|---|---|---|
| C9 | 12m | 27535 | 446 | 61.74 |
| C11 | 12m | 17183 | 459 | 37.44 |
| C13 | 12m | 9056 | 422 | 21.46 |
| C24 | 50m and 80m | 2178 | 310 | 3.51 |
| C25 | 50m and 80m | 7258 | 359 | 10.11 |

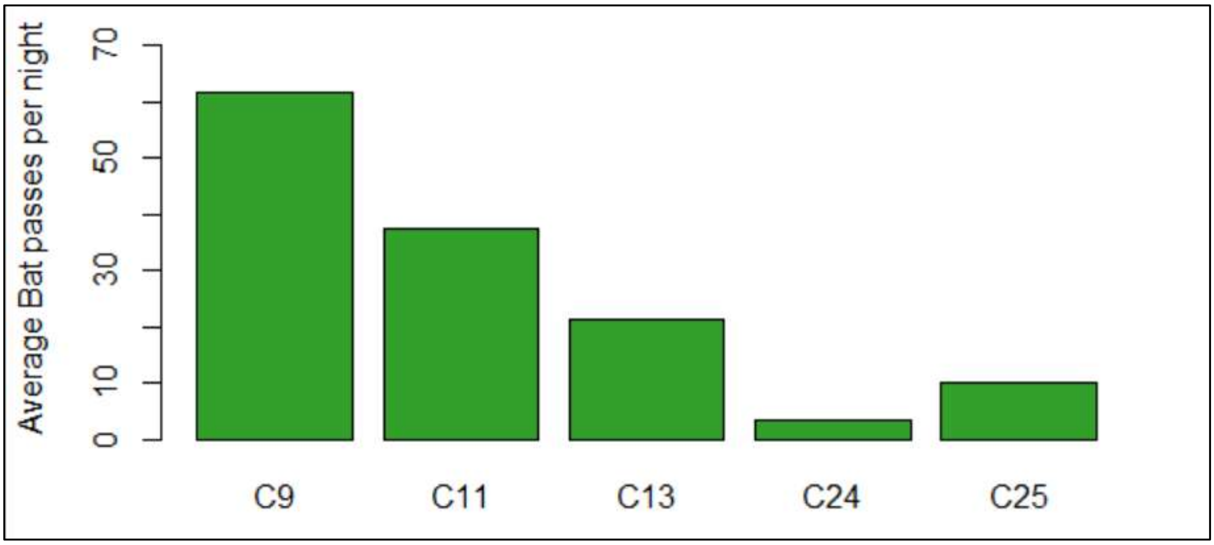


*Figure 1 - Average number of bat passes per night plotted by site*

*Table 2 - Summary of recording sites split by height*

| Site | Height | Total Bat passes | Average bat passes per night |
|---|---|---|---|
| C24 | 50m | 1242 | 4.01 |
| | 80m | 936 | 3.02 |
| C25 | 50m | 1045 | 2.91 |
| | 80m | 6213 | 17.31 |

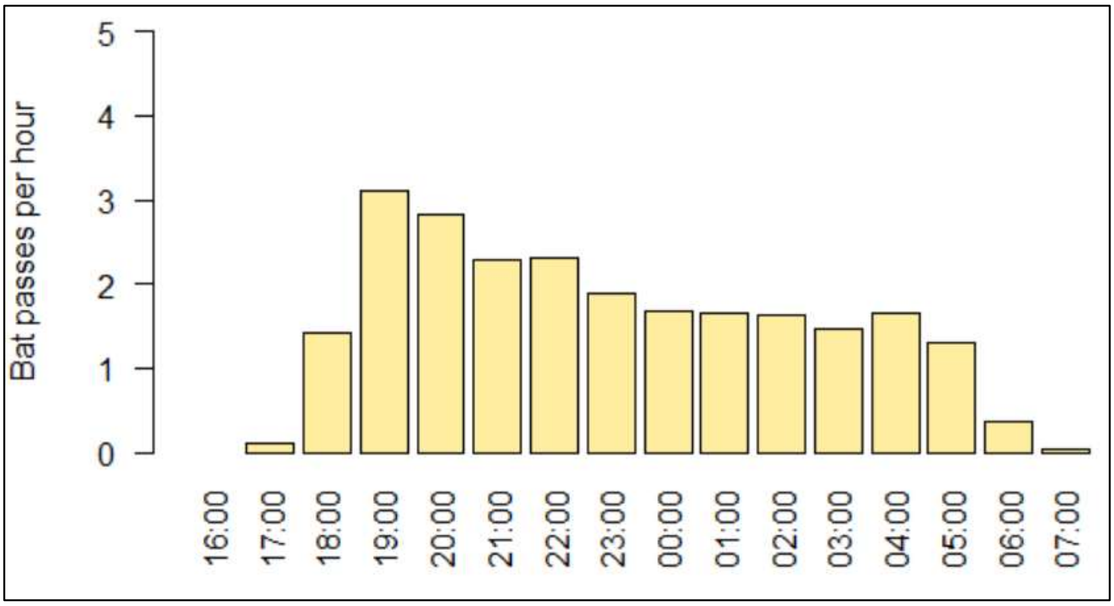


*Figure 2 - Average number of bat passes per hour by time of day*

The bat activity showed a peak around dusk and early night (19:00 and 20:00) and declined slowly through the night until 05:00 after which there was a substantial decrease in activity, see Figure 2. This pattern was consistent during autumn and spring. 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).

