Habitat selection for sleeping sites of the Sunda pangolin (*Manis javanica*) in the Lower Kinabatangan Wildlife Sanctuary: A case study on a resident wild female.

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a. Reflection

My time at Danau Girang Field Centre was nothing like I expected but I believe it helped me grow both academically and personally. It was different to the other placements I applied for, but I am so glad I was offered the opportunity to spend nine months able to fully immerse myself in the work and the culture. It was a very steep learning experience from the moment I arrived.

The main skills developed were field work, such as trapping and tracking animals. I would now say I feel fully confident in both UHF and VHF tracking; baiting and setting mammal traps; I even had the chance to be vet assistant on a flat headed cat procedure. I also know how to set up camera traps. There were other non-zoology aspects, such as maintenance of the botanic plots and learning how restoration ecology is applied in secondary forest. Apart from field work there was also the opportunity to learn more statistics relevant to our reports, from Rich, a PhD studying reticulated pythons (we also got to assist with this project, going out at night on boat surveys). I also worked with the pangolin conservation officer Elisa Panjang on her sleeping site project.

It definitely took a couple of months to adjust to the climate and on top of that doing several hours of field work every day, however it always felt rewarding and all the volunteers would take it in turns to be scheduled different projects. Working in the morning was good because you could get out before the sun really started to make it uncomfortable but that did mean early starts so it was good that there wasn't a set weekly schedule and you could ask for mornings off if necessary!

I did get quickly used to the fixed mealtimes with everyone else. The social aspect of this was nice most days, and everyone respected the need for alone time. I did not ever feel like there was a pressure to be constantly working in the office as that was also our living space. I felt like the placement was so well organised as accommodation was sorted before we left the UK and once we arrived Audrey helped us to collect visas and organise holiday dates.

The Covid-19 pandemic meant that my placement finished 3 months early. I was lucky compared to the other students because I finished collecting most of my field data. However, after arriving home it was hard to adjust to the UK again. I struggled to find motivation to complete the work once I was no longer in the working environment. All my supervisors and other PhD students at the field centre were helpful over message but the time difference did make it quite difficult. It feels like quite an anti-climax, but I am still so thankful for the time I spent there.

b. Scientific Report

Abstract

Pangolins are the most trafficked mammal in the world. The Sunda pangolin (*Manis javanica*) is critically endangered (CR) and protected under national and international law. Very little is known about these animals and, given their decreasing population trend, it is crucial that their ecology and lifestyle are well understood to support management plans in the wild to protect them from extinction. Pangolins can be tracked using radio telemetry, enabling the identification of individual animals' sleeping sites. The characterisation of sleeping sites for the species is of utmost importance as these largely define the habitat's suitability for pangolins. Here, a total of 68 different sleeping sites were recorded for 'Berkat', a VHF-tagged Sunda pangolin. This was carried out in a highly fragmented secondary forest under threat from increased land conversion to oil palm plantation in the Lower Kinabatangan Wildlife Sanctuary (Sabah, Malaysian Borneo). The aim of this project was to determine what environmental variables were selected for when the focal animal chooses its sleeping site. Habitat was assessed and the following variables were tested: tree height, presence and number of hollows, vine score, diameter at breast height and canopy cover. The null distribution for those variables was determined by recording the same variables on random trees with unknown pangolin presence. A binomial generalized linear model was used to determine any relationships between a tree choice and its characteristics. The results support the hypotheses that diameter at breast height and tree-height are significant predictors of pangolin habitat, with plotted trends showing a preference for wider and taller trees. This study highlights the importance of conserving fragmented forest as habitat for Sunda pangolins.

Introduction

1.1 Background

Pangolins have been recognised as one of the most threatened mammals on this planet (Khwaja *et al.* 2019). There are eight species of three extant genera which all belong to the Manidae family. Pangolins are described as being nocturnal, secretive and solitary animals (Lim and Ng 2008). They are rarely seen as by-catch in camera trap data which indicates there are few individuals left in the wild. Little is known about the eight extant species of pangolin (*Manis* has four species all found in Asia), and there is a particular gap in the research surrounding the Sunda pangolin (*Manis javanica*). For example, there is one published report on the reproduction of pangolins, where one offspring was observed receiving approximately three months of maternal care (Lim and Ng 2008).

Pangolins are known as ecological service providers (Pappin 2011). Their morphology indicates they are adapted to a highly specialised diet of ants and termites. Their long, sticky tongues and powerful long claws suit digging into mounds, and their body shape is the reason they are often referred to as scaly anteaters (Mahmood *et al.* 2013). They are exclusively insectivorous, with one individual able to eat up to 70 million insects per annum. Consequently, pangolins play an important role in their ecosystem controlling the ant and termite populations, reducing the damage on trees in their ecosystem (Pappin 2011). A pangolin weighing 3kg can protect up to 16 hectares of forest from being overrun with ants, therefore supporting healthy ecosystems. Furthermore, as a burrowing animal they are ecologically valuable as their digging actions provide shelter and/or breeding habitat for other animals, ultimately contributing to the overall animal diversity of the surrounding area (Hua *et al.* 2015).

All pangolin species are protected under Appendix I. of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), which introduced a total ban on international commercial trade in 2017. Despite their IUCN Critically Endangered (CR) status, thousands of these animals are sold in the illegal trade every year. They are bought for their keratinized scales to be used in traditional Chinese medicine (TCM), or for their meat which is considered a delicacy in some cultures (Challender and Waterman 2017). Topically pangolins have featured recently in the news as a potential carrier of COVID-19. This has made people more aware of the species and the threats they face.

The second threat to pangolins, along with many other rainforest species, is the increasing land conversion of forest to plantations, oil palm in particular. Not much is known about the impact of land use change on population dynamics as there are few records for pangolin populations. Habitat loss and fragmentation are the two main threats to biodiversity (Wilson 1992). Habitat loss has direct consequences for species abundance and diversity because it reduces the available living space. Another concern surrounding the conservation of the pangolin specifically is that captivity programs tend to fail, due to rescue centres facing problems with preparation of a suitable diet. Knowledge of pangolin habitat use, and their distribution is crucial for conservation plans (Mahmood *et al.* 2015).

To be able to protect a species, their habitat requirements need to be fully understood, then research needs to be conducted to explore their adaptations to fragmentation. More background research is needed to characterize pangolin habitats to apply this information to an effective management plan. Gaining a better understanding of an animal's movement ecology within their home range is essential to developing better conservation plans for a species. An important part of a pangolin's habitat is their sleeping site, as this helps to protect them from predation.

This study only focuses on investigating sleeping sites but there have been previous studies that already show a significant difference between the height and width of sleeping and feeding burrows. Feeding burrows rely on prey availability, whereas living burrows last longer but are usually abandoned after a few months (Mahmood *et al*. 2013). Other researchers have previously documented features such as metres above sea level, existence of termite colonies and vegetation analysis. They also measured depths of both feeding (temporary) and sleeping (permanent) burrows (Mahmood *et al*. 2015). Some studies focused on presence of pangolins and their burrows in different habitat types, with only secondary forest hosting resting burrows, and pine-dominated forests having a higher abundance of feeding burrows (Karawita *et al*. 2018). The same study identified for the Indian pangolin (*Manis crassicaudata*), that important parameters included tree species, vegetation cover and geological features, such as water bodies. However, they did not use tracked pangolins only sign surveys which meant distinguishing burrows from those of other animals was a key challenge. Therefore, in our study only known sites were analysed.

