Bearded pig nesting site selection and influence on sapling structure in the degraded forest of the Lower Kinabatangan Wildlife Sanctuary, Sabah, Malaysia

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Part A:

My year at Danau Girang Field Centre was an amazing experience. I had the opportunity to assist PhDs and master's students in their research as well as plan and carry out a research project of my own. My own project involved walking transects and sampling pig nests as well as sampling sapling vegetation plots in various Lots of forest. I selected the appropriate methods for this project and successfully carried out a survey of the pig nests and saplings in four of the Lots of forest along the Kinabatangan River.

Dave Kurz was an invaluable source of knowledge and help during my project, as he was carrying out his PhD research on bearded pigs at the same time. He was incredibly helpful during the planning, field work and analysis areas of my project. I was also able to gain some hands-on experience with a bearded pig during a sampling on a young female we carried out.

In addition to this, I was able to be involved in projects on other animals too. I frequently tracked the slow lorises using VHF technology and got to see an accelerometer on a collar being changed on one slow loris. I also tracked some monitor lizards also with VHF and set several monitor lizard traps with Dr Segio Guerrero-Sanchez.

I gained more hands-on experience with animals with Meg Evans where I was able to be the vets assistant for several civet samplings we carried out. This involved monitoring the animal's temperature, pO2, respiration rate and pulse. I was able to get experience sampling snakes with PhD student Richard Burger who caught and sampled reticulated pythons. I helped catch and sample multiple pythons which involved measurements as well as blood, scale and ectoparasite samples.

A highlight of my time at DG was witnessing the release of a pangolin by Elisa Panjang who was doing her PhD on pangolins. I also got to do transects and set camera traps with Elisa which I enjoyed greatly.

I was also involved with several master's students' projects and shorter-term PhD students projects including ones on macaque monitoring, mosquito anopheles, primate faecal parasites and termites and ants. I was able to see raptor, crocodile, gecko and reticulated python post mortems which all were very interesting.

My other responsibilities included writing the Jungle Times monthly newsletter with the other PTYs and taking out field course groups into the forest. We would take field course groups to track various animals and on night walks, as well as on the various projects happening at the centre at that time. We would also send them up to the 18m high canopy platform to view wildlife as the sun rises.

A valuable skill I have improved this year is my presentation skills. The PhD, masters and PTY students presented their research to field courses which improved my confidence and ability to present to large groups of people.

This year has been an invaluable experience and I am very grateful for the opportunity and to the people who made it so amazing.

Part B: Bearded pig nesting site selection and influence on sapling structure in the degraded forest of the Lower Kinabatangan Wildlife Sanctuary, Sabah, Malaysia

ABSTRACT

The Bornean state of Sabah consists of fragmented and degraded forest dispersed with oil palm plantations, impacting the organisms living in the forest, including the bearded pig (*Sus barbatus*). This endangered species of pig is threatened by habitat loss and overhunting, however, their use of palm fruits as a food source may be causing hyper-abundance of bearded pigs in the remaining forest fragments. Bearded pig behaviours, including foraging and nest building, can impact the forest structure, therefore it is important to study the effects of this hyper-abundance. This study aimed to assess the impact of bearded pig densities on the structure of the forest in the Lower Kinabatangan Wildlife Sanctuary. It was also aimed to identify trends in the environmental variables upon nest building. Six sites were sampled, with transects searching for pig nests conducted in each one, and five sapling vegetation plots being carried out in each area. At each nest and sapling vegetation plot several variables were measured. Camera trap images were reviewed to estimate litter sizes. None of the variables (canopy cover, distance from water and distance from oil palm) had a significant impact on the number of pig nests. The canopy cover at the pig nests was significantly higher than at the sapling vegetation plots. Recording wallow presence and soil type at the pig nests both had limitations. None of the variables (number of pig nests, canopy cover, distance from water and distance from oil palm plantation) had a significant impact on the number of saplings. Canopy cover was the only variable to have a significant effect on sapling height. 92 groups of pigs were recorded on the camera traps. The mean and median group size was 5.5 and 5 respectively. Recommendations for future research are also recommended in the study.

INTRODUCTION

Over the past 40 years, the Island of Borneo has undergone dramatic changes in vegetation cover due to intense logging and the conversion of primary forest into oil palm (*Elaeis guineensis*) plantations (Edwards *et al.,* 2010). This large-scale human-caused fragmentation of the tropical rainforest threatens the function and resilience of tropical ecosystems. This is especially the case for the Lower Kinabatangan Wildlife Sanctuary (Sabah, Malaysia) where large patches of forest have been cleared, resulting in fragmented and degraded rainforest surrounded by oil palm plantations (Hai *et al.* 2001). This habitat conversion affects the distribution of floral and faunal species within this area because there is a reduction of biodiversity of organisms in palm oil plantations and negatively impacts adjacent forests. Palm oil plantations have an impact on

biodiversity levels, spatial distribution and density of many species, including the Bornean bearded pig (*Sus barbatus*) (Koh and Wilcove, 2008).

