Assessing the leopard cat's (*Prionailurus bengalensis*) habitats and prey species in the Lower Kinabatangan Wildlife Reserve using existing home range data.

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Biological Sciences (with Professional Training Year)
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Part A

Reflection

I chose to do a PTY as I was unsure about the direction I wanted to take with my future in biology. My year-long placement at Danau Girang Field Centre (DGFC) has shown me that a career in conservation research is exactly what I want. I have loved living in the jungle where I have been surrounded by incredible wildlife. From being woken up by elephants to finding leopard cats in the plantation, this unique experience is one I will never forget. DGFC especially has been a very welcoming home and I have been so lucky to have formed close bonds with students and staff here which has been a huge help in adjusting to the huge change in culture and environment. I feel I have fit very well into this environment and within this small research community, something that has not surprised me too much as I have also wanted to work at a place like DGFC.

Fieldwork has been very insightful, and I have gained many skills that have prepared me to continue in this field after my degree. DGFC has allowed me to be involved in a variety of different projects including bird mist netting, carbon sampling with soil, primate surveys and tree planting. I now feel very confident in tracking (both UHF and VHF) after tracking the leopard cats and pangolins throughout the year. I have also assisted the vet in minor surgery on domestic cats in the village and in several post-mortems including the leopard cat, palm civet and flying fox bat. Camera trapping has been a useful tool to learn as well as using programmes such as DigiKam to identify and digitally tag species, this massively helped me get to know the different species found in Borneo. By learning about these animals, I was able to teach other students participating in field courses about the wildlife around us, on night boats, night walks, bird and primate boats and jungle/plantation walks. I also built on my communication skills as I presented my project to all field courses and visitors to the centre.

My own project involved night walks in both the forest and the plantation as well as small mammal trapping. This first-hand experience has given me a great perspective into the effects of the oil palm industry which I had previously only read about.

Designing my project methods and collecting my own data has been very exciting, not to say this did not come without challenges. Having to adapt to flooding events and working around a changing schedule was useful in teaching me how to overcome such obstacles. My project is linked to the cat project of Amanda Wilson ongoing at DGFC and it has been my favourite project to volunteer with and even lead when Amanda has multiple responsibilities. I have very much enjoyed cat tracking a lot and cat trapping has been the most enjoyable experience for me here as I joined the team trying to catch leopard cats with pole nets in the plantation at night.

I have enjoyed keeping myself busy on other projects to fully experience field work and help others as they have helped me. I would like to especially thank PhD student and research officer, Amanda Wilson, who I have worked closely with for my project, she has provided a lot of help and guidance for me, and I couldn’t have asked for a better mentor. I am extremely grateful to be using her master’s data to establish this PTY project.

ABSTRACT

As the oil palm industry continues to expand throughout Malaysia, the wildlife of Borneo is being forced to occupy small forest areas or learn to adapt to new environments. The Leopard cat (*Prionailurus bengalensis*) is able to utilise the open canopy and simple landscape of the oil palm plantations and exploit the abundance of rodents. By studying the species diversity and abundance of these prey groups within plantations, we can gain a better understanding of how to conserve predator and prey populations. Small mammals, amphibians, small reptiles, small birds, and bats are all a part of the leopard cat's diet. This study investigates the diversity of the leopard cat prey and how the habitat differences influence different communities within the forest environment and the plantation land. Although the species richness and number of individuals were not significantly different between the landscapes, the habitat variables proved important in determining the abundance of prey observed. This study suggests that the openness of the canopy, the lack of vegetation density and leaf litter greatly influence a higher number of observations of prey items. Although the plantation may not support a higher diversity or abundance of prey items for the leopard cat, its environment provides the leopard cat with a more open space for foraging.

1. INTRODUCTION

In Borneo, there are five species of cats in the Felidae family, namely the Sunda clouded leopard (*Neofelis diardi borneensis*), the marbled cat (*Pardofelis marmorata*), the bay cat (*Catopuma badia*), the flat-headed cat (*Prionailurus planiceps*), and the most abundant felid, the Leopard cat (*Prionailurus bengalensis*) (Mohd-Azlan et al., 2022). Despite being the most widely distributed cat in Asia, the ecology, behaviour and population sizes of the leopard cat are still understudied (Rajaratnam et al. 2007; Mohd-Azlan et al. 2022; Ghimirey et al. 2022). Research on the wildlife in Borneo is becoming vital as Borneo has experienced some of the world's highest rates of deforestation, this is mainly a direct result of the expanding oil palm (*Elaeis guineensis*) industry (Cushman et al. 2017). The leopard cat is currently of particular interest because it can tolerate and, in some cases, prefers agricultural land including oil palm plantations. It is believed that these areas provide an abundance of rodents, which make up a significant portion of the leopard cat's diet in Asia (Silmi et al., 2021; Rajaratnam et al., 2007). The urgent threat to Borneo's wildlife from deforestation for oil palm plantations makes research imperative, the leopard cat's adaptability can provide information on land conversion to oil palm's limit on sustaining wildlife and the need for forested areas.

1.1 Diet

The Leopard cat is a carnivorous, opportunistic hunter with a broad diet, making it a generalist species (Khan 2004). They are nocturnal mammals and can be both terrestrial and arboreal, known to forage and sleep both on the ground as well as in the canopy of palm trees (Silmi et al. 2021; Mohd-Azlan et al. 2022; Rajaratnam et al. 2007). Studies have been conducted in several countries, including Bangladesh, the Philippines, Thailand, and Japan, regarding the feeding habits of Leopard cats. These studies have reported that Leopard cats primarily consume small mammals, such as squirrels, tree shrews, and largely rodents (Silmi et al. 2021; Khan 2004; Rajaratnam et al. 2007). It has been noted that they eat amphibians, small reptiles (such as skinks), small birds, bats, insects, and fish (Khan 2004).

1.2 Oil palm plantations

With some of the highest rates of deforestation in the world coming from Borneo, Malaysia has lost 20% of its forest land in the last 30 years with the palm oil industry contributing to this land change (Wilcove 2010; Cushman et al. 2017; Wicke et al. 2011). Oil palm provides huge economic and social benefits to local communities within Southeast Asia however it is also considered the biggest immediate threat to biodiversity (Wilcove 2010). In Malaysia, Sabah is the largest oil palm-planted state contributing 28.6% of the country's total oil palm extent and producing over 7% of the world's palm oil (Rosner 2018). As the expansion of oil palm cultivation on a large scale is expected to continue globally, it is crucial to conduct more research to find ways to balance the benefits of oil palm cultivation while also preserving the biodiversity of the species residing in these tropical areas (Wilcove 2010). However, despite being generally perceived as entirely detrimental to conservation efforts, the conversion of forests to plantations can benefit and even attract some species (Dahaban et al 1996). Rodents are particularly attracted to oil palm plantations and the damage they infer results in substantial economic loss to the industry (Phua et al. 2017). Leopard cats exploit this abundance of rats within the plantations, and this can encourage cat populations too (Silmi et al. 2021). Also, a part of the cat's diet, tree shrew species can be found in plantations however their populations are negatively impacted by the logging of primary and secondary forest types (Meijaard & Sheil 2006). Habitat niches are important in determining species' presence and communities. Amphibians are particularly sensitive to changes in habitats and climates, the logging of secondary forests has led to the decline in populations and in particular, specialist species adapted to the forest environment (Gillespie et al. 2012).