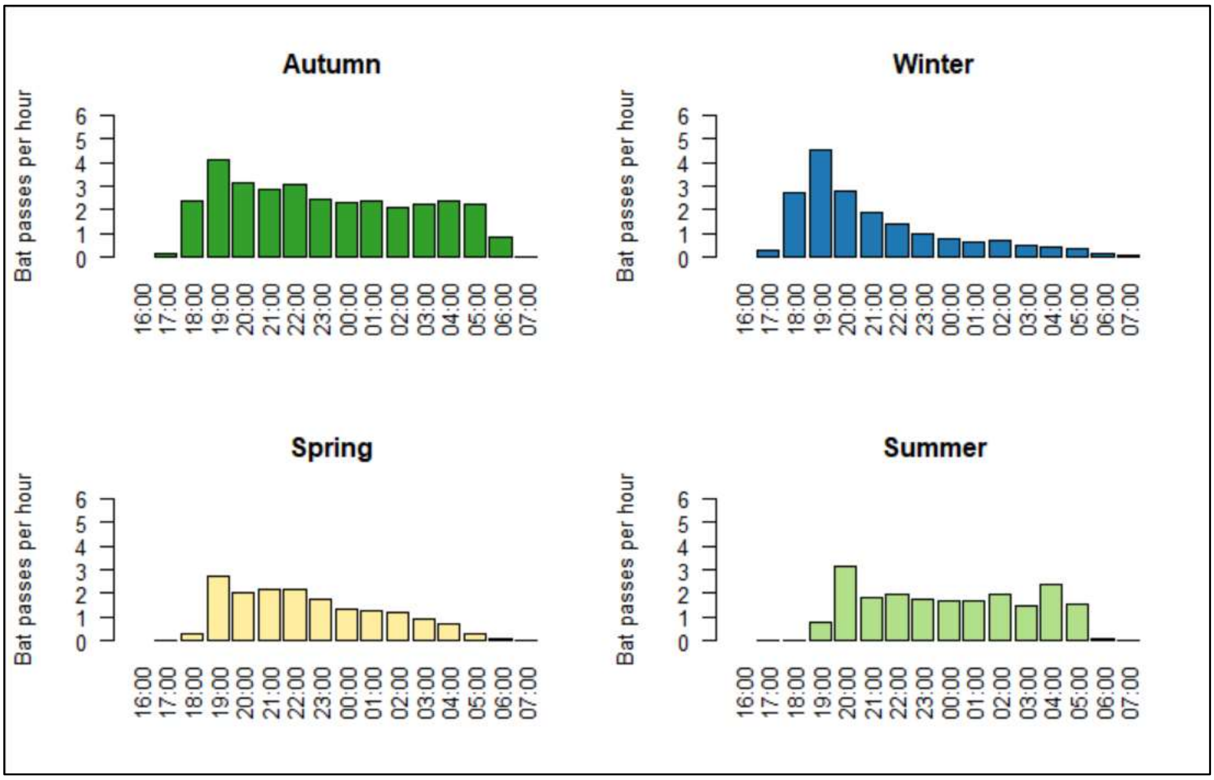


*Figure 3 - Seasonal split showing average number of bat passes per hour by time of day*

**<u>Vertical Activity Profiles</u>**

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 C9, which is approximately 3km south of the development footprint. C11 and C13 which fall within the Wind Garden footprint show lower activity levels. C24 has similar activity levels at both heights, this site is approximately 4km west of the development footprint, however C25 which falls within in the footprint shows considerably higher activity levels, particularly at the 80m height (see Figure 4).

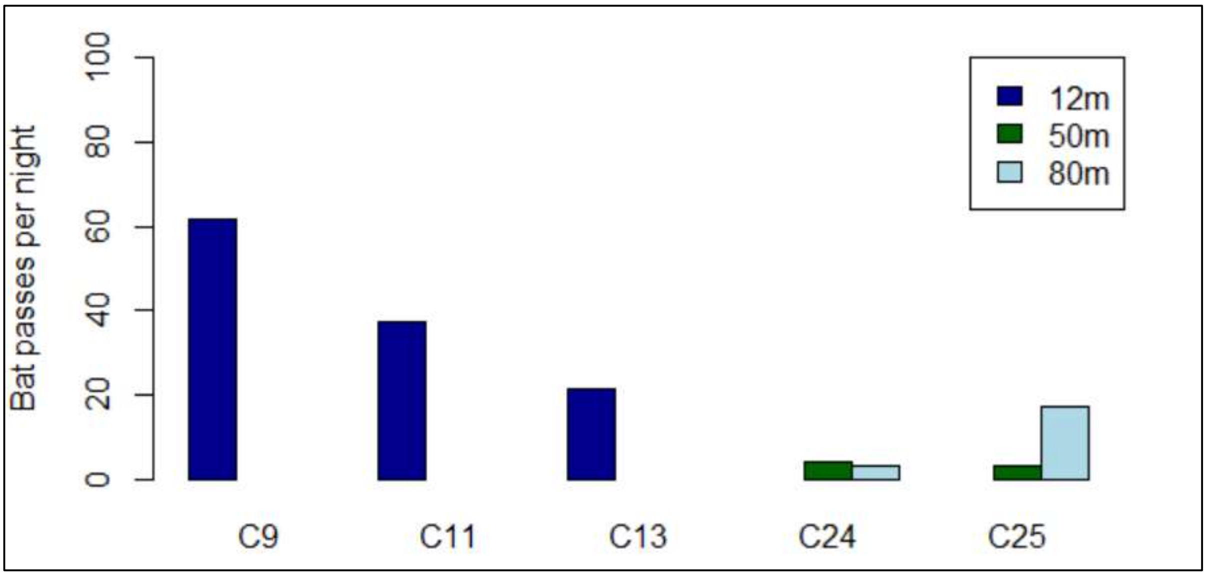


*Figure 4 - Average number of bat passes per night plotted by site and height*

The vertical activity for all sites pooled shows that most activity took place at a lower height (below 50m), see Figure 5 with more activity at 80m than at 50m.