Bearded pigs are a species of pig found in Southeast Asia which are known for their long legs, long distance migrations and recognisable beards. Typically, family units will consist of a mother and her piglets, with these groups commonly joining up (Iucnredlist.org). Bearded pigs are economically and culturally significant in Borneo as they are consumed by many rural people and are an important source of protein. Additionally, bearded pigs are an important prey source for predators including clouded leopards (*Neofelis nebulosi*) (Ross *et al.,* 2013) and can impact the forest structure. Trends in bearded pig populations indicate a serious decline in population size of approximately 30% in a recent 21-year period, causing the species to be classified as vulnerable by the IUCN since 2008 (Luskin *et al.,* 2017). Habitat fragmentation and habitat loss due to conversion of rainforest to oil palm plantation are major causes of this decline in bearded pig population numbers (Iucnredlist.org). Additionally, the Bornean bearded pigs are heavily hunted and comprise approximately 72% of the dressed weight of hunted animals in the state of Sarawak and 53.7% in the state of Sabah (Bennett et al. 2000). Hunting and habitat degradation can drastically reduce the population sizes of bearded pigs, which has important consequences on the structure of the rainforest.

Fruit supply is thought to have significant influence on growth rate and reproduction of the bearded pig and the forest areas surrounded by oil palm plantation may be developing abnormally high bearded pig densities (Love *et al*., 2017). Previous studies on wild boar (*Sus scrofa)* have identified that the pigs thrive in forest fragments adjacent to oil palm plantations due to the high availability of oil palm fruit, which is exploited by the pigs as a food source (Ickes, 2001). However, wild boar remain heavily dependent on nearby rainforests for nesting and protection from humans and predators, indicating that the oil palm plantations are useful as a supplementary food source but little else. A high density of bearded pigs in forests surrounding oil palm plantations may therefore have a detrimental effect on forest structure due to pig foraging and nesting behaviour. Bearded pigs affect the structure of the forest through rooting, frugivory and nest building (Luskin et al. 2017). In addition, Grandos *et al.* (2017) found that bearded pigs would forage more in areas of logged forest than unlogged when dipterocarp seeds were available. Foraging can aid the spread of invasive plant species (Fujinuma and Harrison, 2012) and kill seedlings, as well as altering nutrient concentrations in the soil (Singer, Swank and Clebsch, 1984). In contrast, the rooting behaviour of bearded pigs can also be beneficial to forests. A study performed by Lacki and Lancia (1986) on wild pigs in North America, concluded that pig rooting promoted increased shoot elongation of beech trees. Frugivory by wild pigs may also be affecting the structure of the forest as it may cause the seeds in the fruits to die (Ickes, Dewalt and Appanah, 2001). Pigs are known to eat large amounts of fruit and seeds when it is available to them which indicates that bearded

pigs may take advantage of the high number of oil palm fruits available to them within the plantations (Ickes *et al.,* 2001, Love et al. 2017). While a lot is known about how oil palm is replacing forest (Fitzherbert *et al.,* 2008), it is becoming increasingly apparent that the presence of oil palm is also affecting the forest by providing a supplemental food source that changes dynamics within the nearby forest as well. This can be seen with wild pigs and their behaviours of snapping saplings for nest building which can have an impact on the structure of the forest. As pigs respond to fruit cycles, and therefore respond to oil palm by exploding in populations, they build more nests and snap off many saplings in the forest.

Nest building is found to be common behaviour in bearded pigs and has been described in several pig species. For example, the bushpig (*Potamochoeru porcus),* was found to make nests of grass covering the new-borns for the first few days after birth until the piglets are strong enough to follow her (Skinner *et al.,* 1976). It was found that pig nest building had more of an impact on some species of plants than others. Dipterocarpaceae were approximately twice as likely to be used to construct a nest by wild boar compared to other plant species (Ickes, Paciorek and Thomas, 2005). Furthermore, a study carried out by Fernández-Llario (2004) indicated that wild boar in the Mediterranean preferentially selected areas with high plant cover, close to water and with higher temperatures compared to other areas. They also concluded that the distance between the nests was significant.

Bearded pigs alter the structure of the rainforest by snapping or uprooting saplings, which they use for nest building. Nest site selection is a very important component in determining the survival of the piglets and the location of the nest depends on factors such as the presence of saplings (Fernández-Llario, 2004). Pigs can use over 500 saplings in a single nest, altering the sapling density within the nest site area. A forest area with high pig densities would be more likely to have lower numbers of saplings and therefore the composition of the forest floor may alter drastically compared to areas of low pig density (Ickes *et al.,* 2001). Previous studies, predominantly on wild boar and carried out in small forest reserves, identified that wild boar exclosures had higher sapling densities and greater vertical growth of plants between 1 and 7 m tall (Ickes, Dewalt and Appanah, 2001). Additionally, the growth of shoots after the saplings had been snapped was slow in the understory (Ickes, Dewalt and Thomas, 2003), indicating that high pig densities in small forest reserves would have a significant impact on the tree community in that area.