Understanding more about the ecology and lifestyle of pangolins is of key interest to researchers in this field. This is particularly important in a fragmented landscape such as the Lower Kinabatangan Wildlife Sanctuary (LWKS), as it is unknown how they are using the forest, or how the land use changes might impact them. There has been previous research into pangolin habitat characteristics in Peninsular Malaysia, which was mostly exploring their use of mature forest and the need for protection of the habitat, but there are not any conclusive studies in Borneo (Chong, Muhammad and Marina 2016). Hence, findings from this research will contribute to a better understanding of pangolin habitat, which is fundamental to successful conservation planning of the species.

1.2 Aims and Hypotheses

Sleeping sites are an important aspect of an animal's habitat (Mahmood *et al.* 2013). Pangolins are nocturnal animals which means they move around in the night to feed on ants and termites, and before sunrise they settle into one location for the whole day. This study aimed to characterise the sleeping site of 'Berkat', a wild female Sunda pangolin, by collecting data from the tree identified to have been used for sleeping.

The first part of this requires collecting data for several variables and using this to produce a model to see which characteristics have a significant impact on a site being chosen. The second part of this research is to use this model for predicting a sleeping site.

This study investigates what environmental factors influence sleeping site selection for the Sunda pangolin. Habitat selection is defined as: "the process by which a species chooses its habitat" (Morris 2019). This study is based on the understanding that the sites analysed were used for sleeping, whereas the random sites were unused, so this research aims to explore habitat preference and selection. We use seven variables to characterize the sites: diameter at breast height (DBH), tree height, presence of hollows, number of hollows, vine score, canopy cover and distance from water body.

We hypothesise that 1) diameter at breast height, 2) tree height and 3) the presence of hollows are environmental factors influencing pangolin sleeping site selection. The study conducted was successful in indicating the individual's preference, and in using the model to predict a sleeping site. Defining sleeping site habitat is an important step in understanding more about pangolin ecology, which will therefore assist in the effort to conserve remaining wild individuals.

Materials and Methods

2.1 Study Area

The research was conducted in Lot 6 of the Lower Kinabatangan Wildlife Sanctuary (LKWS), Sabah, Malaysian Borneo (5°18'N to 5°24'N and 117°54'E to 118°33'E) (Evans *et al.* 2016). This area is characterized by secondary forest, a mix of riparian and semi-inundated forests, little to no dipterocarps remain, also peat swamp and limestone karst in some parts. The dominant geological feature of the area is the Kinabatangan River and its oxbow lakes, Danau Girang and Danau Patong. There is a narrow strip of wildlife corridor flanking the Kinabatangan river, but the landscape is oil palm plantation dominated. The closest palm oil plantation is Hillco on the opposite side of the river to the study site. This research concentrates on a pangolin that was released in the vicinity of the Danau Girang Field Centre (DGFC). The nearest human settlement is around 10km away (Fig 1). The LKWS has an annual temperature of around 21-34˚C and it receives an average rainfall of 3,000mm (Acrenaz *et al.* 2004, Estes *et al.* 2012). The area has a (not so distinct) wet season from December to February. The study site, including each individual sleeping site, in relation to nearest water bodies and human settlements is shown in the sub panel in Figure 1.

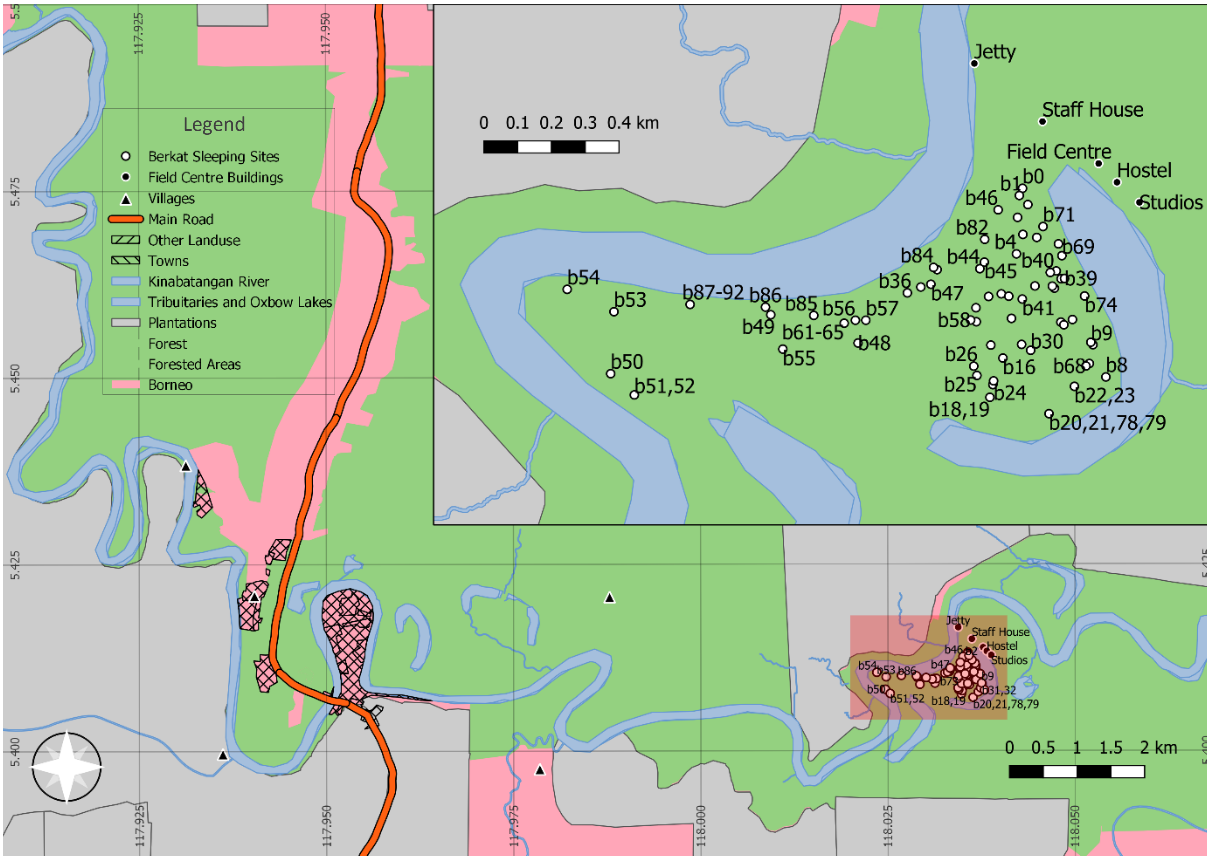


Figure 1. Map showing the study site and sleeping sites of the pangolin. *We used the most recent land use and cover layers from 2016, and imported data points from the sleeping sites and DGFC buildings. The labels for each sleeping site are named based on which night into the tracking period they were identified. Scale bars on both maps show the largest range between any two sleeping sites is less than 2km. The study site is demonstrated by the map in Figure 1, which has waypoints imported from Garmin Basecamp software which was initially used to visualise distance from main building, water bodies and marked trails etc. Map created using Geographic Information System (GIS) Noosa 3.6 (QGIS3.6 2020).*