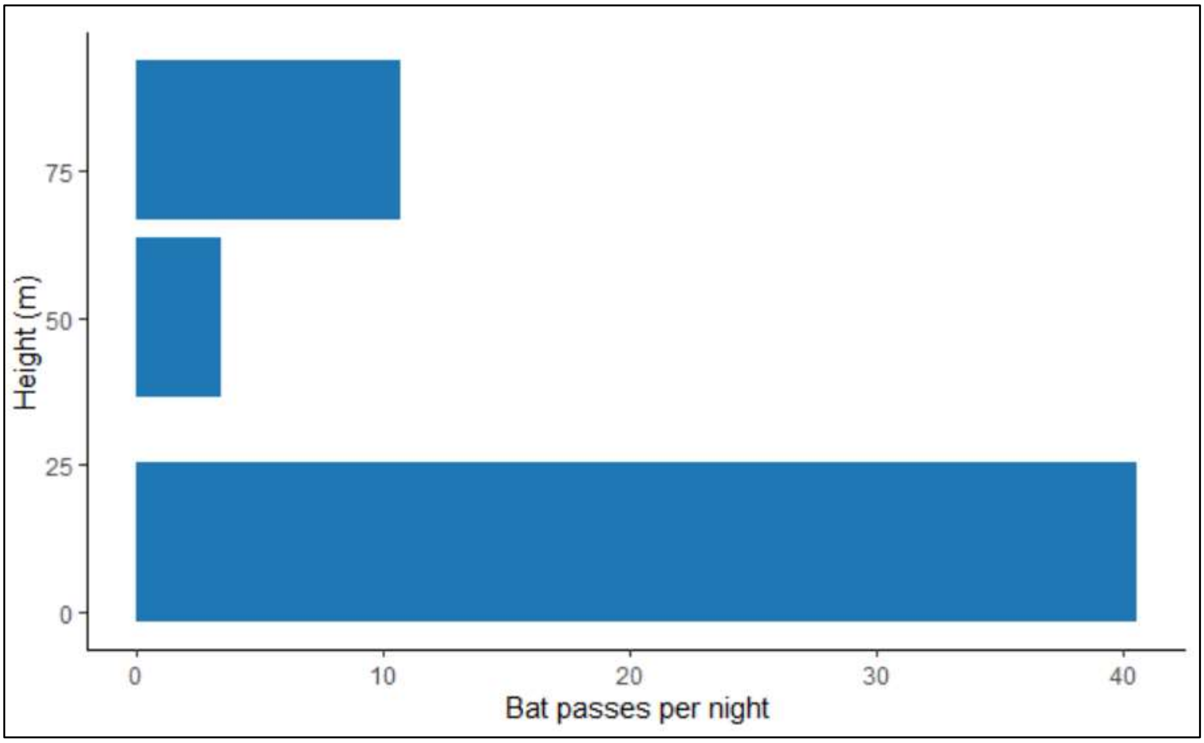


*Figure 5 - Observed vertical bat activity profile*

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 ($t = -2.203, p = 0.271$).

Similar models were then run for the two most commonly occurring species, 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 6. 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 summer, there is an increasing predicted number of bat passes with increasing height. However, none of these seasonal models were significant for either species.