There has only been limited research carried out on the selection of the nest site of bearded pigs and on the sizes of the litter. Most of the available information comes from interviews with local hunters who indicated that the median number of piglets of an adult female, and the median number of foetuses found in dead females was seven (Oliver, 1993). There have not been any studies of this subspecies of bearded pigs, except for the study carried out by Love *et al.* (2017),

looking at how bearded pigs have adapted to the abundance of oil palm in the Lower Kinabatangan Wildlife Sanctuary. Bearded pig behavioural ecology is a driver of change in the composition of the forest floor, and the structure of the vegetation present. Thus, it is important to quantify the impacts of these behaviours in order to conserve both the bearded pig and its ecosystem.

This study aims to assess the impact of bearded pig densities on the structure of the forest floor in the Lower Kinabatangan Wildlife Sanctuary and aims to identify trends in the environmental variables upon nest building. It was hypothesised that areas of high pig nest density and consequently high density of mothers with juvenile groups will have fewer saplings between the heights of 30cm and 300cm as these will be used to construct the nests. It was also expected that pig nests would show a trend in the presence of water, oil palm plantations, and wallows in the vicinity. Additionally, it was hypothesized that pig nest sites will have higher than average canopy cover as compared to the rest of the forest.

MATERIALS AND METHODS

Study Site and Transects

The sites selected for this study were located along the Kinabatangan river of Sabah, Borneo. The Lower Kinabatangan Wildlife Sanctuary consists of ten Lots of protected forest, surrounded by palm oil plantations, all of which are located on a floodplain. The climate is warm, wet and humid, with the temperature ranging between 22-32ºC and an average annual rainfall of 2,600 mm (Azmi, 1998). There are various habitat types in the area, of varying degrees of degradation. The type of habitat surveyed in this study was secondary degraded forest which has previously been selectively logged. Six sites, containing a transect area of six hectares in each, were surveyed for pig nests. These sites were selected in Lots 5, 6, 7 and 8 and in the corridors adjacent to them in the Lower Kinabatangan Wildlife Sanctuary (Fig 1.). All fieldwork was carried out during the time period of December 2017 to April 2018.