2.2 Tracking

PhD student Elisa Panjang had previously collared and VHF tracked a resident female pangolin which was released in the vicinity of DGFC, LKWS. GPS points of the location of the sleeping sites were recorded every morning (if a signal strong enough to accurately identify the sleeping site was obtained) between March 2019 - August 2019 (Garmin GPS v. 64s). Over 98% of these sites were either classed as ‘in the tree’ or ‘in hollow of tree’ (total sites 87 over 134 tracking days, 68 of which were unique). The other types of microhabitats were ‘in bushy area’ or ‘in burrow’. When the pangolin was recorded in one of these two latter microhabitats, the data point was excluded because the sites could not be adequately characterized by the variables included in our habitat assessment. It was decided that for this study, trees are the most relevant aspect to a pangolin sleeping site. Therefore, our chosen environmental parameters were based on the trees, and not the surrounding area. All sleeping-site trees have individual GPS locations and were named based on the night number of the sleeping site (Fig 1).

2.3 Habitat Assessment.

Data collection took place over a three-month period (January 2020 – March 2020) following the "design II study" model as described by Thomas & Taylor (1990). For the design II study model data is collected through a field habitat assessment. Using a handheld GPS-device, each previously identified sleeping site was located. The main aspects of habitats measured were of the trees identified as sleeping site trees. To characterize the site a variety of six variables were observed and measured, which were designed to quantify the habitat. These included diameter at breast height (DBH) (cm) of the tree, height of the tree (m), presence and number of hollows in the tree, vines covering the tree and canopy cover. The same data was recorded for three random trees within 10m radius of the confirmed sleeping site. Characteristics of the 52 occupied sites were compared to a random sample of 150 sites of unknown pangolin status.

To record DBH in cm, a tree caliper was placed at 1.3m height from the base of the trunk. If the tree had a buttress root, then 1.3m was measured from the section where the buttress root system develops into the trunk (rather than the base). Often a ladder was used, and if the tree was too large for the calliper, then the circumference was taken with a tape measure and the final value divided by pi before being entered into the spreadsheet.

To calculate the height of the tree in metres, two measurements were taken whilst at the sleeping site which contributed to the final absolute estimated value. This uses the trigonometric method demonstrated in Figure 2. Standing on the forest floor in a place where the canopy of the tree is clearly visible, the clinometer was pointed upwards until the reader could align it with the canopy. The angle in degrees was read off the clinometer. The reader stands in the same place and the distance from the person making that measurement to the tree was recorded in centimetres. If the tree leans at an angle, the distance between the person reading the angle and the tree is measured in a straight line to directly underneath the canopy, rather than to the base of the trunk.

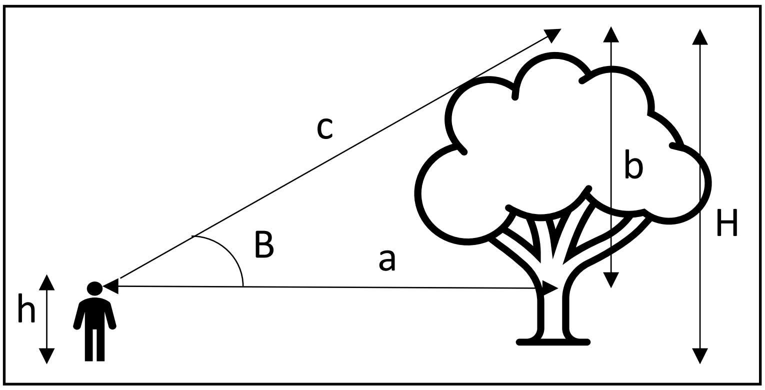


Figure 2. Diagram showing how an absolute estimate for tree height is measured in the field. *Adapted from White and Edwards (2000). Labels are as follows: h) eye height of the measurer (cm), a) distance between tree and researcher (cm), c) the direction in which the clinometer is pointed, B) the angle read off the clinometer (degrees), all these are entered into the equation in appendix II to produce: b) height of the tree minus eye height of the measurer (cm) and H) total absolute estimate of tree height (m). This method is often referred to as the clinometer and tape method (White and Edwards 2000). Aside from the more obvious human error of misreading angles and distance, there is also an assumption made that the canopy of the tree is at a right angle above the base of the tree, however this only tends to be applicable to young trees grown in a plantation fashion, not the older trees around DGFC.*

The final measurement for tree height used the same tape measure to measure the eye height (h) of the same person who read the angle (B). The equation demonstrated in appendix II was then used to convert these values and eye height of the person using the clinometer into an absolute estimate of total tree height (m). There are other methods that suggest including measuring the angle from the eye to the bottom of the trunk and adding the results of the two triangles together (White and Edwards 2000). However, as most of the area around DGFC is relatively flat land this was deemed unnecessary. It was decided the method we used had enough accuracy.

At every site, any tree with a hollow large enough to accommodate a pangolin was scored as 1 (presence), while those without hollows scored as 0 (absence). If there was more than one hollow then the number was recorded. We included holes that looked nearly closed off but that would have been wide enough to allow the pangolin to enter at the time of use (several months earlier). It was decided to not include hollow height from the ground as pangolins are excellent climbers and are therefore likely able to reach the hollow at any height (rendering hollow height from ground level irrelevant as habitat selection criteria). Another habitat variable considered as relevant was vine score, which was scored on a scale of 0-5 (0 meaning no vines present, 5 meaning a site covered fully in vines, see reference pictures in Appendix I). As this variable is quite subjective, we aimed for measure-consistency by using the same person to score vines every time.

Finally, to determine canopy cover, a photograph was taken by the same person for reproducibility standing under the sleeping tree, with the camera directed upwards to capture canopy cover. This was repeated north, south, east and west facing to get an average, and to allow for the difference in light intensity penetrating the canopy. This whole method was then repeated measuring the same variables for the three random tree sites.

2.4 Habitat Assessment for Computerized Variables.

The software ImageJ was used to process the images taken in the field of the canopy. Because the images were taken at different times of day the light intensities are different and therefore each image had to have its threshold separately adjusted before analysing the percentage of cover in the photo. For each site, the average canopy cover was calculated and added to the spreadsheet for analysis. The other variable that required computer software was distance from water body for the sites with a pangolin present. In QGIS3.6 NOOSA (2020) the ruler tool was used to measure the distance from each sleeping site point to the nearest permanent water body. Distance from water body was not collected for the random sites as they were geographically too close to the sleeping sites, so it was unlikely to be a significant indicator of whether a site was chosen or not, therefore it was not included in analyses.

2.5 Data Analysis.

The raw data was collated to produce a dataset, that included the tree height estimates. For any sleeping sites that had been used more than once the data of that tree was multiplied meaning a total of 82 presence sites were analysed, along with 150 absence sites (Walters, Mazzotti and Fitz 2016, Grenier and Nelson 1995). Once summary statistics such as mean values were calculated, the results were run through an R script for visualization of the data collected from the sites and for each variable, and for comparison of sleeping sites and random trees. Statistical analyses were carried out using R (version 3.6.3, R Core Team 2015).