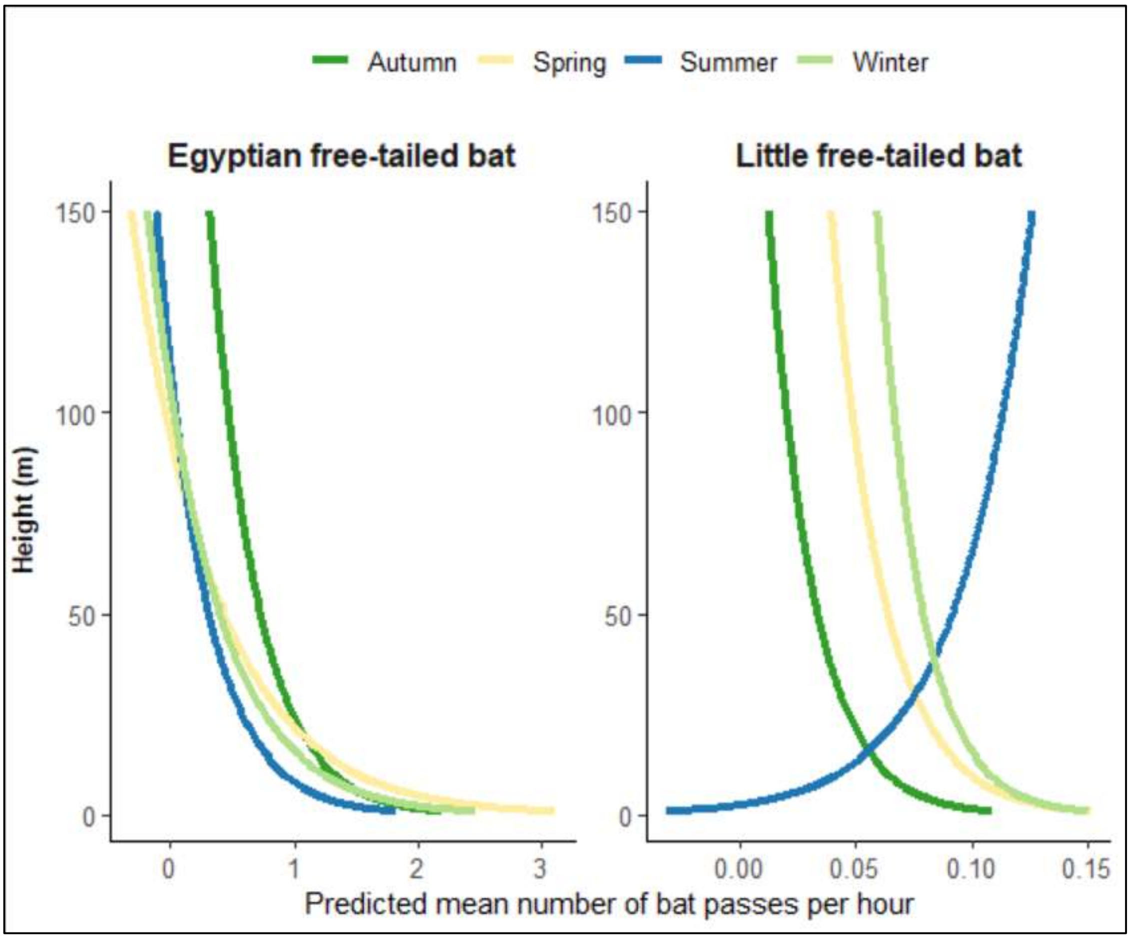


*Figure 6 - Predicted mean number of bat passes per hour with height*

## **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 | 11.542 | 1 | <0.0001 |
| 50 | Maximum wind speed | 13.27 | 1 | 0.0003 |
| 80 | Average wind speed | 195.56 | 1 | <0.0001 |
| 80 | Maximum wind speed | 205.68 | 1 | <0.0001 |

Plots of the fitted models are shown in Figure 7. At 50m, the probability of bats being present at very low wind speeds is low (<10%) and from 14m/s this probability drops below 5%. At 80m the effect of wind speed is more pronounced, with a 32% probability of occurrence at very low wind speeds and this decreases exponentially, dropping to below 5% from 19m/s. The effect of the average or the maximum wind speed is very similar.

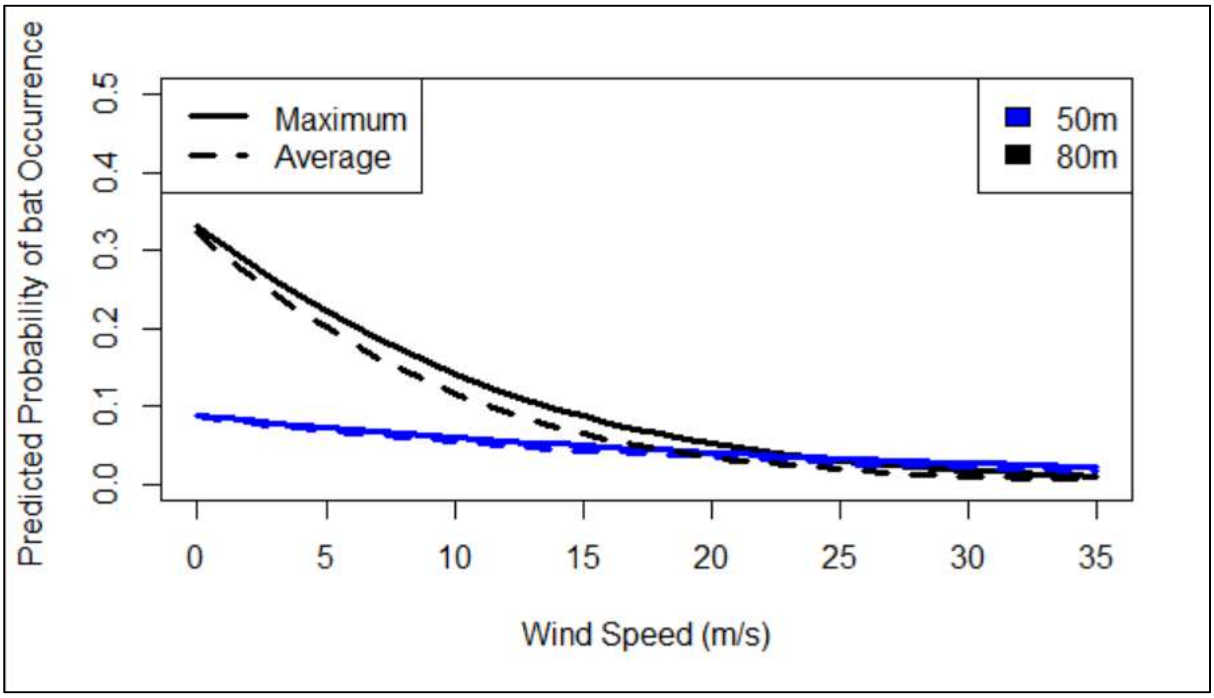


*Figure 7 - Predicted probability of bat occurrence from logistic regression models*

I also fitted multiple logistic regression models using the average wind speed and the time of day as predictor variables. I used 19:00 as the reference time, since this time period had the highest number of bat passes per night (Figure 2). For the 50m height, all time periods were significant compared to 19:00 except for 07:00 and 20:00. At 80m, all time periods were significant compared to 19:00 except for 07:00 again, 21:00 and 22:00. Figure 8 provides a plot of the adjusted odds ratios. For 80m, the odds are highest at 20:00 compared to 19:00 of a bat being present. All other times show lower odds of bats being present compared to 19:00. For the 50m height, the odds of bat presence were lower for all time periods compared to 19:00.