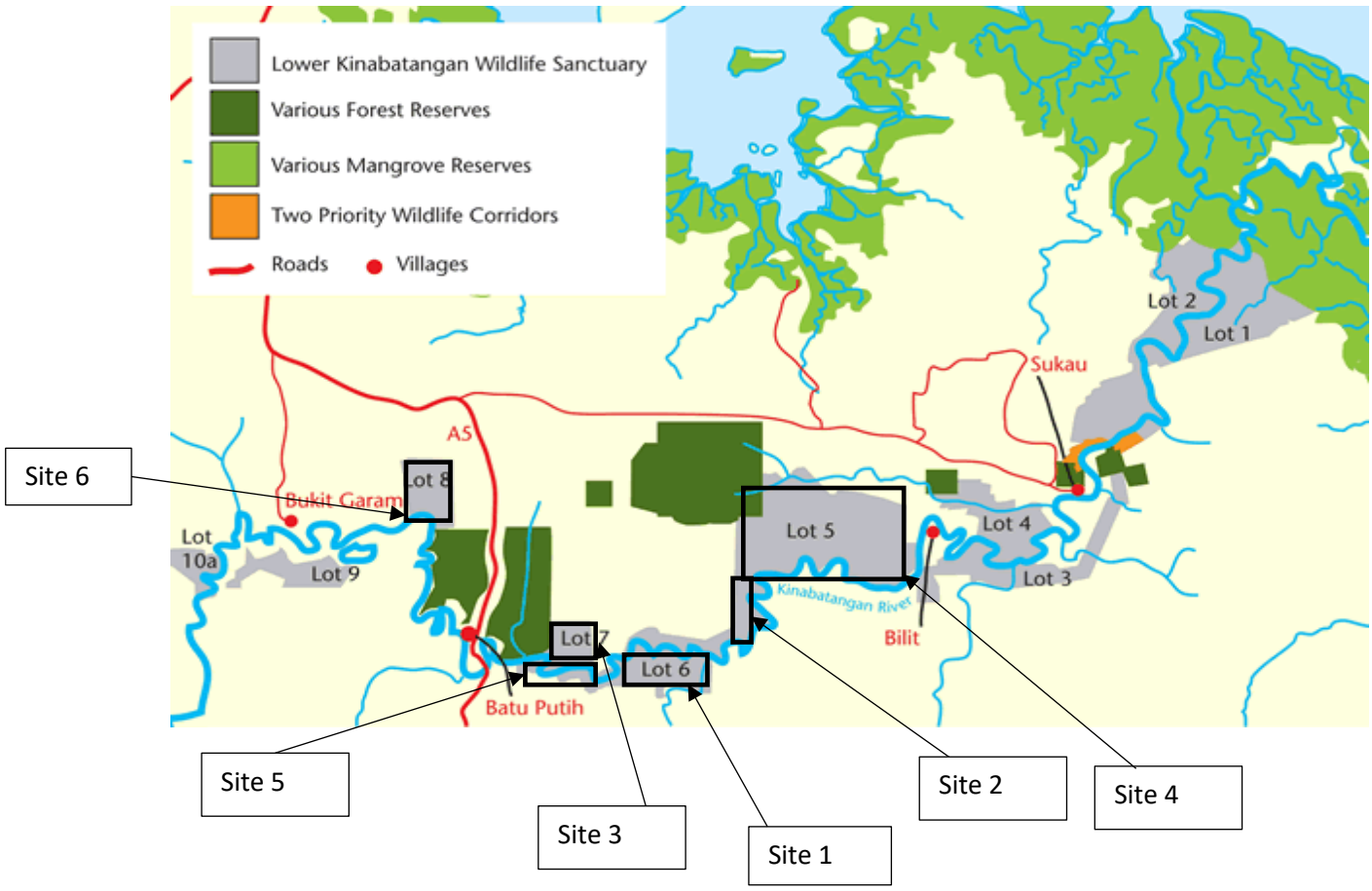

Figure 1. Diagram of locations of Lots and sites in the Lower Kinabatangan Wildlife Sanctuary. The six sites are shown in the diagram as boxes. All sites are located in the Lots 5, 6, 7 and 8 or the surrounding forest, which are found along the Kinabatangan River. (Diagram adapted from Worldlandtrust.org, 2018)

Transects started ten metres from the river or trail. A compass direction was randomly selected using a random number generator (Google), where a number between one and eight was selected and each number corresponded to a direction. After the direction was selected, surveyors walked at the same pace alongside each other in the selected direction using a compass, until a forest edge (water or plantation) was reached. At this point, a different compass direction was randomly selected for surveyors to walk until an area of six hectares had been surveyed.

Surveys were completed over several separate days, using at least two different starting points to produce a representative indication of pig nest densities at each site. If a starting point was selected and it was within 500 metres of an existing, previous starting point, then a new starting position was selected. If small areas of forest were deemed impassable or dangerous, they were circumnavigated. If larger areas were impassable or dangerous, this area was treated as a forest edge and the compass direction surveyors walked was changed altogether. The search effort was carried out by

two to five surveyors that walked each transect positioned at ten metre intervals from each other. To ensure uniformity in the surveying method, each survey was conducted and supervised by the same researcher (JW). Each surveyor searched for pig nests five metres either side of the transect line (five metre distance from the transect line was considered small enough to reliably identify a pig nest), covering a width of ten metres of the transect for each surveyor and a total area cover of 20-50 metres, depending on the number of surveyors. Each transect was surveyed once as it was considered more important to survey multiple sites over a larger area than to repeat the same transects.

Nest cataloguing

Each pig nest identified in the transect was marked with a handheld GPS (GARMIN GPSMAP 64). To confirm a pig nest had been identified, sapling stem breaks were searched for in the near vicinity and photographs were taken to confirm with additional scientists. The age of the pig nest was estimated and classed in the categories as: less than 1 week old (leaves still green, nest still at full volume), 1 week to 1 month old (majority of leaves still green, less volume), 1 month to 9 months old (leaves going brown, nest significantly reduced in height), 9 months to 1 year old (leaves all brown and nest has little volume left) or 1 year to 2 years old (nest may just be circular imprint in ground). In addition, the width, length and height of each nest were recorded, as well as the canopy cover using a spherical densitometer and the presence of wallows in a 10 metre radius of the nest. Distance from oil palm plantation and water were calculated using Google Earth Pro (version 7.3.2.5491 (64-bit)). Soil condition was recorded as being muddy or not muddy, in a depression or not in a depression, dry or damp and debris present or debris absent.

Vegetation plots

In each transect, five random locations were selected to measure sapling structure (sapling vegetation plots). Each sapling vegetation plot covered an area of nine metres^2. A total vegetation plot area of 45 meters^2 for each transect was considered to be representative of the whole transect and would not take an excessive amount of time to survey. The number and height of saplings were measured and recorded. Only freestanding woody saplings were counted and the height of saplings standing over 2.5 metres tall were recorded to the nearest metre. Shorter saplings were measured and recorded to the nearest centimetre. Only saplings between the heights of 30 centimetres and 300 centimetres were measured and recorded. At each sapling vegetation plot, canopy cover and soil condition were also measured, as with the pig nest sites.