A binomial generalized model (GLM) was carried out to test whether the dependent variable (presence of pangolin) could be explained by various combinations of the independent variables (see above). This model tests the explanatory variables that might correlate with a difference between the sleeping sites and random sites. Binomial GLM was chosen as it works best with binary data, with presence or absence of a pangolin at a potential sleeping site denoted by 1 or 0 (Rodriguez 2007). A drop1 function was used to carry out stepwise deletion of non-significant interaction terms from the starting model, to arrive at a final model with only significant terms remaining (Labonee, Allouche and Gaudin 2003). All tests were conducted using an *alpha of 0.05* to assess significance. For the second aim a prediction script was used to assign a probability to each site being selected for occupancy. Using the packages “ggeffects” and “ggplot2”, trends were explored, and graphs produced to show the effect changing significant variables had on the probability of a site being chosen.

Results

3.1 Statistical Analysis.

Habitat data was collected by measuring a set of variables at known sleeping sites first and then measuring the same set of variables at sites where pangolin presence is unknown. If a sleeping site had been used for more than one night, the row of data was duplicated for each extra night. Fourteen sites were reused, up to five times each. All statistical analysis was done in the R Studio statistical package v. 3.6.3 (R Core Team 2020). Using a binomial generalized linear model (GLM), a comparison was made between the following tree characteristics at the site used by the pangolin to those of three nearby (unused) trees; presence of hollows, number of hollows, vine score, DBH, height and canopy cover. The aim of this statistical test being whether or not certain variables can explain a pangolins preference for a site.

3.2 Visualising the Data.

Boxplots (Figure 3) were constructed to show any differences between the data collected for sleeping sites and random site, and some descriptive statistics were carried out on other variables to give an idea of the type of habitat used by pangolins.

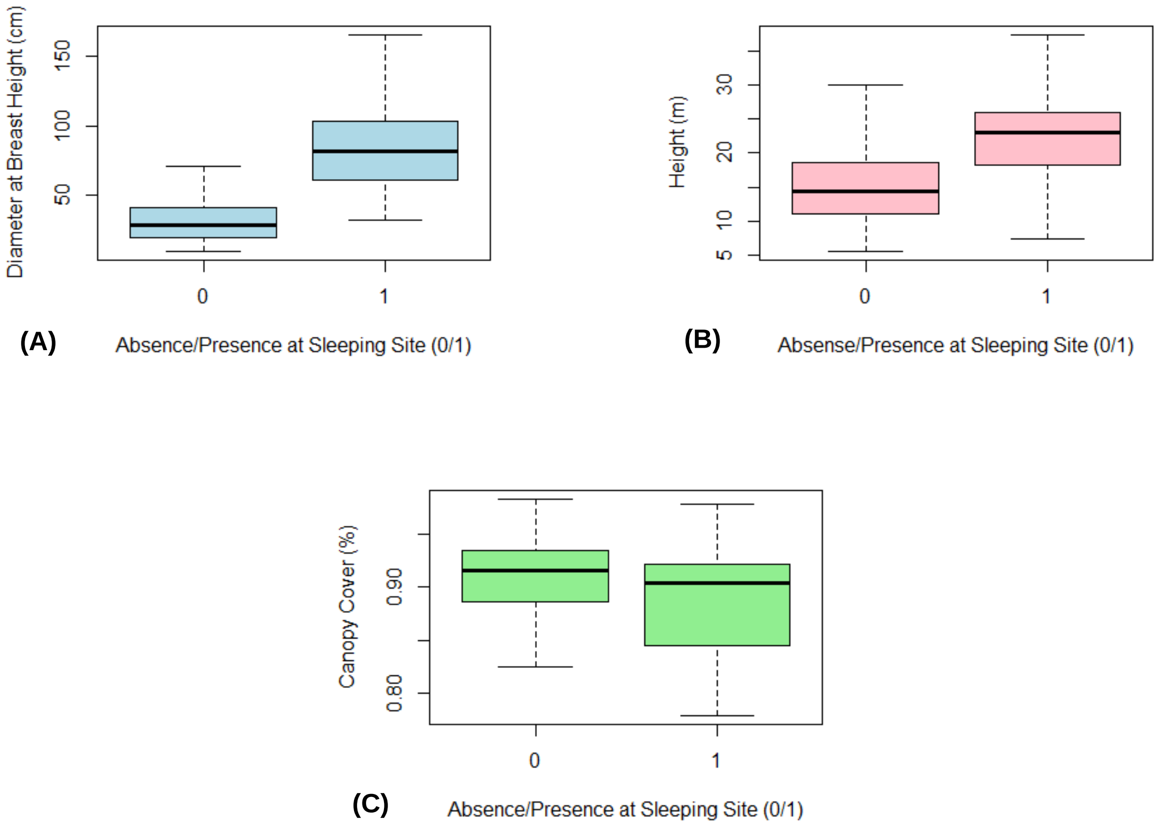


Figure 3. Boxplots of the relationships between the continuous variables and presence / absence of pangolin at sleeping site. *Outliers were removed to give clearer view of overlap or non-overlap of boxes. Panel A shows diameter at breast height, Panel B shows tree height and Panel C shows canopy cover.*

For sleeping sites there were trees with up to six hollows, whereas random sites only ever had one or zero, with zero being the mode number of hollows. The mean average DBH of a sleeping site (presence) was 93.33cm, and absence (or random) was 32.65cm (A, Fig 4). The mean average height of the tree of a sleeping site was 25.21m compared to 15.45m, as visualised in panel B (Fig 4). The mode vine score for sleeping sites was three compared to zero for random sites. Canopy cover was removed from the model as the first term in the stepwise deletion. The boxplot (C, Fig 3) has been included to show overlap between sleeping and random sites. For this data set no variables were normally distributed, this was checked using the Shapiro Wilks test and looking at the histograms.

3.3. Choosing and Refining the Model.

For the final binomial GLM the AIC was lower than before stepwise deletion of the variables “vine score”, “canopy cover” and “presence of hollows”. The residual deviance was lower than the null deviance which shows any outcomes of this model are not random, and the R^2 is high which means a high proportion of the variance is explained by the model, and the model would be better at predicting the dependent value from the explanatory terms used. These values before and after stepwise deletion are reported in Table 1, hence showing why it is necessary to remove terms to make the model fit and try to explain the data better.

Table I. Shows the Model fit values before and after stepwise deletion of three terms: canopy cover, number of hollows and vine score. *The most important value when comparing models is the AIC which was reduced by removing the three insignificant variables (vine score, canopy cover and presence of hollows), leaving a model with three variables (dbh, tree height, and number of hollows) that best describe the data. df = degrees of freedom.*

Fit Values	Before Stepwise Deletion	Final Model
Residual Standard Error	1.207	1.611
Residual Deviance	105.54 on 225 df	108.08 on 228 df
AIC Value	119.54	116.08
Null Deviance Value	301.39 on 231 df	301.39 on 231 df

The null hypothesis that the final model is a good fit was also tested, using both the chi-square distribution function, and McFadden's pseudo-R^2. Distribution function of chi-square gave a value of 1 so is greater than 0.05 which supports goodness-of-fit. The McFadden's pseudo-R^2 value was 0.641391, any value greater than 0.2 represents excellent fit (McFadden 1973). The link "logit" was used for a binomial regression, Breslow (1996) and Pregibon (1980) suggest it is a reasonable choice for link.