A study in 2015 (Konopik et al. 2015) in Borneo's oil palm plantations, demonstrated the importance of forested areas in sustaining the diversity of anuran communities. The study suggested that only generalist species were able to cope with the drastic changes in the environment presented within plantations (Konopik et al. 2015). Amphibians are highly sensitive to changes in temperature, humidity and water quality and can be dependent on dense canopy cover, lacking inside the plantations (Konopik et al. 2015). Due to the requirement to sustain such changes, only generalist frog species with lower environmental sensitivities can survive in plantations, thus giving rise to a different community than that found within the forests (Gillespie et al. 2021).

Leopard cats are currently categorised as “least concern” by the IUCN; however, their long-term survival may depend on the adaptability of their prey to changes in agricultural landscapes (Ghimirey et al. 2022). If environmental changes cause a decline in populations of animals such as frogs, small reptiles, and rodents, this could potentially put the survival of leopard cats at risk. Leopard cats as flagship species can help us highlight the conservation value of an area (Mohd-Azlan et al. 2022). Little has been revealed about the prey availability of leopard cats within oil palm plantations of Borneo. A recent study in Kalimantan, Indonesian Borneo, highlighted the significance of leopard cats as biological controllers of murids (Family: Muridae) within agricultural areas (Silmi et al. 2021). It is important to further the research on prey availability as leopard cats utilise oil palm plantations at high levels and account for a significantly large area within the home range of the leopard cats used in this study (Chua et al. 2016; Wilson 2022, unpublished).

1.3 Aims and Hypotheses

The home range of an organism is the area in which it lives, containing the essential resources required for it to survive and reproduce, such as food, space, and protection from predators (Britannica 1998). The more concentrated areas, that are used more frequently within the home range, are referred to as the core area and it is usually driven by a more dependable food source (Kaufmann 1962; Ewer 1968). The average home range for a male leopard cat is around 1.36 km^2 (Silmi et al. 2021). The focus of this study is the home range and core locations of 4 leopard cats collared and tracked in the Lower Kinabatangan Wildlife Sanctuary. Data on the home range and core locations of these leopard cats were estimated in 2022 by Wilson (unpublished data). Two of the cats (LCM02; Lincah, LCM03; Bulan) were captured and GPS-collared at Pontian Hillco estate and the other two cats (LCM04; Laju, LCM05; Bintang) were captured and GPS-collared at Pontian Pendirosa plantation. All cats were tracked using VHF (Very High Frequency). Lincah was tracked for around six months, Bulan was tracked for almost seven months, Laju was tracked for over one month and Bintang was tracked for around five months.

The two objectives for this study are as follows; assess the species diversity of the leopard cat’s prey communities existing within the cat’s’ home ranges and assess the habitat features within the leopard cat’s home ranges. This study will focus on looking at the species abundance and richness at each site and the habitat features to analyse the difference, particularly between the oil palm plantations and forest areas and look for underlying drivers for the leopard cat to be attracted to such areas. I hypothesise that the abundance of prey species will be higher within the core locations compared to the home ranges outside of the core areas, after statistical analysis this hypothesis was rejected due to insignificant differences. However, this study was successful in proving the second hypothesis that the openness of the plantation habitat will reduce the abundance of prey species. Although the species richness and abundance of individuals were not significantly different, the composition of prey communities differed between the oil palm plantation and the forest sites and even between the 2 different plantation sites. These results solidify the suggestion that even with a lower abundance of species due to the logging of secondary forests, leopard cats can hunt efficiently due to the openness of the canopy and lower vegetation density revealing prey items easier.

2. METHODS

My research was conducted in the Lower Kinabatangan Wildlife Sanctuary (LKWS). The LKWS (5°10’-5°50’N, 117°40’118°30’E) is made up of 10 lots of protected forest in Sabah, Malaysian Borneo. These lots consist of 27,970 hectares of fragmented forest patches, including secondary forests, riparian forests, and mangroves (Gillespie et al. 2012; Jumail & Salgado-Lynn 2021). The

Kinabatangan River, which is 560 kilometres long, flows through these lots (Hearn et al. 2020; Jumail & Salgado-Lynn 2021). Land converted for agriculture, predominantly for the oil palm industry is found between the forest reserves (Abram et al. 2014). My study sites include two oil palm plantations; Pontian Hillco and Pontian Pendirosa, both located on either side of Lot 6.

2.1 Oil palm plantations

Both plantations' estates are managed by the same company; Pontian United Plantations-Felda Global Ventures Holdings (PUP-FGV) and have been planting since 1996. Hillco has a larger planted area of 20.54 km2 and further downriver is Pendirosa, which has 17.26 km^2 of oil palm planted areas. The plantations are around 50-400m from the Kinabatangan River. Although under the same company, both plantations have different approaches to High Conservation Value (HCV) areas which provide forest habitats to support a different species community compared to those within the plantation. The approach to conserving forest environments within agricultural landscapes was developed in 1977 to allow protection of threatened and endangered species, encourage biodiversity and provide natural environments to allow ecosystem services to continue despite the impacts of anthropogenic land conversion (HCV Malaysia Toolkit Steering Committee, 2021). HCV approaches within Hillco include the preservation of secondary forest patches surrounding the plantation as well as patches in between oil palm areas, this can be seen in Figure 1 which shows the gravel roads of both plantations and one of the areas in Hilco where HCV is among oil palms. Unlike Hillco, Pendirosa contains no designated HCV areas, but several areas are considered buffer zones. The buffer zones include a ridge around the planted areas where bamboo thrives and a border of secondary forest between the ridge and the Kinabatangan River. The transition of habitat types aims to reduce edge effects and allow forest species to adapt to plantation environments to support a higher diversity (Gotmark et al. 2000).

Figure 1. Three transects were set up along plantation roads. The left image shows the transect set up in the core location of one of the leopard cats within the Pontian Hillco Plantation. The middle image shows the transect in the overlap of 2 cats' home ranges, also in Hillco, however, this site has High Conservation Value (HCV) areas between the planting sites. The image on the right shows the core area transect set up in the second oil palm plantation, Pontian Pendirosa.