Camera Trap Data

Camera trap data was reviewed to estimate average group sizes of mother pigs and piglets in order to calculate pig density according to the number of pig nests present at sites. Camera traps (PC800 Professional and HC500 Hyperfire) were placed at sites along the Kinabatangan from Lot 5 to Lot 7 of the wildlife sanctuary over a 1.5 -year time period (April 2015- August 2016). Data was used from two separate years to account for the possible fluctuations in litter sizes during said time period. Group size, age class of the pigs (infant, juvenile, sub-adult and adult), body condition (very good, good, fair, poor, very poor (according the method by Te Wong *et al.* 2005) and time and date were all recorded for each mother with piglets photographed. If photographs of mother and piglet groups were taken within one hour of each other, only the group with the higher number of individuals was counted. If photographs taken within one hour of each other showed clearly different groups of pigs (e.g if one group consisted of infants and another juveniles), the photographs were counted as different groups. Large groups of pigs with multiple adults were not counted. If a group of infants or juvenile pigs were seen without the mother, it was assumed that the mother was in close proximity but not present in the photograph. Therefore, the pigs were recorded as one group and it was noted that the mother was not in the photograph. Noting the mother as being absent from the photograph was recorded only when more than two juvenile pigs were identified in the photograph. If only one juvenile pig was viewed, it was assumed that the rest of the group was close by but not in the photograph. Any groups with more than ten piglets with or without a mother were not counted as it was assumed that the piglets may be from two or more mothers.

Statistical Analysis

All data analysis was carried out using R software (version 3.4.0). Significance was accepted at 0.05. Three Generalised Linear Mixed Models were used in the *lme4* package to analyse the effects of variables on the number of pig nests, the number of saplings and the height of saplings. In these tests, site was taken into account as a random effect. A GLMM was conducted to analyse the effects of canopy cover, distance from water and distance from oil palm plantation on the number of pig nests. Second and third GLMM's were conducted to analyse the effects of the number of pig nests, canopy cover, distance from water and distance from oil palm plantation on the heights and numbers of saplings. A Mann-Whitney test was carried out on the canopy cover data from the pig nests and the sapling vegetation plots. The Mann-Whitney test was used because the data was not normally distributed. The number of pigs per hectare of forest was estimated by multiplying the number of pig nests at each site by 5.5 (the average group size found on the camera trap data) and then dividing it by 6 (the number of hectares covered at each site). Data on wallows was not statistically analysed due to there being an insufficient number of sightings. Soil types were not statistically analysed as the results were too homologous to carry out statistical tests. Therefore, for some of the data, it is represented using graphs which were produced using Microsoft Excel.

RESULTS

A total of 60 bearded pig nests were sampled. Of these, 25 were found in corridors of forest, 13 were found in larger plots of forest and 22 were found in smaller plots of forest. In total 330 saplings were sampled. Of these, 141 were found in corridors of forest, 115 were found in large plots of forest and 74 were found in smaller plots of forest. Two sites were carried out in corridors of forest, two in smaller plots of forest and two in larger plots of forest.

Pig nest site selection

It was found that none of the variables (canopy cover, distance from water and distance from oil palm plantation) had a significant impact on the number of pig nests. However, distance from oil palm plantation was the approaching significance (having a negative correlation).

It was found that there was a significant difference between canopy cover at pig nest sites and the sapling vegetation plot sites (p-value= 0.031), with canopy cover at pig nest sites being higher on average than at the sapling vegetation plot sites.

Only one pig nest was found with a wallow within 10 metres of it. Thus, there was insufficient data for analysis of a significant relationship.

Regarding the soil condition of the pig nest sites and the sapling vegetation plots, it was found that 88.3% of pig nests were in areas with damp soil (with the remaining 11.7% being dry), compared with the sapling vegetation plots where 93.3% was damp. At the pig nest sites 100% of the sites had debris present, while at the sapling vegetation plots 96.7% had debris present. 93.3% of the pig nest sites were muddy, while only 83.3% of the sapling vegetation plots were muddy.

The number of pigs per hectare was calculated for all sites and is shown in table 1. The numbers calculated are conservative due to the methods of the camera trap data analysis, therefore it is likely these numbers are higher in reality compared to those shown in table 1.

Site	**Forrest plot size**	**Number of pigs per hectare**
Lot 6	Large	6.4
Corridor before Lot 5	Corridor	11.0
Lot 7	Small	13.8
Lot 5	Large	5.5
Corridor opposite Lot 7	Corridor	11.9
Lot 8	Small	6.4

Table 1. Table showing the number of pigs per hectare for each site sampled. It is evident that corridors and smaller forest plots have more pigs than the larger plots of forest.

Sapling vegetation plots

It was found that none of the variables (number of pig nests, canopy cover, distance from water and distance from oil palm plantation) had a significant impact on the number of saplings. However, the number of the pig nests was the approaching significance. Interestingly, the number of pig nests had a positive correlation with the number of saplings, which is the opposite of what was hypothesised. This correlation was the strongest of all the variables by a considerable amount (with the correlation being 0.266 and the second strongest correlation being -0.079). However, canopy cover was found to have a significant effect on sapling height (p-value= < 0.001), with the correlation being strongly negative. None of the other variables had a significant effect on sapling height, and the distance from oil palm plantation also had a negative correlation with sapling height, while the number of pig nests and the distance from water had a positive correlation.