3.4 Exploring the Model Outcomes.

Using a logistic regression, it suggested the model worked best when the insignificant terms "vine score", "canopy cover" and "presence of hollows" were removed, leaving "diameter at breast height", "height of tree" and "number of hollows" to be significant predictors of a sleeping site (Table 2).

Table II. Shows the binomial GLM with canopy cover, presence of hollows and vine score variables dropped in stepwise deletion. *All outcomes are significant at $p<0.05$(*) which means there is only a 1/20 chance that this data pattern has arisen by chance. Model was refined by first removing canopy cover and then number of hollows and then vine score.*

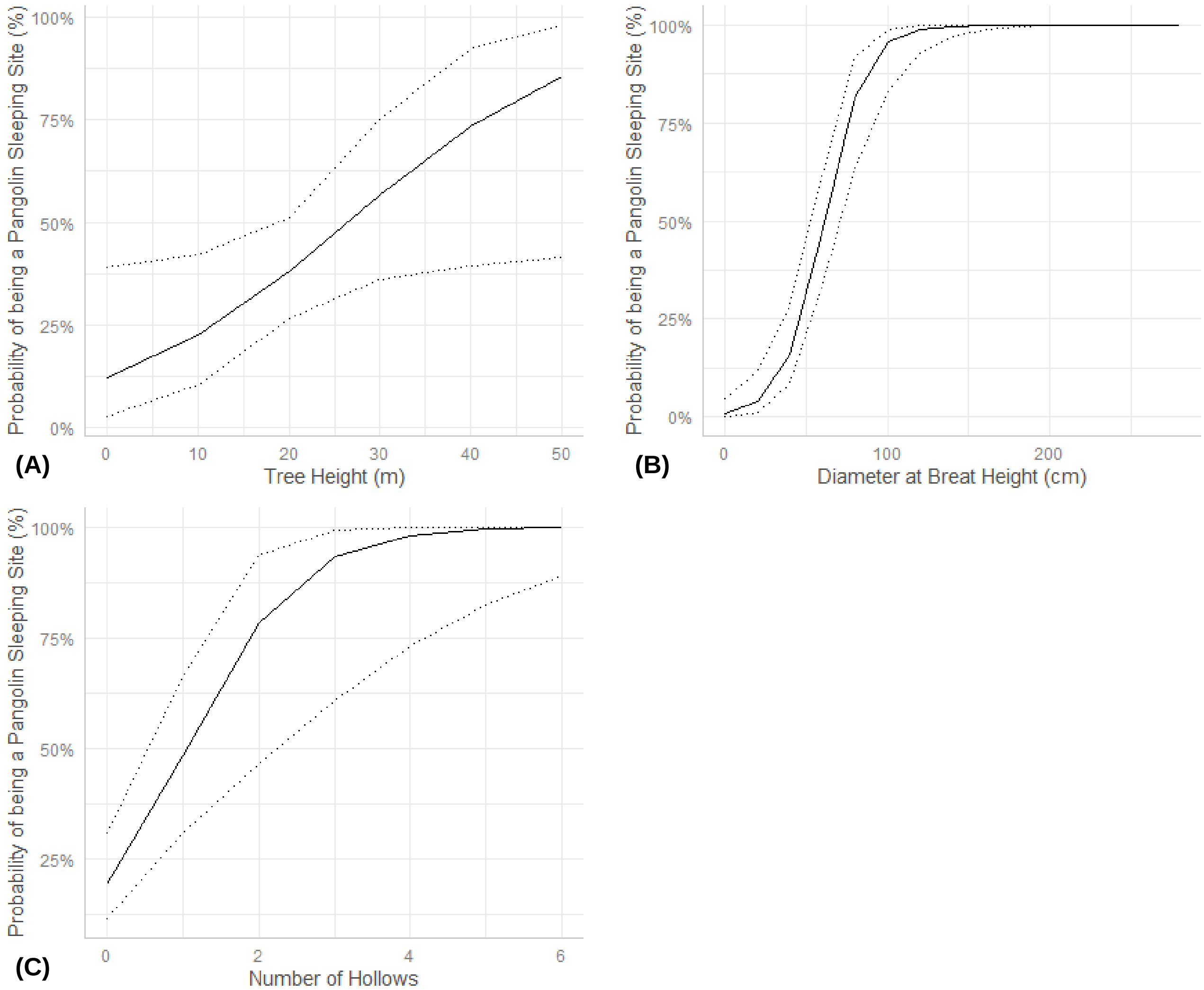
Variable	P value
Height	0.03582 *
Number of Hollows	0.00002694 *
Diameter at Breast Height	0.00000000007414 *

The presence of pangolins was significantly associated with tree height (m), number of hollows, and diameter at breast height (cm).

3.5 Using the Model to Predict Trends.

R^2 value for the model was over 0.6 which shows the model is suitable for making predictions. Using a prediction script, the trends of changing significant variables and the effect they have on the probability of a site being chosen were investigated (Fig 4).

Figure 4. Graphs showing the trends predicted by the binomial GLM of the significant variables. *Panel A shows increasing tree height has a positive effect on the probability of a site being used. Panel B shows diameter at breast height also has a positive effect on the probability of a sleeping site being used. Panel C shows the positive effect increasing number of hollows has on the pangolin using the sleeping site.*



With diameter at breast height set to mean average (53cm) and the number of hollows set to its median (1), the model predicted that there was only a 25.4% probability (SE+/-0.66) of trees 5m tall being used as a pangolin sleeping site, while trees 30m tall had a 69.2% (SE+/-0.62) probability of being a sleeping site. Keeping number of hollows set to its median (1), and tree height set to mean height (18m), the model predicts a 3% probability (SE+/-0.69) of trees with a diameter at breast height of 10cm, while trees with a diameter at breast height of 150cm had a 99% probability (SE+/-0.82) of being used as a sleeping site. With diameter at breast height set to mean average (53cm) and tree height set to mean average (18m), for the final significant variable, number of hollows, the model predicted that a tree with five hollows had a 99% probability (SE+/-0.87) of being used as a sleeping sites, whereas trees with one hollow had a 47.6% probability (SE+/-0.59) of being selected as a sleeping site.