2.2 Transect sites

Data on the home range and core locations of 4 male leopard cats were estimated in 2022 by Wilson (unpublished data). Two of the cats (LCM02; Lincah, LCM03; Bulan) were captured and GPS-collared at Pontian Hillco estate and the other two cats (LCM04; Laju, LCM05; Bintang) were captured and GPS-collared at Pontian Pendirosa plantation. All cats were tracked using VHF (Very High Frequency), Lincah was tracked for around six months, Bulan was tracked for almost seven months, Laju was tracked for over one month and Bintang was tracked for around five months. The study also included the home range of one female but for the purpose of this study, only the males were studied as the home ranges for a female can differ based on reproductive cycles (Rajaratnam 2007).

Six transect locations were established by overlaying the core locations and home ranges onto Google Earth maps and creating a straight 200m line track. A transect was put within the core locations of Lincah, Bulan and Laju, one transect was set up in Hillco within the overlap of the home ranges between cats Lincah and Bulan and a transect within the overlapping home ranges of Bintang and Laju in Pendirosa. A control site was set up within the HCV area of Hillco where no leopard cats have been observed and no home ranges extend to. Figure 2 shows each transect compared to the home ranges and core locations of the leopard cats utilised for this study and also observations of leopard cats currently frequenting the same areas. For the core locations and home range areas, I used the ranges calculated by Wilson (2022) using the Kernel Density Equation (KDE) which rules out unused areas that are included when using the Minimum Convex Polygon (MCP) estimator. A 50% contour was used to estimate the core areas and a 95% contour for the home range. All transects were horizontal and parallel to each other. All transects except for the Lincah core, and the forest control were established on North-South gravel roads within the plantation, leopard cats are known to use the roads as they provide an open space for hunting (Laton et al. 2017). The core location for Lincah was within the HCV area of Hillco and therefore set up within a forested area.

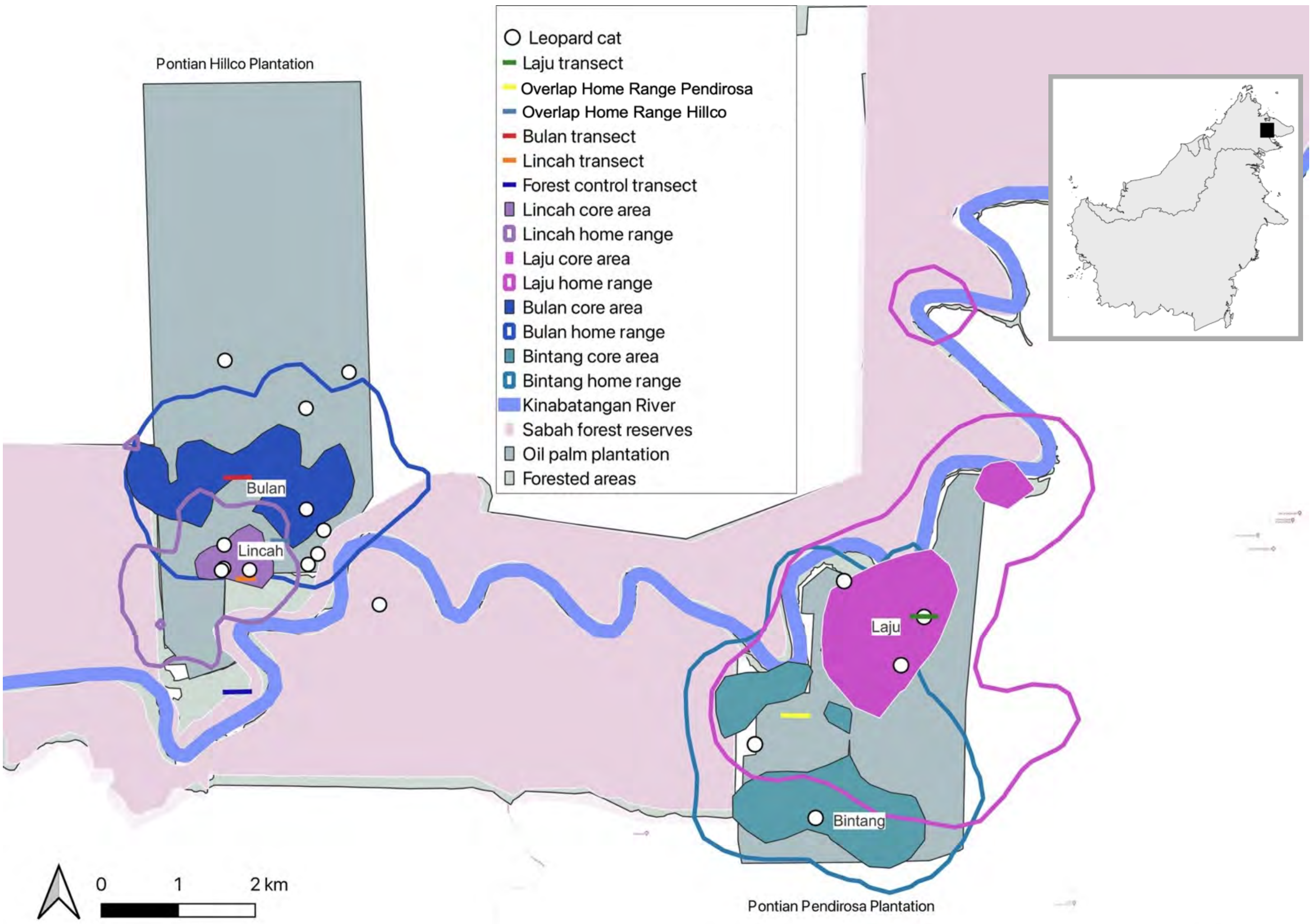

Figure 2. The study sites along the Kinabatangan River, in the Lower Kinabatangan Wildlife Sanctuary (LKWS), Sabah, Malaysia. For this study, two plantations between Lot 6 of the LKWS were used based on the previous collaring and tracking of 4 leopard cats (Wilson 2022, unpublished). Transects were established in 3 different core areas, 2 overlapping home ranges and a forest site that no leopard cats are known to utilise. Leopard cat surveys were also carried out for this study to confirm the current presence of leopard cats within these areas, observations of cats are shown as white dots in this figure. This map was created using the QGIS programme (Version 3.26.3-Buenos Aires) (QGIS Development Team 2022).

2.3 Night surveys

The activity patterns of the 4 collared leopard cats showed crepuscular tendencies with twilight activity peaking between 18:00hrs and 19:00hrs, accelerating again around 5:00hrs (Wilson 2022, unpublished). Due to the nocturnal habits of the leopard cats, night surveys for prey availability were conducted between 18:00 and 19:00 in all locations. Night surveys were carried out on foot along 200-metre transects and for no longer than 1 hour to standardise the time taken at each site. Surveys were carried out for 4 consecutive nights (when possible) for two rounds of data collection per site. During these surveys, observations of amphibians, small reptiles, small birds, and bats were conducted using torches. At the same time, point transects were used along the same 200m to survey for birds and bats with one observer stopping every 5 metres to look, these observations were also recorded opportunistically if another observer spotted one by chance. The bird and bat observations included any visible from the transect. In amphibian and reptile sampling, observations were limited to 2 metres left and right extending the transect route and any height above. Acoustic records were also made for all taxa during surveys. Every night, habitat parameters were recorded, this included temperature, wind speed, wet/dry ground and whether it had rained that day. Classification of species was made using identification books; Birds of Borneo (Phillipps & Phillipps 2014), Lizards of Borneo (Das 2004) and Frogs of Borneo (Inger et al. 2017).