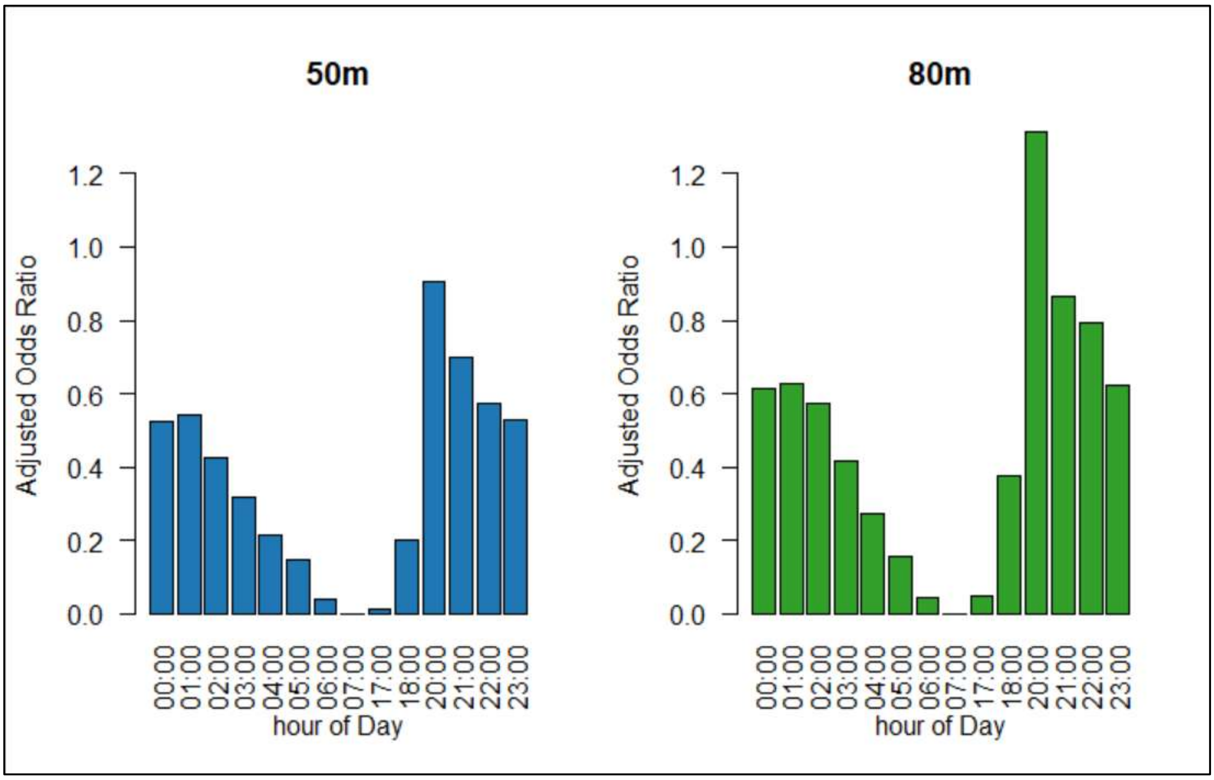


*Figure 8 - Adjusted odds ratio of logistic regression models of bat probability against time and wind speed for 80m (left) and 50m (right)*

I then fitted a multiple logistic regression model using average wind speed and season as predictor variables, with site as a random effect. And also, a multiple logistic regression model using average wind speed and month as predictor variables, with site as a random effect. 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 9 and of the monthly model in Figure 10.