Discussion

4.1 Overall Preferences.

Specific objectives of the research were to 1) asses the significant variables in sleeping site selection and 2) using this data to predict attractive characteristics of sleeping sites. Looking at the results of the model the first aim of being able to show significant predictors of pangolin sleeping habitat has been met. Results supported our hypothesis that “DBH” and “tree height” would have the greatest influence on ‘Berkat’ being present or absent at a potential sleeping tree. The results of our study are in line with the findings of Mahmood *et al.* (2015) which also concluded that there are significant variables when a sleeping site is selected. According to previous literature and our results we can interpret that the most important aspects of a pangolins sleeping site tree are the diameter and height of the tree – typically going for a wider and taller one, which may offer more protection. The results also show that number of hollows is an attractive attribute to the pangolin when it chooses where to rest for the night. These findings are consistent with unpublished data (Ioos and Hicks, unpublished). It can be suggested that arboreal pangolins are likely to use hollows as protection from predators’ reach. Canopy cover was not likely to be a significant variable as the random trees were geographically so close to the sleeping site which meant the canopy was quite similar anyway, as is most coverings in secondary forest.

It cannot be ruled out that distance from water body may also play an important part in determining the suitability of a habitat for a pangolin, however, it was discarded from the model as we did not have the corresponding values for the random sites. One way to improve this research would be to have randomly located trees within the animal’s home range. Other pangolins in Elisa Panjang’s dataset were recorded to have crossed the Kinabatangan River into the oil palm plantation, however, as the sites in plantations could not be characterized by the variables used in this project they were left out of data collection. Rescue pangolins and resident pangolins respond very differently to tagging and tracking. Rescue pangolins are likely to be more stressed meaning their movement and behaviour patterns may not be an accurate representation of their habitat selection in their natural home range. To be able to accurately test whether sex and translocation status have an effect on sites used, a large sample size (over a long period of time) would be needed for each individual. This is hard to get with translocated animals they often cover large distances quickly to find unoccupied territory meaning signal cannot be located to record their location.

4.2 Method Bias.

The first observed limitation of the protocol of tagging, releasing, and immediately tracking could be initial disorientation due to the veterinarian procedure. This is mitigated for by releasing the resident animal at its capture site. In this study, it was based on one wild female pangolin, however Elisa Panjang has data recorded for translocated pangolins who do not know the area. It is possible that the capture event and tagging procedure resulted in the pangolin being disoriented, but there is a lack of knowledge to pangolin response to veterinary practices to support this. In the procedure, the animal is not drugged but the handling stress is evident. There is research on other taxa which shows their response to being handled having a negative impact on their cognitive function (Cattet 2002).

For this research sleeping sites for only one pangolin were explored due to time constraints. Therefore, the results are based on individual preference so future research needs to be done looking at the sleeping sites of other tagged pangolins in Elisa Panjang's dataset, to see whether this is a general pattern of the species in secondary forest. It is not appropriate to merge data sets with other pangolins, into one model. As stated above, there may be confounding factors such as sex and translocation status that can have an impact on their selection of sleeping site. A clear next step to this study would be to include more pangolins and use a mixed model to explore whether sex and translocation also has an impact on significant variables. This study can be used as a starting point to supplement the data with either more variables or other pangolins, future research could compare the differences between translocated and non-translocated, and male or female animals.

Furthermore, when tracking an animal GPS error must be accounted for. Considering the GPS error margin marking a single tree in a rainforest, could have meant that the tree measured as a sleeping site may have not actually been the sleeping site, unless a visual of the sleeping pangolin was obtained. An additional limitation to our study was that the sleeping sites were visited and assessed several months after the animal has utilised these sites. Rainforest environments can go through dramatic changes in a short period of time. Therefore, there is a reasonable chance that the habitat characteristics have changed between the time the animal was using the sleeping site and environmental factors were assessed. It would be recommended to assess the sleeping sites as soon as the animal has vacated the area, in order to gather the sleeping site variables while they are still recent (Brito 2003). Even then, there is a possibility that the animal has vacated the sleeping site due to changes in the environmental variables that rendered the site no longer attractive. For example, vegetation analysis would not give an accurate representation of how it was when they pangolin was there, and prey count was left out as it was nearly a year later which means presence or absence may be incorrect.

Even though this study did not use a GPS tag to track the pangolin, there is GPS data for each site as a handheld device was used to record the location each morning. Elevation data is also stored in Garmin Basecamp and previous research by Karawita *et al.* (2018) suggests that resting burrows were located at higher elevations, however for this study it was not included as it was only one pangolin over a relatively small area of forest. LKWS is also on a floodplain where elevation barely changes (Evans *et al.* 2016).

The graph in panel B (Fig 4) predicts that there is a 100% probability that any tree over 150cm diameter at breast height is a pangolin sleeping site. There is likely a level of bias from the sampling method which included nearby trees as the random sites. This could be due to a tendency to find smaller trees near the larger trees occupied by the pangolin. It could also suggest that large trees are rare in the study area, meaning every available tree was occupied by the pangolin, therefore showing it is a severely limiting resource for pangolins in selectively logged forest. The same observation can be made for number of hollows, as the only site with six hollows was a known sleeping site meaning a tree with that number of hollows will always be predicted to be occupied. Similar to a study by Blouin-Demers and Weatherhead (2000) it is recognised that the random points are not truly random samples because they are in the vicinity of pangolin sleeping trees, they were meant to represent what the pangolin could have chosen and did not. Ideally we would have also measured one entirely random tree per site further away (to look at larger scale variables such as distance from water body), but due to the Covid-19 pandemic there was no opportunity to extend this field work.

Due to the Covid-19 pandemic there was insufficient time to identify and record the tree species of the sleeping sites, however Elisa Panjang intends to have KOPEL assist her with this, as phenology is thought to be a helpful indicator of presence. It is believed this will be an important part of their ecology as it also may determine how favourable the tree is for ant and termite nests.

4.3 Conservation Context.

Being able to define an animal’s sleeping site habitat is a crucial part of understanding their ecology, general habitat requirements and, therefore, conservation needs (Beyer 2010). It is well documented that the forest that makes up the Lower Kinabatangan Wildlife Sanctuary has been subjected to selective logging over the past 50 years (Ancrenaz 2004). The conversion to palm oil plantations began in 1980 and it was not until 2005 that the wildlife corridor was actually gazetted for protection under the Wildlife Conservation Enactment 1997 (Fletcher 2009). Unfortunately, these land conversions from forest to agriculture are still ongoing and pose a serious threat to wildlife that are losing their habitat at an alarming rate and are exposed to illegal poaching and trade as the forest becomes more accessible to hunters (Fletcher 2009). Even now, it is still hard to quantify the biodiversity loss and how ongoing deforestation worldwide is affecting biodiversity levels and animals’ access to natural resources (Ding *et al.* 2017).

Thus far there has been a research gap on pangolins, ranging from research gaps in veterinary medicine, to zoonosis, ecology and conservation (Khatri-Chhetri *et al.* 2015). Increasing deforestation across Malaysia provides easier circumstances for people to get closer to pangolins and to be able to sell them into the trade for TCM. In an article published this year the Chinese government called for a complete ban on trading pangolins (Standaert 2020). This call for a ban was provoked by the notion that pangolins may be a vector for the current COVID-19 virus, and the consumption of pangolins may have been the cause for a global pandemic (Alberts 2020). On closer observation of this ban, the trade of live pangolins may be prohibited, but the trade of pangolin scales is still allowed, creating a legal loophole for the trade of this critically endangered animal.