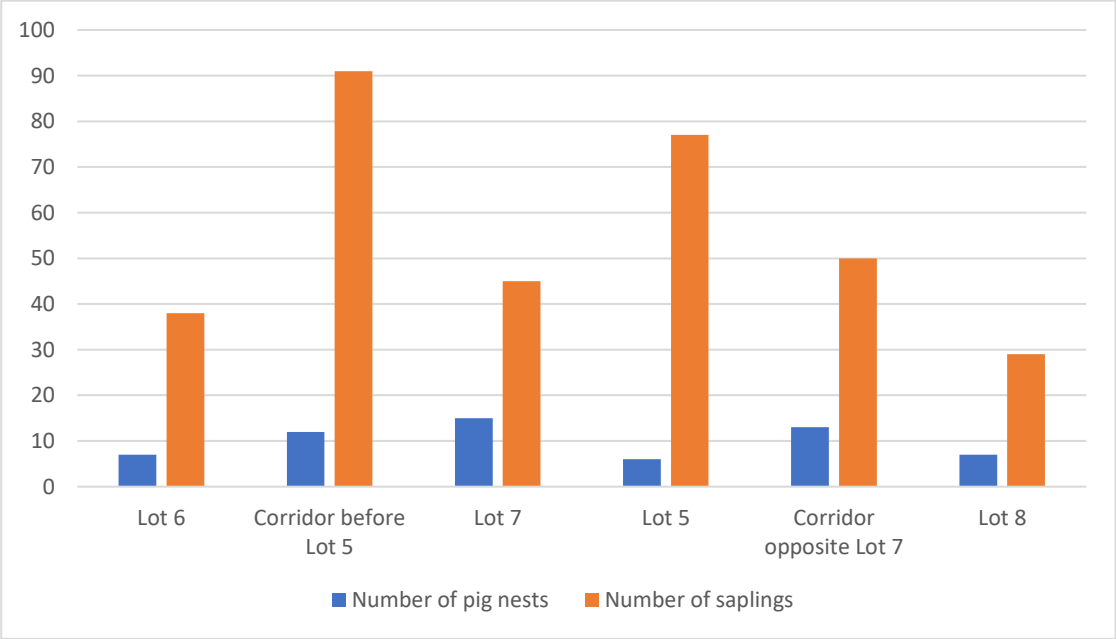

Figure 2 The number of pig nests and the number of saplings at each site. Graph showing the number of pig nests found in transects and the number of saplings found in the sapling vegetation plots in each site in the Lower Kinabatangan Wildlife Sanctuary. Sites Lot 7, Lot 5 and the corridor opposite Lot 7 seem to follow the trend of a negative correlation between the number of pig nests and the number of saplings. However, the other three sites do not seem to show this correlation and instead seem to show a positive correlation.

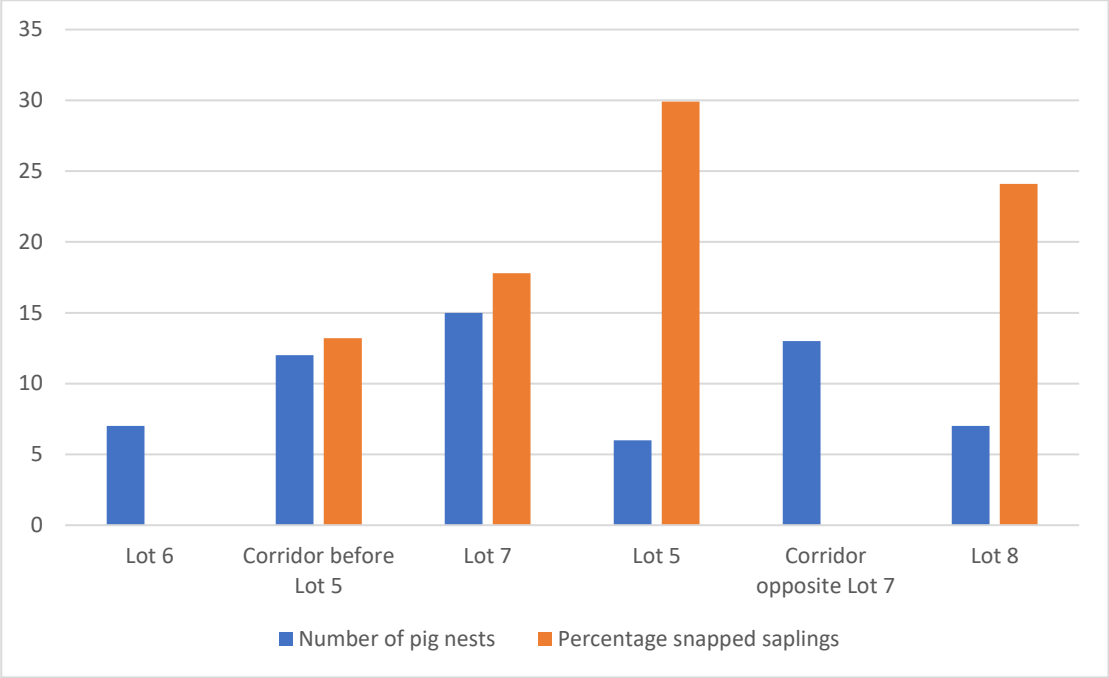

Figure 3 The number of pig nests and the percentage of snapped saplings at each site. Graph showing the number of pig nests found in transects and the percentage of snapped saplings out of the overall number of saplings found in the sapling vegetation plots in each site in the Lower Kinabatangan Wildlife Sanctuary. There was not a significant trend between the number of pig nests and the percentage of snapped saplings.