Night surveys were conducted to locate leopard cats using the same spots for hunting as those tracked in 2020/2021. Surveys were carried out at 20:00 hrs for around 1.5 hours, by foot, motorbike or car using white and red lights. Both plantations were surveyed on 7 nights each and the routes taken were randomly selected within the plantations, inside or near the previously established home ranges. When a cat was observed, the location was marked on a GPS and the waypoints were exported to Google Earth Pro (2022) to compare to the home ranges of the cats in this study. These observations do not aim to look at the abundance of leopard cats, only which areas leopard cats are using in relation to the home ranges of Lincah, Bulan, Laju and Bintang.

2.4 Small mammal trapping

To assess small mammals as potential prey items, 11 hook and spring-door traps were placed alternately to the left and right and no more than 10 metres away from the middle of the transect. They were placed on flat ground from the start of the transect and then approximately every 14m apart, this was more of a guideline as some gaps would be longer due to the presence of drains or large trees in the plantations. A mix of 3 different-sized traps was used: small traps (15x31x20cm), medium (18x33x22cm) and large (20x38x23cm). The size of the traps was recorded for each capture. Traps were set at each site for 4 consecutive days and then repeated for another 4 consecutive days after completing one round of all sites. Consecutive days were not always possible due to heavy rain. Traps were baited with fresh bananas and set up between 18:00 hrs and 19:00 hrs and checked the following morning between 7:00 hrs and 8:00 hrs. The top of the trap was covered with leaves underneath the handle to protect any animals inside the trap from rain and predators, this also helped to conceal the trap. If a small mammal was successfully captured it was identified to species level while still in the cage, if possible, to minimise handling time, it was then put into a cloth bag and weighed using a digital scale. The animal was then gently handled, with the handler wearing a protective glove and appropriate personal protective equipment (PPE) such as a surgical mask. A small section of fur was then shaved from the hind leg which would be visible if captured again. Upon recapture of an animal, the other hind leg would be shaved and subsequently, the front leg in the event of another recapture. If identification was unsuccessful from observation, then further measurements would be taken such as body and tail length. The identification of small mammal species was done based on the Mammals of Borneo guide (Phillipps & Phillipps 2016).

2.5 Habitat Assessments

Although the leopard cats utilise both oil palm landscapes and forested areas, the average of oil palm areas within the core areas of the leopard cats used in this study was 76%, a study by Rajaratnam et al (2007) suggested that the locations chosen by leopard cats are based on the ‘catchability’ of prey rather than abundance. This implies that the open habitats found within plantations could be the main reason for determining their home ranges. To consider this, habitat variables were measured at each transect. This was done using 5x5 metre grid plots established at 4 random points along each 200m transect. Habitat features measured included: understory and mid-story density, percentage leaf litter cover, ground vegetation cover, canopy cover, number of trees (categorised by diameter at breast height DBH: <10cm, 10-40cm and >40cm) and vegetation height. Understory and mid-story density were measured using a vegetation density stick which has equal vertical black and white strips along the stick. The stick was held horizontally at knee height (on the same person or at the same height to keep it consistent throughout) and the number of black stripes fully visible to the observer standing at the mid-point was recorded. The number of stripes visible was multiplied by 2 and subtracted from 100 to get a percentage of density cover. This was repeated at chest height to estimate the mid-story density. All habitat variables were carried out in the centre of the grid as well as at the points of north, south, east, and west, 5 metres from the centre point. The percentage of ground cover included estimating the area of ground covered by leaf litter, vegetation, and others (mainly the gravel of the plantation roads). This was a subjective measure therefore carried out by the same person at each transect to ensure consistency in value estimates. The canopy cover was measured using the CanopyApp (University of New Hampshire 2018) which utilises a phone camera, the image taken can be filled in depending on the presence of the canopy at a sensitivity of 100 to produce a percentage of cover. Vegetation height was taken by measuring the tallest vegetation at each point and the number of trees was counted for the whole 5x5 metre plot. To get an average of the transect, each individual grid was averaged by the 4 points and the centre point. The average of the 4 whole grids was then used to get an overall habitat assessment for each transect.

2.6 Statistical analysis

Collected data was recorded in Excel (v. 16.76) and analysed in R studio (v. 2023.06.1+524). A Shapiro-Wilk was used to check for a normal distribution of data. Boxplots, histograms, and QQ plots were also used to check for normality. A Shannon’s Diversity Index and the Simpson’s Index were used to estimate species diversity based on richness and evenness. Due to data being not normally distributed, a non-parametric t-test, the Mann-Whitney U test was used to test the difference in the species diversity between the different sites. An ANOVA was also used to analyse the difference across all sites. An ANOVA was then used to look at the difference in diversity of each taxon separately and to test if there is a significant difference between the different taxa. A Generalised Linear Model (GLM) will be used to analyse the difference in species abundance and species richness including the features of the habitat of each site. A Poisson Regression GLM was used for this analysis, including all 10 habitat measurements to test if the environment types potentially influence the abundance or species richness. A species accumulation graph was created to look for the presence of an asymptote to suggest that the sampling effort is representative of the observations found in this study. Rank abundance curves were also generated to visualise the species richness and evenness.

3. Results

Overall, 1817 individual potential prey items were observed. 95.3% of these observations were amphibians, 0.39% were birds, 0.44% were small reptiles, 0.83% were bats and 3.1% were small mammal captures. The abundance of each species was recorded at each site and put into a table shown in Table 1. Across the different sites, 15.8% of the total observations were made at Lincah's core transect, 2.3% at Bulan's core, 23.78% at Laju's core, 18.84% at the overlapping home ranges in Pendirosa, 16.73% at the overlap in Hillco and 24.44% in the forest control site. Figure 3 shows the composition of prey available at each site based on observations in this study.