Having a model with more variables in may give a more accurate picture of attractive characteristics to the pangolin. Gaining a better understanding of their habitat is an important part of knowing what parts of forest need better protection. Knowing what makes a good habitat is important for translocating rescued animals and choosing a good release site. It can also help when determining areas that could be turned into sanctuaries or give an indication of how many pangolins an area could support. Being able to quantify habitat is also necessary to be able to carry out more accurate camera trap surveys that may contribute towards population estimates (Khwaja *et al.* 2019). Population estimates are crucial in the next stage of producing up to date conservation plans and making people more aware of how few of these animals are left in the wild (Lee *et al.* 2018).

4.4 Conclusion.

Understanding a species behaviour, including their habitat selection, is vital to ensure that effective conservation measures are put in place sooner rather than later to prevent further population decline. The LKWS represents just part of the forest types covering Borneo. Rainforests are threatened by ever increasing land conversion, which is destroying the pangolins' habitat, moving them closer to boundaries with humans. We achieved the aim of collecting enough data to statistically show the variables that are selected for when a Sunda pangolin is looking for a sleeping site, and we were able to use this model to predict trends of the significant variables. More detailed information is important for understanding what factors and natural conditions influence use of habitat. This case study, if extrapolated over different animals of different sex and history, may give an important insight into crucial habitat requirements, such as for sleeping site selection. Sleeping sites are an important habitat component helping to protect pangolins from predators, and this knowledge can be implemented in vital habitat protection.

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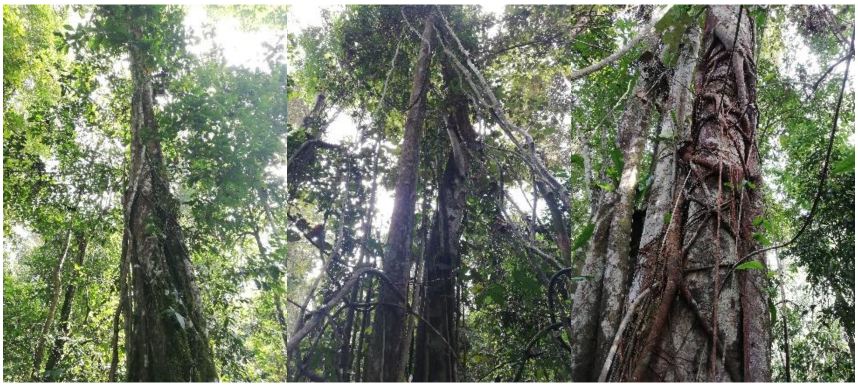
Supporting Information

Appendix I. Pictures of varying vine score of trees. *These pictures were used as reference when assigning vine count, final vine score was decided by the same person every time to avoid being too subjective. Due to the Covid-19 pandemic here was insufficient time to collect pictures from all six categories however some have been included just to give reference to secondary forest. From L to R: 3, 4, 5.*



Appendix II. Trigonometrical equation used to calculate tree height in excel spreadsheet. *The value for the degrees in each case has to be converted to radians for this equation to work, this adjustment is visible in the first part of the equation after the third open bracket.*

$$\begin{aligned} Absolute\ Estimated\ Tree\ Height\ (m) \\ &= ((TAN(RADIANS(Clinometer\ Angle\ (°))) * Distance\ From\ Tree\ (cm)) \\ &+ Eye\ Height(cm))/100 \end{aligned}$$

Appendix III. Table showing data collected from known sleeping sites. *It shows all the variables: height, presence of hollows, number of hollows, vine score, DBH, canopy cover and distance from water body. It also shows the number of nights this site was used for, whether that was consecutively or returned to. There are 50 rows of data. See results section for mean average or modes for these variables.*

No. Nights	Height of Tree (m)	Presence of Hollows (0/1)	Number of Hollows	Vine Score (0-5)	Diameter at Breast Height (DBH) (cm)	Canopy Cover (%)	Distance to Nearest Water Body (m)
1	19.015	0	0	4	165	78.53%	84.612
1	25.637	0	0	5	63.7	77.87%	55.452
2	15.744	0	0	3	85	87.93%	51.611
1	16.898	1	2	4	52	90.98%	63.197
1	18.076	0	0	4	90.4	88.52%	42.071
6	18.166	1	2	2	81.5	92.22%	29.827
1	42.746	1	1	4	103.5	91.51%	23.888
1	12.954	0	0	2	55	86.26%	47.67
1	31.373	0	0	3	55	92.52%	79.943
2	22.965	1	1	3	66.7	89.00%	84.307
1	19.533	1	3	4	71.5	89.66%	100.294
1	32.874	0	0	3	67.5	91.23%	74.309
1	26.740	1	4	1	258.8	90.17%	71.405
1	18.210	1	1	2	142.3	93.93%	89.062
1	31.382	0	0	1	93	92.27%	131.921

1	25.007	1	2	3	177.3	81.57%	76.092
1	32.353	1	1	3	56.6	91.59%	150.809
5	21.355	1	1	3	95	84.49%	90.424
1	17.717	1	1	5	53.2	90.67%	156.278
2	35.418	1	4	1	280	83.78%	130.793
1	7.331	1	1	2	61	94.43%	98.476
1	25.296	0	0	0	49.2	92.26%	114.759
1	20.250	0	0	3	57.4	91.82%	52.331
2	23.759	1	4	5	107.5	91.85%	30.481
1	22.204	1	4	2	127	82.81%	37.664
1	41.150	0	0	2	56	92.36%	176.24
1	23.735	1	2	3	177.9	78.21%	179.277
1	25.985	1	3	3	73	68.68%	91.098
1	23.570	0	0	0	93	87.96%	74.037
4	29.971	1	1	5	77.5	89.81%	66.972
1	37.376	1	1	5	57.7	70.77%	34.386
3	23.130	0	0	2	62.9	94.63%	73.873
1	20.767	1	2	1	116	92.79%	258.622
2	11.262	1	1	5	84.2	95.44%	248.657
3	23.843	1	2	3	51	94.57%	235.894
1	22.851	1	1	2	127	97.83%	202.943
1	31.332	1	1	5	127	70.24%	248.052
2	21.423	1	3	5	129.2	90.66%	270.512
1	17.817	1	6	3	58.9	92.70%	263.865
2	24.646	1	2	5	127	92.13%	266.362
1	26.027	1	1	4	49.7	93.79%	226.997
2	13.314	0	0	3	58	91.18%	265.238
1	25.795	1	1	4	127	85.28%	255.708
2	21.545	1	3	5	88	72.80%	108.332
1	11.884	1	2	1	34.5	82.80%	145.676
1	18.318	0	0	4	82	92.59%	159.653
1	23.197	0	0	2	32.3	89.38%	160.996
1	31.944	1	1	5	127	93.30%	185.778
4	23.038	1	5	1	65.4	89.40%	58.398
2	27.219	0	0	0	60.9	62.02%	89.706
2	24.211	1	1	3	61	90.42%	119.542
1	30.529	1	1	2	133.7	82.62%	60.607

Appendix IV. Table showing data collected from random sites. *It shows all the variables: tree height, presence of hollows, number of hollows, vine score, DBH, canopy cover. For the random sites, distance from water body was not recorded so this is not shown. There are 150 rows of data.*