Figures 2 and 3 demonstrate that the data did not show a significant trend between the variables.

Camera trap data

92 groups of pigs which fitted the criteria (a group of non-adults with or without a mother) were recorded on the camera traps. The mean group size for all the groups recorded was 5.5, and to calculate this any group viewed without the mother had one added to the group size so the inclusion of the mother was uniform. The median group size number was 5. The highest group size was 10 which was set as the maximum in the methods, and the lowest group size was 3 which was set as the minimum in the methods. The majority of the groups consisted of juveniles (49), with there being fewer infants (34) and very few sub-adults (9), as show in Figure 4.

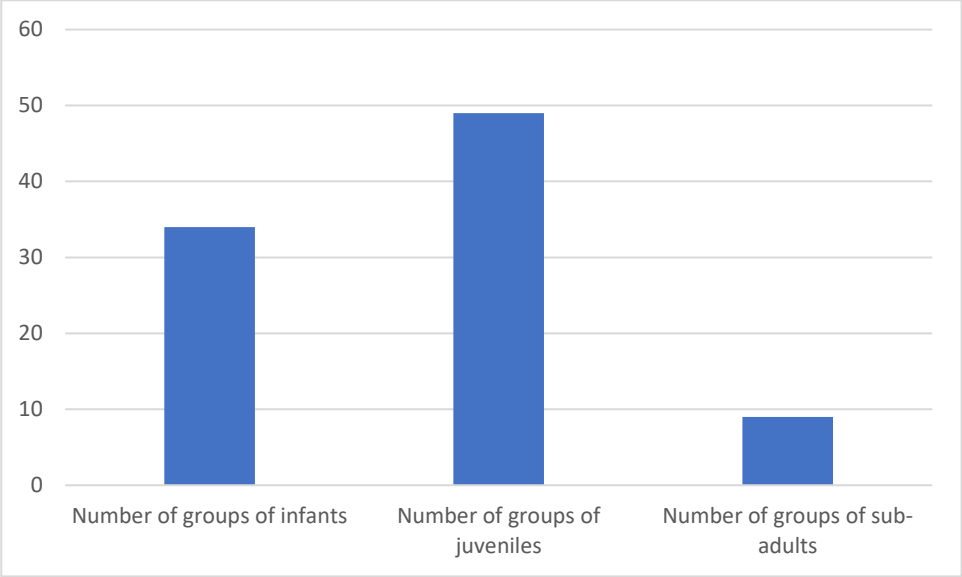

Figure 4 The number of groups of different age classes of bearded pigs viewed on the camera trap data. Graph showing the number of groups of infant, juvenile and sub-adult pigs viewed on the camera trap data collected from the Kinabatangan Wildlife Sanctuary. The majority of the groups are juvenile, while there are few sub-adult groups.

In addition, the mean numbers of group sizes differ between age classes of pigs. The mean group size for infants was 4.9, for juveniles was 4.4 and for sub-adults was 3.6. These numbers do not include the mother in the group size. Therefore, it is evident there is much variation in the group sizes and therefore the overall mean taken may not be wholly accurate and representative.

Regarding the body condition of the bearded pigs, 3.3% of the pig groups were categorised as being ‘very good’, 92.4% were categorised as ‘good’, and 4.3% were categorised as ‘fair’.

Nest age

Of all the nests sampled, 6.6% were less than one week old, 18.0% were one week to one month old, 34.4% were one month to nine months old, 26.2% were nine months to one year old and 14.8% were one to two years old. It can be seen that the majority of nests found were within one month to one year old, and far fewer were found which were much younger or much older than this.

DISCUSSION

From the results of this study, it appears that canopy cover had a significant impact on the number of pig nests found. While canopy cover was found to not have a significant effect on the number of

pig nests in the GLMM, this may be explained by the fact that the pig nests all have similar canopy cover as they are all relatively high. Therefore, a statistical test is unlikely to find any significance. This is supported by the result showing that there was a significant difference between the canopy cover at the pig nests and the canopy cover at the randomly located sapling vegetation plots, indicating that the bearded pigs are selecting areas with higher than average canopy cover, as well as with higher numbers of shorter saplings, to make their nests in. The pigs are likely nesting in areas of high canopy cover to serve as some protection from predators for the piglets, as predicted in the 2004 study by Fernández-Llario. It appears that no other variables had a significant effect on the number of pig nests. However, these results must be taken in the context of this study, as there may be factors causing the results to seem to hold less significance than they do.