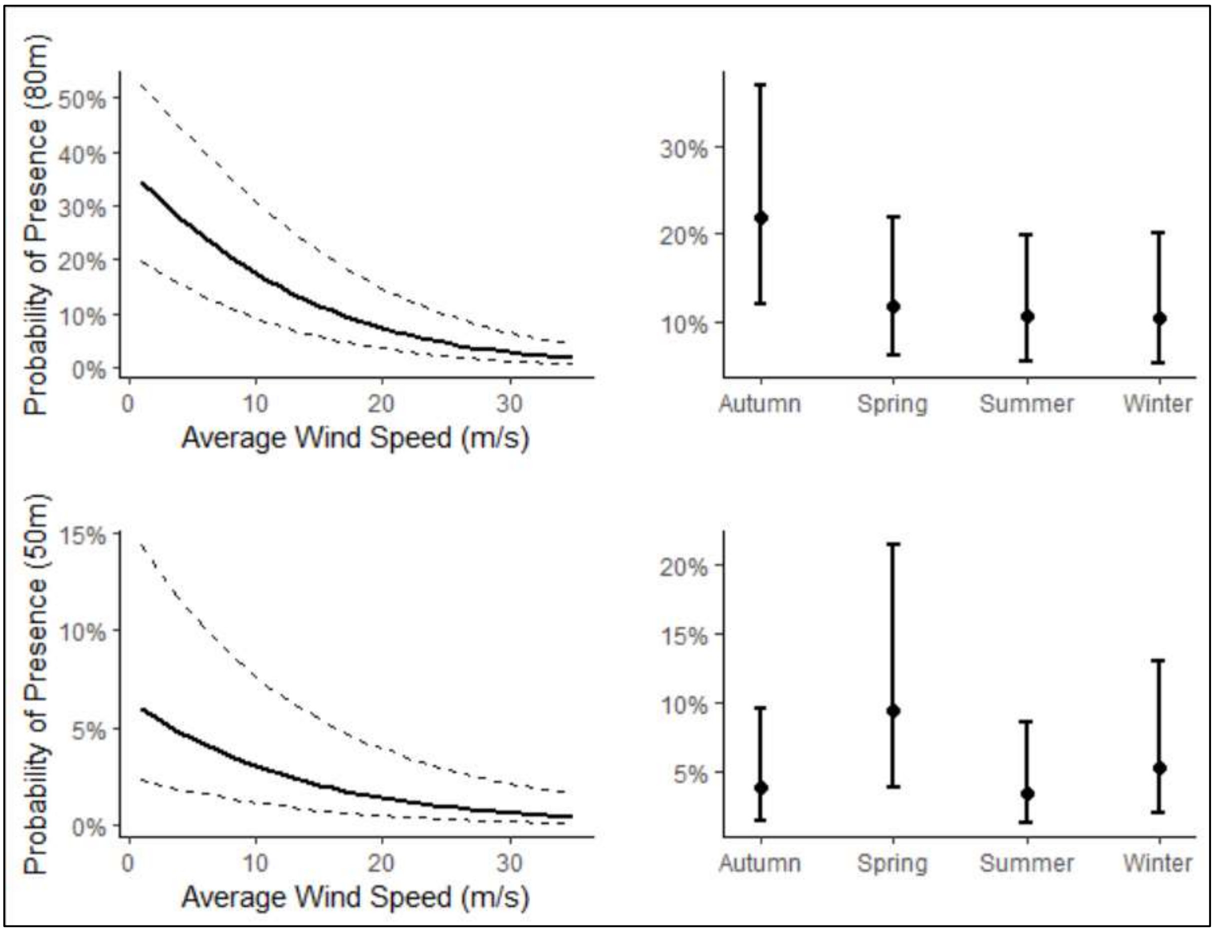


*Figure 9 - Logistic regression using sites with wind data (random effect) with height and season*

There is a different pattern of probability of presence at the two heights, with spring having a higher probability of presence at 50m while autumn has the highest probability of presence at 80m. This can be seen through the monthly model (Figure 10) where at 50m, the higher probabilities of presence occur in August, September and October, whereas at 80m, the highest probability occurs during March and April. The effect of the wind speed to predict the probability of presence is reduced once the month of the year has been considered.

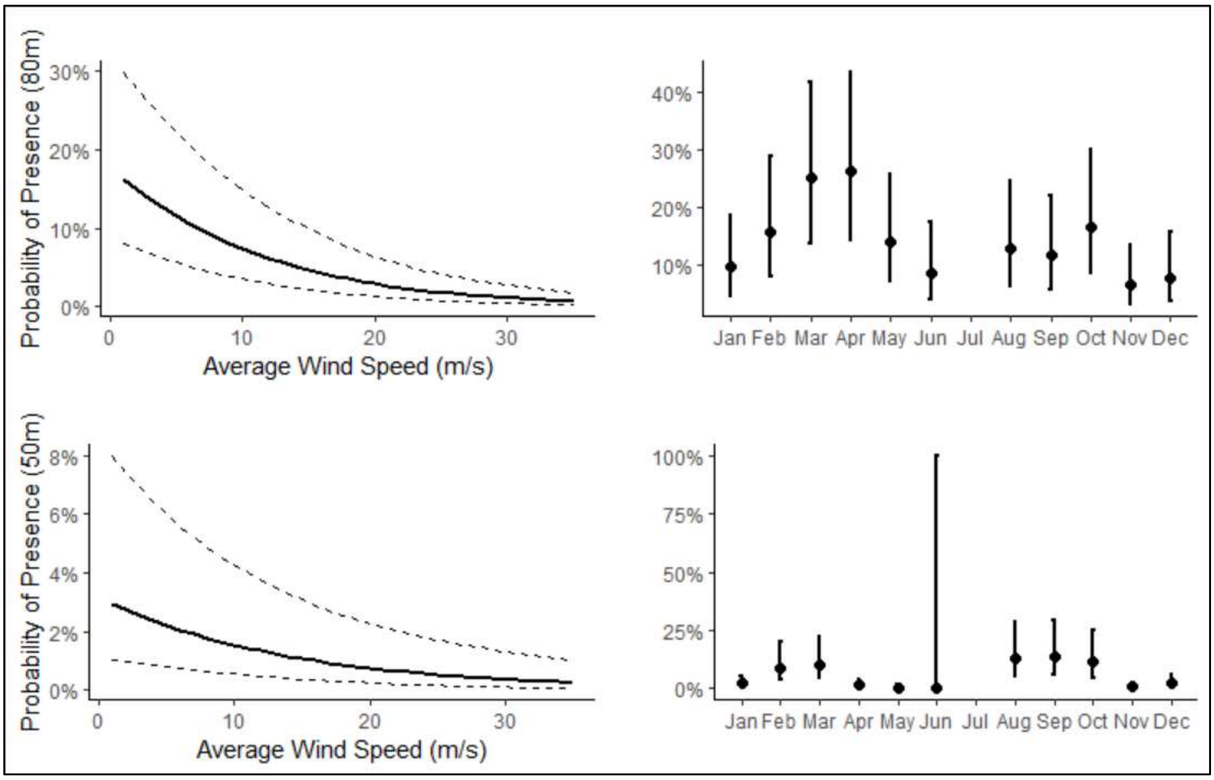


*Figure 10 - Logistic regression using sites with wind data (random effect) with height and month at 80m (top) and 50m (bottom)*