Table 1. The overall observations of the leopard cat's prey species available across all sites. Observations that could not be classified to species level were also included as 'species unidentified' to get a total abundance of each taxon

Species	Lincah's Core	Bulan's Core	Laju's Core	Overlap Home Range Pendirosa	Overlap Home Range Hillco	Forest Control	Total
Amphibians							
White-lipped tree frog (*Hylarana raniceps*)	247	4	4	11	235	306	807
Bornean narrow-mouthed frog (*Microhyla borneensis*)	4	0	1	0	7	5	17
Brown bullfrog (*Kaloula baleata*)	0	0	0	0	6	18	24
Dark-eared tree frog (*Polypedates macrotis*)	0	0	0	0	1	0	1
Four-lined tree frog (*Polypedates leucomystax*)	0	0	11	1	9	0	21
Frilled tree frog (*Rhacophorus appendiculatus*)	13	0	0	0	0	13	26
Grass frog *(Fejervarya limnochari*)	0	8	163	116	12	0	299
Greater swamp frog (*Limnonectes ingeri*)	0	2	6	1	6	0	15
Green paddy frog (*Hylarana erythraea*)	0	14	160	102	0	0	276
Least narrow-mouthed frog (*Microhyla perpava*)	1	0	1	0	0	83	85
Mangrove frog (*Fejervarya cancrivora*)	0	0	59	40	0	0	99
Rough-sided frog (*Hylarana glandulosa*)	4	1	7	1	6	2	21
Saffron-bellied frog (*Chaperina fusca*)	0	0	0	0	0	1	1
Species unidentified	5	0	15	10	7	2	39
Total	273	29	427	282	289	430	1731
Birds							
Blue-eared kingfisher (*Alcedo meninting*)	0	0	0	0	1	0	1
Malaysian night heron (*Gorsachius melanolophus*)	0	0	0	1	0	0	1
Red-headed tailorbird (*Orthotomus ruficeps*)	0	0	0	0	1	0	1
White-breasted waterhen (*Amaurornis phoenicurus*)	0	0	0	3	0	0	3
Species unidentified	0	0	0	1	0	0	1
Total	0	0	0	5	2	0	7
Reptiles							
Gecko (Family: Gekkonidae)	0	0	1	1	0	0	2
Mangrove skink (*Emoia atrocostata*)	0	0	0	1	0	0	1
Skink (Family: Scincidae)	1	0	2	0	0	2	5
Total	1	0	3	2	0	2	8
Bats							
Flying fox (*Pteropus vampyrus*)	1	0	0	0	0	0	1
Species unidentified	7	0	0	5	1	1	14
Total	8	0	0	5	1	1	15
Small mammals							
Common Treeshrew (*Tupaia longipes*)	4	0	0	0	0	3	7
Dark-tailed tree rat (*Niviventer cremoriventer*)	0	1	0	0	0	0	1
House mouse (*Mus castaneus*)	0	1	0	1	1	2	5
House rat (*Rattus tanezumil*)	0	1	0	1	2	0	4
Large treeshrew (*Tupaia tana*)	0	0	0	0	1	1	2
Lesser treeshrew (*Tupaia minor*)	0	0	0	0	0	1	1
Malaysia field rat (*Rattus argentiventer*)	0	1	0	0	0	1	2
Muller's rat (*Sundamys muelleri*)	0	8	1	12	7	0	28
Plantain squirrel (*Callosciurus notatus*)	0	0	1	0	0	0	1
Ricefield mouse (*Mus caroli*)	0	1	0	0	0	0	1
Small spiny rat (*Maxomys surifer*)	0	0	0	0	1	1	2
Whitehead's rat (*Maxomys whiteheadi*)	0	0	0	0	0	2	2
Total	4	13	2	14	12	11	56
Total number of prey items observed	287	42	432	306	304	444	1817

Data was analysed including all species observed and captured and the number of individuals for each species. A one-way ANOVA (Analysis of Variance) test was used, and data was found to not be significantly different between the different sites ($F(5,210) = 0.434$, $p = 0.825$). Shannon's Diversity Index was used to compare the species diversity for each site and a non-parametric two-sample t-test (Mann-Whitney U test) was used to test for significant differences using these indices. The results of the t-test on the species diversity show that the difference was not significant between each of the sites. Simpsons Index was then used, these results were also not significantly different when comparing all sites ($p>0.05$). An ANOVA was used to test the significance of the means of individuals observed when comparing the 4 prey groups (amphibians, birds, reptiles, small mammals, bats) at each site, the results suggest that the composition of prey availability is significantly different ($p = 5.1e-08$). Figure 3 shows the composition of prey available at each site based on observations in this study. Rank abundance graphs showing the species abundance and rank for each location can be found in Appendix 2.