Height of Tree (m)	**Presence of Hollows (0/1)**	**Number of Hollows**	**Vine Score (0-5)**	**Diameter at Breast Height (DBH) (cm)**	**Canopy Cover (%)**
19.284	0	0	0	49.9	84.12%
18.682	0	0	0	31.6	90.19%

14.363	0	0	0	17.8	87.82%
17.514	0	0	2	41.3	92.71%
16.310	0	0	1	40	73.34%
35.665	0	0	1	68.2	71.89%
22.305	0	0	0	44.1	76.79%
16.986	1	1	2	71	91.29%
14.347	0	0	0	21.5	90.33%
10.994	0	0	0	21.5	92.41%
10.360	0	0	0	38	91.27%
14.955	0	0	0	29	93.67%
19.966	0	0	0	47	87.41%
15.662	0	0	4	16.5	89.27%
18.660	0	0	1	29.5	88.66%
12.741	0	0	0	34.2	92.23%
44.238	0	0	0	31.5	91.60%
15.988	0	0	0	17	93.08%
18.552	0	0	0	27	87.51%
10.930	0	0	2	18.5	87.35%
10.839	0	0	0	12	93.46%
8.839	0	0	1	26.5	90.08%
11.982	0	0	0	20	88.24%
16.166	0	0	0	51.5	80.86%
19.044	0	0	3	48	94.19%
14.586	0	0	2	13.2	94.46%
14.038	0	0	0	29.5	78.56%
13.785	0	0	4	36	87.29%
19.703	0	0	0	28.5	76.46%
15.120	0	0	2	25.5	90.78%
15.250	0	0	1	32.6	89.30%
10.964	0	0	0	17	93.67%
15.547	0	0	0	41.6	87.13%
12.121	0	0	1	26	88.99%
13.223	0	0	0	35.5	92.11%
10.042	0	0	0	14.3	92.21%
11.729	0	0	0	25.3	91.32%
13.863	0	0	1	39.2	93.51%
10.129	0	0	0	15	91.68%
21.519	0	0	0	39.6	91.43%
10.708	0	0	3	18.2	92.03%
23.866	0	0	1	56.9	93.53%
10.613	0	0	5	26.4	94.86%
15.247	0	0	0	25.1	80.25%
11.773	0	0	1	15.6	92.05%
13.457	0	0	2	30.4	93.84%
17.664	0	0	1	33.9	91.87%
24.230	0	0	0	27	92.33%

10.184	0	0	0	20.5	92.97%
14.901	0	0	0	16.6	94.32%
19.786	0	0	1	34.8	93.29%
23.165	0	0	0	37	89.63%
14.976	0	0	0	31.9	92.16%
18.136	0	0	0	47	91.90%
20.457	0	0	3	53.4	93.59%
13.272	0	0	0	16.3	95.11%
15.087	0	0	4	28.1	94.36%
14.252	0	0	1	21.6	95.94%
10.236	0	0	4	41.6	89.79%
6.020	0	0	0	27.4	89.41%
15.203	0	0	2	40.5	88.23%
14.712	0	0	0	33.9	91.55%
12.354	0	0	3	19.2	96.03%
17.357	0	0	2	57.9	91.12%
30.082	0	0	0	35.8	89.60%
13.352	0	0	4	28	94.92%
13.647	0	0	1	32.9	91.49%
23.331	0	0	0	50.2	85.23%
7.791	0	0	0	12.9	91.61%
14.976	0	0	1	20.9	95.54%
12.987	1	1	1	43.8	93.27%
10.016	0	0	2	28.9	94.50%
28.647	0	0	1	41.8	94.75%
12.108	0	0	2	46.9	94.70%
21.041	0	0	2	50.7	88.71%
11.446	0	0	5	34.2	92.41%
11.812	0	0	3	44.2	91.97%
19.916	0	0	2	59	92.30%
12.898	0	0	2	22.6	89.85%
6.267	0	0	0	10.8	93.41%
24.356	0	0	1	43.6	82.84%
10.598	0	0	0	23.5	92.93%
11.260	0	0	0	28.4	92.51%
22.334	0	0	0	38.6	80.84%
14.345	0	0	0	41	90.85%
9.802	0	0	0	11.5	91.57%
11.956	0	0	0	18.4	82.75%
11.802	0	0	1	35.5	93.85%
16.172	0	0	0	19.7	63.54%
18.346	0	0	5	17.6	91.34%
10.145	1	1	2	22.5	94.81%
22.005	0	0	3	67.5	66.26%
23.890	0	0	2	32.8	84.61%
25.334	0	0	3	55.4	92.72%

11.678	0	0	5	17.2	91.83%
11.076	0	0	1	19.4	91.09%
16.868	0	0	2	56	91.97%
14.943	0	0	0	27	91.59%
10.888	0	0	0	14.6	92.64%
12.394	0	0	1	34.2	96.14%
17.374	0	0	0	30	94.83%
10.597	0	0	1	37.3	97.75%
13.935	0	0	1	16.6	94.12%
15.809	0	0	2	39.3	93.22%
10.429	0	0	4	26	87.13%
29.692	1	1	3	50	92.01%
18.028	0	0	0	43.6	75.91%
24.244	0	0	0	57.2	92.15%
14.572	1	1	1	66.8	90.08%
19.942	0	0	1	36.4	92.31%
21.723	1	3	1	89.2	91.54%
13.680	0	0	0	26.7	93.94%
21.469	1	1	3	118	83.40%
11.614	0	0	0	12.1	92.29%
24.057	0	0	4	65	96.40%
11.842	0	0	2	15.3	88.86%
6.191	0	0	0	10.1	93.92%
6.732	0	0	0	24	98.18%
22.303	0	0	5	63	93.10%
8.330	0	0	2	17.3	91.44%
8.499	0	0	1	21.1	87.91%
11.144	0	0	1	19.7	93.70%
5.570	0	0	0	13.4	84.26%
10.694	0	0	4	19.4	92.54%
6.092	0	0	3	14	82.51%
20.579	0	0	5	29	98.32%
11.752	0	0	0	17.5	90.74%
11.021	0	0	0	26.5	96.11%
8.967	0	0	4	11.7	95.39%
9.142	0	0	4	16.3	95.42%
6.940	0	0	2	10.5	93.59%
14.507	0	0	0	17.6	91.04%
9.721	0	0	5	19.2	89.52%
7.874	0	0	4	22.2	92.51%
21.756	0	0	4	65	78.46%
19.596	0	0	5	29.6	87.76%
14.928	0	0	0	14.9	89.79%
18.028	0	0	2	42.9	93.59%
13.625	1	1	4	59.8	87.18%
13.699	0	0	2	50.9	90.61%

14.022	0	0	4	24.9	90.46%
20.177	0	0	2	26.3	51.32%
15.361	0	0	3	26.9	97.64%
19.878	0	0	1	21.3	70.81%
26.232	0	0	5	61.6	89.97%
29.210	0	0	2	67.3	95.70%
17.872	0	0	0	26	75.99%
11.880	0	0	0	23.1	87.75%
10.856	0	0	3	19.6	88.31%
9.525	0	0	3	14.7	93.01%