**<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 11. The predicted probability of a bat being present increases at 2% per unit increase in height. The probability of a bat being present is predicted to be highest in March and April with June having the lowest probability of presence. The model shows an increasing probability of presence with increasing height. As mentioned before, this unusual pattern is as a result of the increased activity at site C25 at 80m.

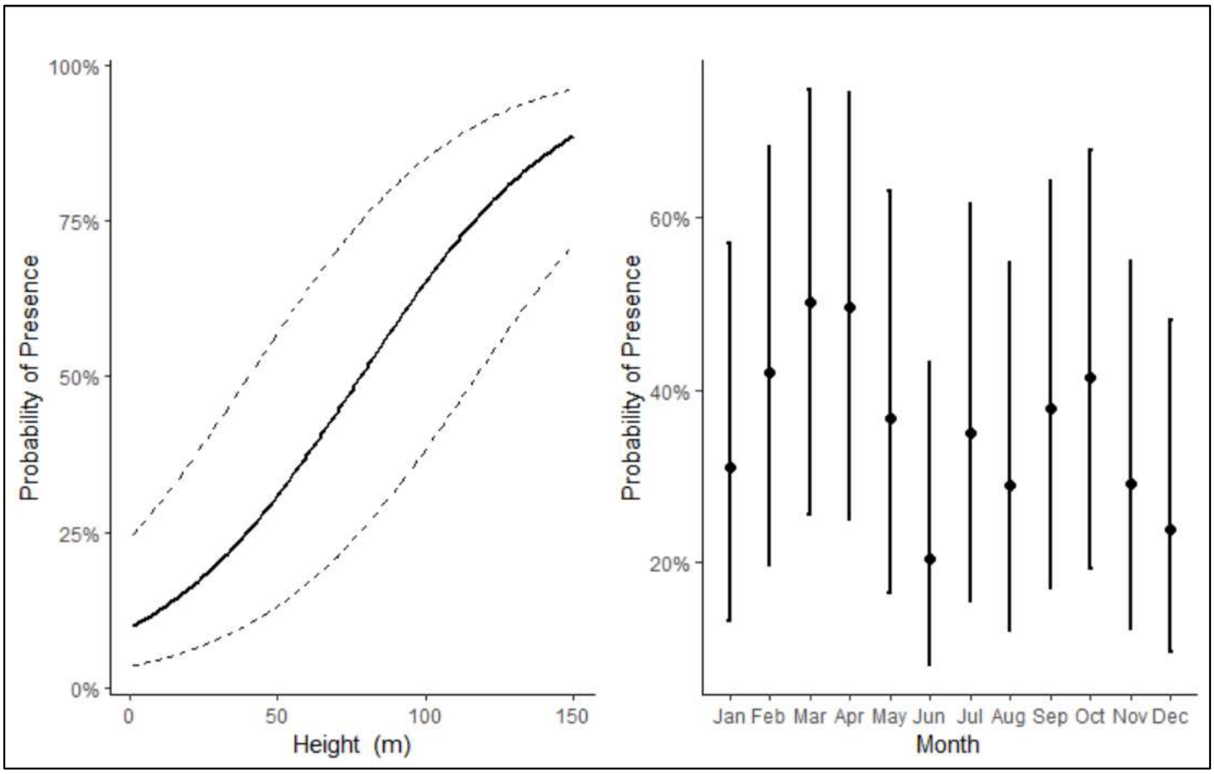


*Figure 11 - Logistic regression using all sites (random effect) with height and month*

A model of presence/absence against height and time of day also showed the pattern of increasing probability of bat presence with increasing height. The plot for time of day is shown in Figure 12. The predicted probability of bat presence peaks at 20:00 and declines consistently through the night.

Figure 13 shows the relationship between the predicted probability of bat presence and height for the two most common species at the two meteorological recording sites. This plot once again shows increased probability of presence at higher heights at site C25, and the opposite pattern for site C24.