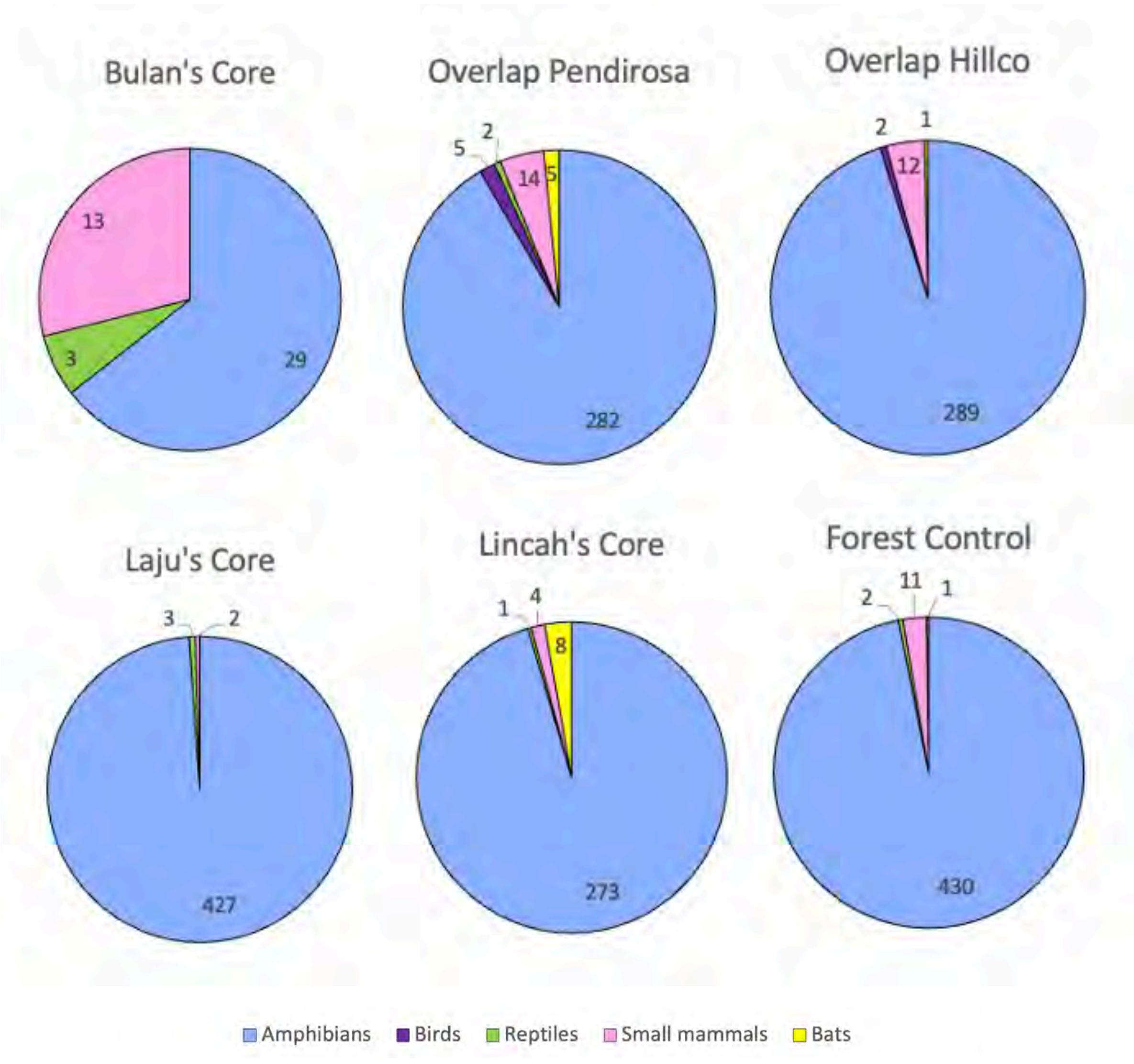

Figure 3. Prey availability composition at each site is based on the abundance of individuals observed. In all cases, amphibians (blue) were the most abundant group observed. The second most abundant group for Lincah's core, in the forest area of the plantation, was bats (yellow) followed by small mammals (pink) and then reptiles (green), no birds (purple) were observed at this site. At Laju's core, reptiles were second followed by reptiles with no birds or bats observed. Both overlap sites showed a similar pattern with small mammals as the second most abundant group followed by birds and then bats; reptiles however were only observed at the Pendirosa overlap site. Although a smaller abundance overall, the composition of prey groups at Bulan's core had a higher

proportion of small mammals compared to the other sites. Reptiles were the third most abundant at Bulan's core, no other groups were observed. The forest site had small mammals following amphibians, then reptiles and bats. The difference in abundance for each taxon was shown to be significantly different.

3.1 Survey results

A total of 1731 frogs belonging to 13 different species were recorded overall. The species of frogs visually observed include; White-lipped tree frog (*Hylarana raniceps*), Dark-eared tree frog (*Polypedates macrotis*), Green paddy frog (*Hylarana erythraea*), Rough-sided frog (*Hylarana glandulosa*), Four-lined tree frog (*Polypedates leucomystax*), Frilled tree frog (*Rhacophorus appendiculatus*), Mangrove frog (*Fejervarya cancrivora*), Grass frog *(Fejervarya limnochari*), Greater swamp frog (*Limnonectes ingeri*), Saffron-bellied frog (*Chaperina fusca*), Brown bullfrog (*Kaloula baleata*), Bornean narrow-mouthed frog (*Microhyla borneensis*) and the Least narrow-mouthed frog (*Microhyla perpava*).

The community of frog species in the forest and plantation and between the two plantations differed, indicating a notable difference in the habitats they provide. The Mangrove frog was only observed at the Pendirosa plantation. The frilled tree frog was found only in the forest areas. Grass frogs were found in all oil palm habitats. Green paddy frogs were strictly found in the oil palm sites and the opposite for the bullfrog which was found only in the forest areas. The plantation and the forest areas showed a clear distinct community difference in frog species.

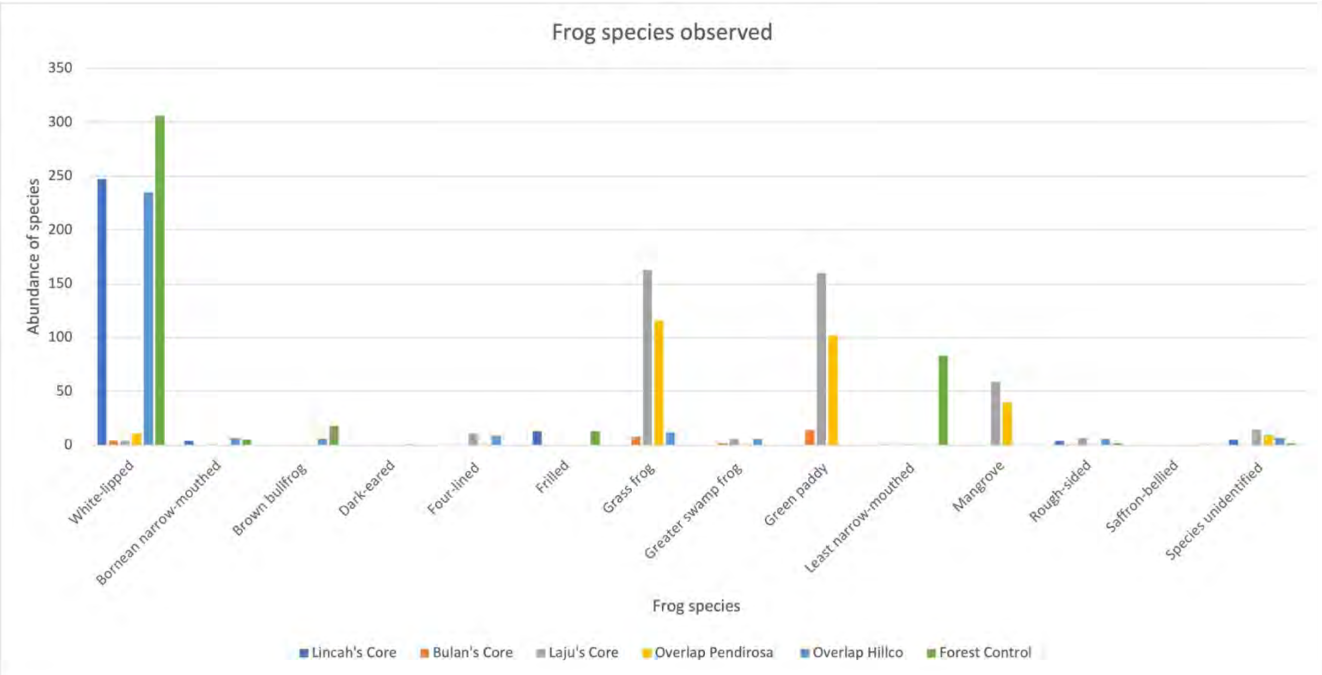

Figure 4. Bar graph showing the number of individuals observed for the species of amphibians within each site. As frogs make up the highest proportion of prey available at each site in this study, the difference in frog species communities can be a good indicator of the difference in the environment of the site location.

3 species of bird were observed: Blue-eared kingfisher (*Alcedo meninting*)*, the* Malaysian night heron (*Gorsachius melanolophus*), the White-breasted waterhen (*Amaurornis phoenicurus*) and the Red-headed tailorbird (*Orthotomus ruficeps*). Birds were only observed at 2 sites which were the two overlapping home range sites in Hillco and Pendirosa. Only 7 birds were observed overall.