While distance from oil palm plantation was not significant, it was approaching significance and had a negative correlation, meaning that further away from oil palm, there are fewer pig nests than there are closer to oil palm. This is supported by the finding that the majority of pig nests were found in corridors of forest and smaller plots of forest (which would both be close to oil palm plantation), with only 13 being found in larger plots of forest. Therefore, while a significant relationship between distance to oil palm and number of pig nests was not found, they may still be selecting areas where oil palm is accessible as a food source, as found by Love et al. (2017). In addition, distance from water may not be significant because all the areas sampled were relatively close to the river, meaning there may not be enough variation to produce statistically significant results. However, it may be that the pigs are using smaller water sources than the river, like wallows and creeks which would explain why they are not taking the distance from the river into account when selecting their nesting site. Due to the nature of the sampling methodology, only water sources within 10 m of the pig nest would have been seen and recorded, meaning it is possible that there were water sources being used by the pigs which were not recorded in this study.

None of the variables measured were found to have a significant impact on the number of saplings. This was expected for the distance from water and the distance from oil palm as these variables were unlikely to have any effect on the number or height of saplings, unless they caused increased human disturbance to the saplings. However, canopy cover would be expected to have an impact as decreased canopy cover would theoretically cause more saplings and cause them to be taller than in areas with higher canopy cover. This has been found in other studies on the effects of canopy cover on saplings, decreased canopy cover increases the densities of Scots pine saplings over 1 m in height, and saplings shorter than 1 m also had highest densities at lower canopy covers (peaking at 20% canopy cover) (Vickers and Palmer, 2000). Canopy cover did have a significant impact on sapling height, with a negative correlation as expected, however it may have not had a significant impact on the number of saplings because other unmeasured variables like the impact of animals in the area may have had more of an effect. Animals have been found to

damage saplings in other studies, including the study on the effect of red deer on foliage by Renaud et al. (2003), which found that the red deer prefer specific heights and structure of saplings, consequently having an impact on the sapling densities. As seen in the results, while insignificant, the number of pig nests had a positive correlation with the number of saplings. This may be because the pigs are selecting to nest in areas with high numbers of saplings for nest building purposes. Alternatively, they may be selecting areas of forest which are more degraded, and consequently have a higher sapling density. More degraded areas of the forest with fewer larger trees would have higher canopy cover resulting in higher densities of saplings. Elephants have been found to prefer degraded forest rather than primary forest in study conducted in Sabah (Evans et al., 2018). Therefore, it may be that bearded pigs also prefer to live and nest in degraded forest, however this may only be because it is close to oil palm as this is where the degraded forest is most prevalent. This supported by the fact that the majority of the pig nests were found in smaller plots of forest and corridors of forest, instead of larger plots. Another hypothesis may be that the removal of saplings by the pigs actually encourages further growth.

Some of the limitations of this study may have impacted its accuracy. Some surveyors were more skilled and experienced at spotting pig nests and therefore more may have been missed on transects conducted by less experienced surveyors. The small area each surveyor had to survey aimed to reduce this, however it still may have had an impact on the numbers of pig nests sampled on each transect. In addition, despite the time frame ‘one month to one year’ being less than half the time period of the potential age of the pig nests, over 60% of nests were estimated to be between one month and one year old. This may be because newer nests are easier to see as they are usually much more obvious due to the nests decreasing in height with age. Therefore, this could indicate that some older nests were potentially missed, meaning that the pig density estimates are lower than the reality. The method used for measuring soil type was coarse, as the categories only had two or three potential options and the majority were the same, meaning the results were very similar for most of the soil found at the pig nests and sapling vegetation plots. This would not give a representative indication of the soil types as a result. In addition, the recording of wallows in the vicinity of the pig nests was not successful as only one pig nest had a wallow within 10 m of it. Furthermore, the numbers of camera traps used in this study were lower than previous studies, including Love *et al.* (2017) in which 110 camera trapping stations were used. Moreover, all the camera traps reviewed for this study were located along the river and restricted to only one side of the river. This means that the data from these camera traps may have not been completely representative if, for example, on one side of the river pigs typically have more piglets than on the other side of the river.

Future studies could potentially measure the distance between the pig nests. In order to do this, a complete area would need to be sampled rather than random transects through it. However, the distance between pig nests may be significant as several nests were found in very close proximity

to another nest of a similar age, indicating that the pigs may be nesting near each other for safety or other reasons. In addition, a larger area and more sites could be sampled in future, as well as more sapling vegetation plots (to ensure it is actually pigs causing a trend), because this study was limited by time and resources and therefore did not sample a very large area. Therefore, more sampling would make the results more representative and accurate. Furthermore, all the transects in this study were started from the river or a trail due to time constraints, however this may mean the results are slightly biased as the majority of the area sampled was near the river. Consequently, future studies could consider starting transects at random points in the forest which may give more representative results. Better and more numerous camera trap placement would also be an improvement for future study.

In conclusion, it is evident from this study that in the areas sampled, a significant relationship between bearded pig nest activity and sapling composition was not found. However, they may be selecting areas to nest in with higher than average canopy cover and high numbers of short saplings. The emergence of relationships between bearded pig nest site selections and forest structure point toward important roles for this species in the rainforest. There is a rich set of possible future studies that could enumerate and demonstrate these relationships more fully.

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