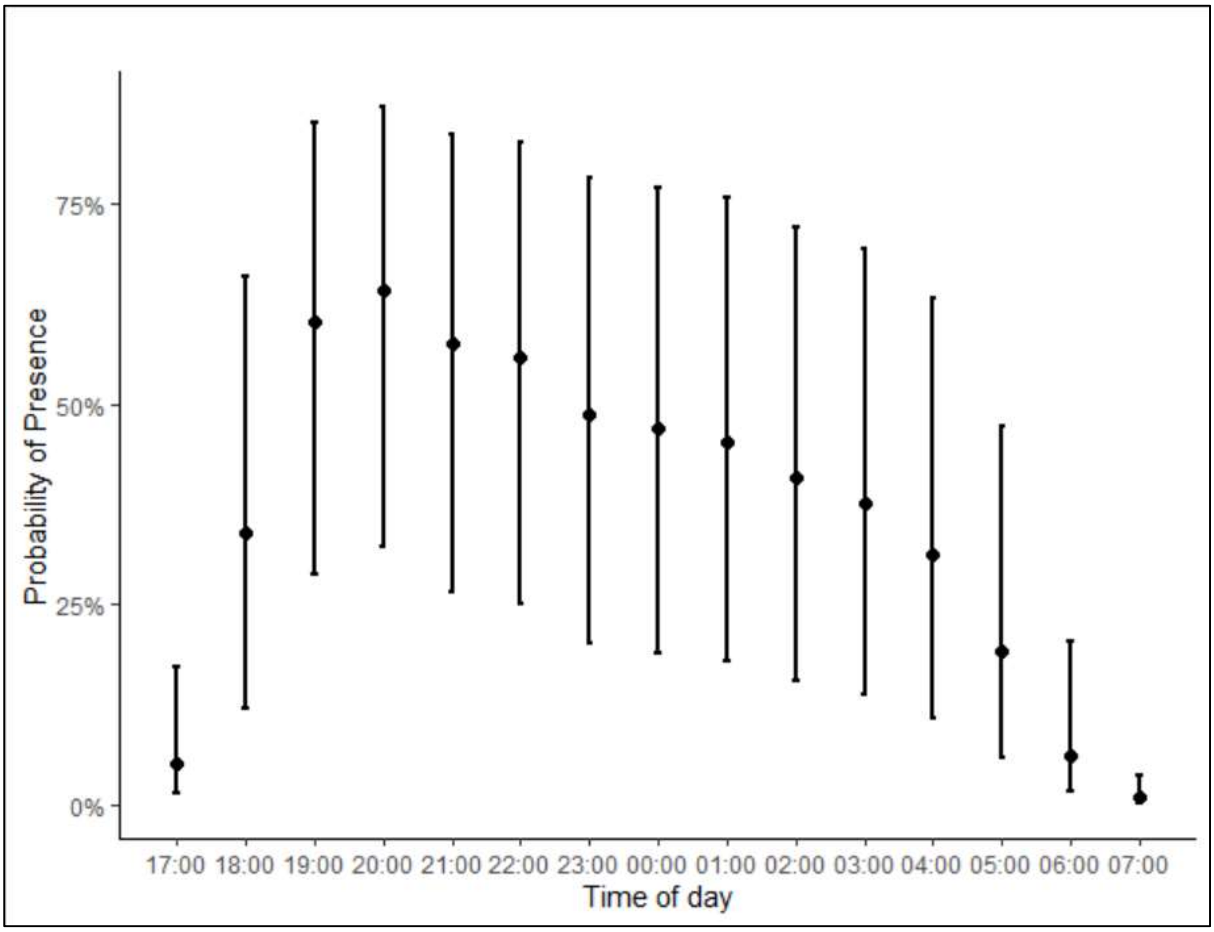


*Figure 12 - Logistic regression using all sites (random effect) with height and time of day*

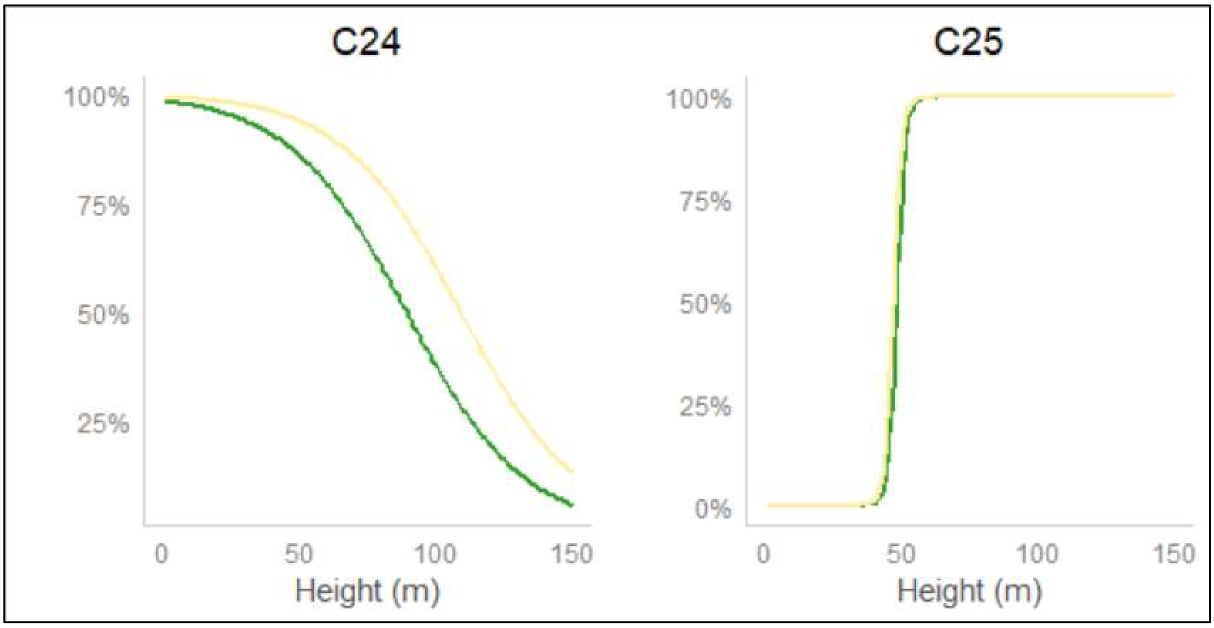


*Figure 13 - Probability of presence of Egyptian (yellow) and Little (green) free-tailed bats with height*