3.2 Trapping results

A total of 48 trap nights resulted in 56 small mammal captures. 12 species were captured overall, this includes; the Common Treeshrew (*Tupaia longipes*), Dark-tailed tree rat (*Niviventer cremoriventer*), House mouse (*Mus castaneus*), House rat (*Rattus tanezumil*), Large treeshrew (*Tupaia tana*), Lesser treeshrew (*Tupaia minor*), Malaysia field rat (*Rattus argentiventer*), Muller's rat (*Sundamys muelleri*), Plantain squirrel (*Callosciurus notatus*), Ricefield mouse (*Mus caroli*), Small spiny rat (*Maxomys surifer*) and the Whitehead's rat (*Maxomys whiteheadi*). One individual (small spiny rat) captured at the Forest Control site, was recaptured the following day, this is the only recapture during this study. An ANOVA was used to determine the difference in small mammal captures across all sites, the results were not significant (p= 0.74).

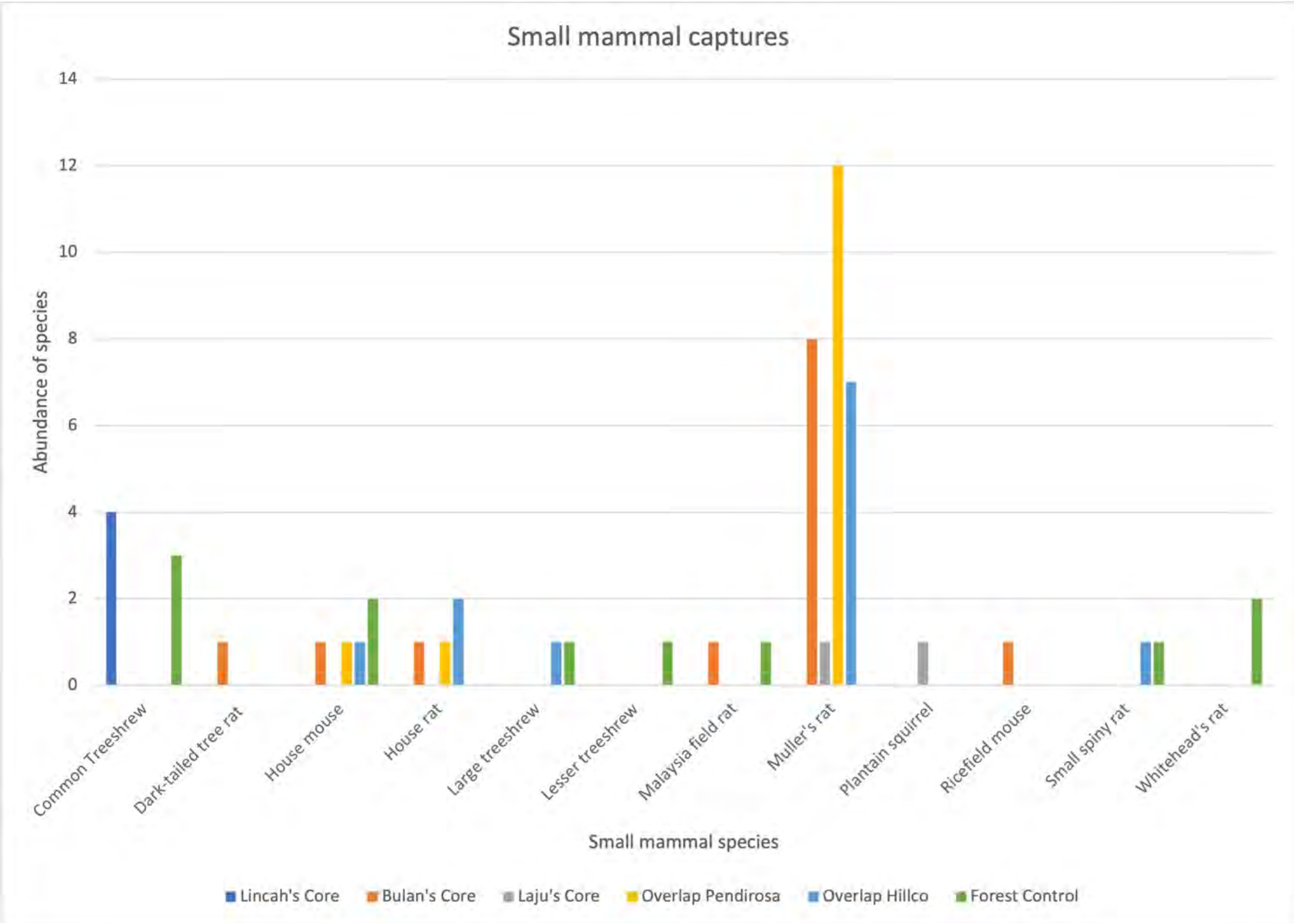

Figure 5. Bar graph showing the difference species and the abundance of each species of small mammals captured across the 6 transect sites. Muller's rat is the most abundant small mammal captured across all sites. 7 different species were captured at the forest control site, 5 species at the Overlap in Hillco, 6 species at Bulan's core, 2 species at Laju's core, 1 species at Lincah's core and 3 species at the Overlap in Pendirosa. Overall, the overlap in Pendirosa site had the most individuals captured (14) followed by Bulan's core (13), overlap in Hillco (12), forest control site (11), Lincah's core (4) and Laju's core with the least abundance (2).

3.3 Habitat parameters

A Generalised Linear Model (GLM), Poisson Regression, was used to analyse the species richness and abundance and add the habitat measures for each location into the model.

When analysed with the species richness, there was no significant difference relating to the habitat variables (p>0.05). However, when analysed against the abundance of prey items, all habitat measurements made a significant difference (p<0.05). As canopy cover increases, the abundance of leopard cat prey decreases (E= -0.037822, p= <2e-16), this is also the case for the vegetation depth (E= -1.567715, p= < 2e-16). A significant difference was also found in the measurements of understory density (p= 0.000259), midstory density (p= 0.000232), and leaf litter (p= 2.77e-05). All other habitat parameters measured showed significant differences with species abundance, these had 'N/A' as the values are identical elsewhere in the model, therefore these values were ignored for the results of this study. A species accumulation curve was generated in Excel to determine if sufficient sampling effort was achieved to represent all observations. Figure 5 shows that the curve does not reach an asymptote.

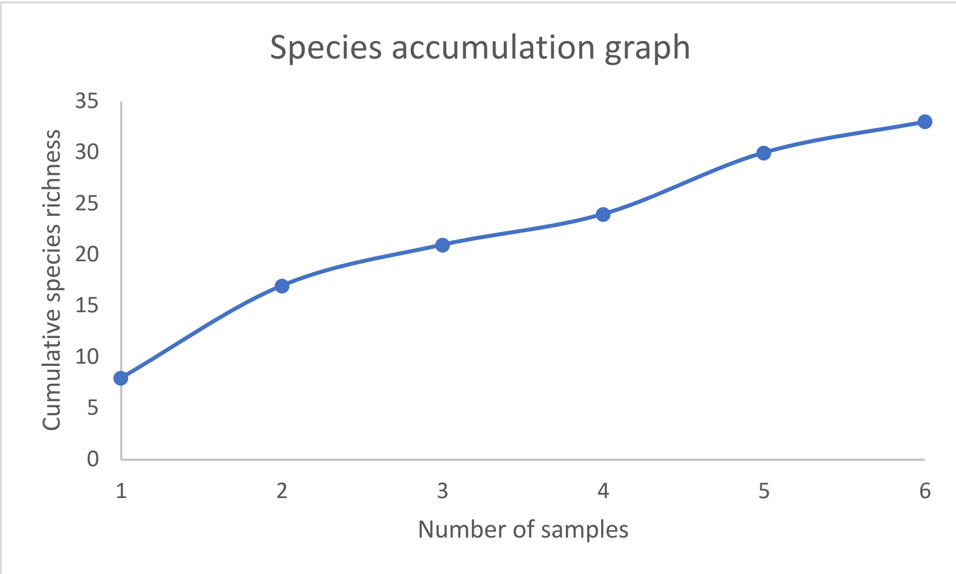

Figure 5. A species accumulation graph for all prey species observed across all locations. The species accumulation curve does not reach asymptote and therefore further sampling is needed to represent the species diversity at these locations.

During surveys conducted over a period of 7 nights in the Hillco plantation, 11 leopard cats were observed. Of these, 4 were spotted in the core area of Lincah, 1 within the core area of Bulan and 4 observations were made within the home range of Bulan. In the Pendirosa plantation, 5 leopard cats were spotted during the 7-night survey. Out of these, 1 was in the core area of Bintang, 1 in the overlapping home ranges and 3 in the core area of Laju. The GPS locations of each cat observation were marked, and waypoints are shown in Figure 2.

4. Discussion

The aim of this study was the investigate the species diversity of prey items available at home range locations for leopard cats. Within the species richness, the abundance of each was also investigated. With no significant difference in species richness and abundance of individuals between the core locations, home ranges and forest control, it can be suggested that the availability of prey is not the main driver attracting leopard cats to these oil palm landscapes. It is also possible that although available to the leopard cat as a generalist species, their preferences may not correlate with the most abundant species or taxon. Previous studies in Southeast Asia looked at the diet composition of leopard cats without investigating actual prey diversity and abundance in their home ranges. The results of this study support the presumption that the habitat itself has a greater influence on the establishment of core locations rather than the species diversity. These findings are consistent with studies that highlight the accessibility of prey due to a more open landscape within the plantation providing a more reliable foraging ground (Rajaratnam 2007; Silmi et al. 2021). In areas where there is no evidence of leopard cats, there is usually a lower number of rodents recorded due to the ability of leopard cats to act as biological pest controllers within plantations (Rajaratnam 2007; Silmi et al. 2021; Chua et al., 2016). The observations of more leopard cats within the home ranges of the previous 4 individuals suggest that the current cats controlling the area are effectively managing the rodent populations. This could explain to lack of difference in small mammal captures between the plantation and forest areas.

4.1 Prey Communities and Habitats

Other things to consider include the difference in species communities in forest locations compared to oil palm landscapes. These differences can occur due to the differences in environments and microclimates. The less complex plantation structure allows generalist species to dominate such as the white-lipped tree frog and the green paddy frog rather than specialist species that are more sensitive to habitat changes and require the forest environment to survive and reproduce (Gillespie et al. 2021). In Kalimantan, the leopard cat's dietary composition was suggested to be 74% rodents, 10% frogs, 5% birds, 4% reptiles and 7% unidentified prey (Silmi et al. 2021). Similar results were found in studies conducted in Bangladesh, Tabin Wildlife Reserve and Singapore (Chua et al. 2016, Khan, 2004; Rajaratnam et al., 2007). The composition of their diet differs from the composition of actual prey available to the leopard cats, as shown in this study. Despite being a generalist species, this diet suggests a preference for small mammals, in particular rodents. With this preference driving the control of rodent populations, amphibians have a better chance to increase populations without heavy control by leopard cats, this could be the reason for the high abundance of frogs observed during this study.

The habitat parameters can determine the assemblage of amphibian communities namely the lack of arboreal species such as the fringed tree frog (Gillespie et al. 2012). Plantation habitat structures are less complex than forests due to their lack of leaf litter, tree diversity and moist breeding habitats (Gillespie et al. 2012). Species such as the Least narrow-mouthed and Bornean narrow-mouthed frogs rely on leaf litter-rich environments and therefore are lacking in the plantations (Gillespie et al. 2012). As frogs make up the highest proportion of prey available at each site in this study, the difference in frog species communities can be a good indicator of the difference in the environment of the site location. However, a bias in this study is that the observational survey method is most effective for surveying frogs, to survey small mammals in the same way would lead to errors in count as well as being difficult to identify species.

4.2 Future Improvements

Comparison of prey availability in the wet season and the dry season would have been ideal within this study, however, due to flooding events and the lateness of the wet season this year I was unable to complete one round in each, instead, the data was pooled together. However, it is entirely possible that the outcome of this comparison could show that the availability of specific species shifts based on the climate particularly as the home ranges for leopard cats also shift in changing seasons (Ghimirey et al. 2022). To solidify this study, hunting events of leopard cats would be recorded to link prey availability to prey consumption or the analysis of scat for prey remains. Also, estimating the population of leopard cats at the study locations could make an interesting connection to the abundance of prey available. Leopard cats' home range in forested areas outside of the plantations could also be used for interesting comparisons.

5. Conclusion

Studies on flagship species, such as the leopard cat, are vital in understanding and raising awareness on the impacts of deforestation and anthropogenic land conversion particularly in environments that support so much wildlife such as the Bornean rainforest. The livelihood of the leopard cat population relies on the ability of other animals, its prey, to adapt to changing microhabitats. As such a huge component to its diet, more research on rodents in plantations is necessary especially as non-natural population controls are used to remove rodents to maintain the economy. Although generalist species of amphibians are able to populate the plantations, this may not be sustainable for frogs and specialist and endemic species will likely be lost to edge effects as the oil palm industry expands. As so much of the landscape of Borneo is being converted to oil palm plantations, it is vital that we look deeper into the life histories of leopard cats and understand to what extent can they thrive within human-altered environments. With enough research, actions can be taken to conserve more of the forest and focus on sustaining forest-dependent species. HCV areas amongst the oil palm for example can provide a mix of vegetation and canopy cover and allow more prey species to thrive as shown in the overlapping home range in the Hillco site. With more areas like this, the balance between prey availability and catchability habitats can allow effective foraging for the leopard cats dwelling within plantations.

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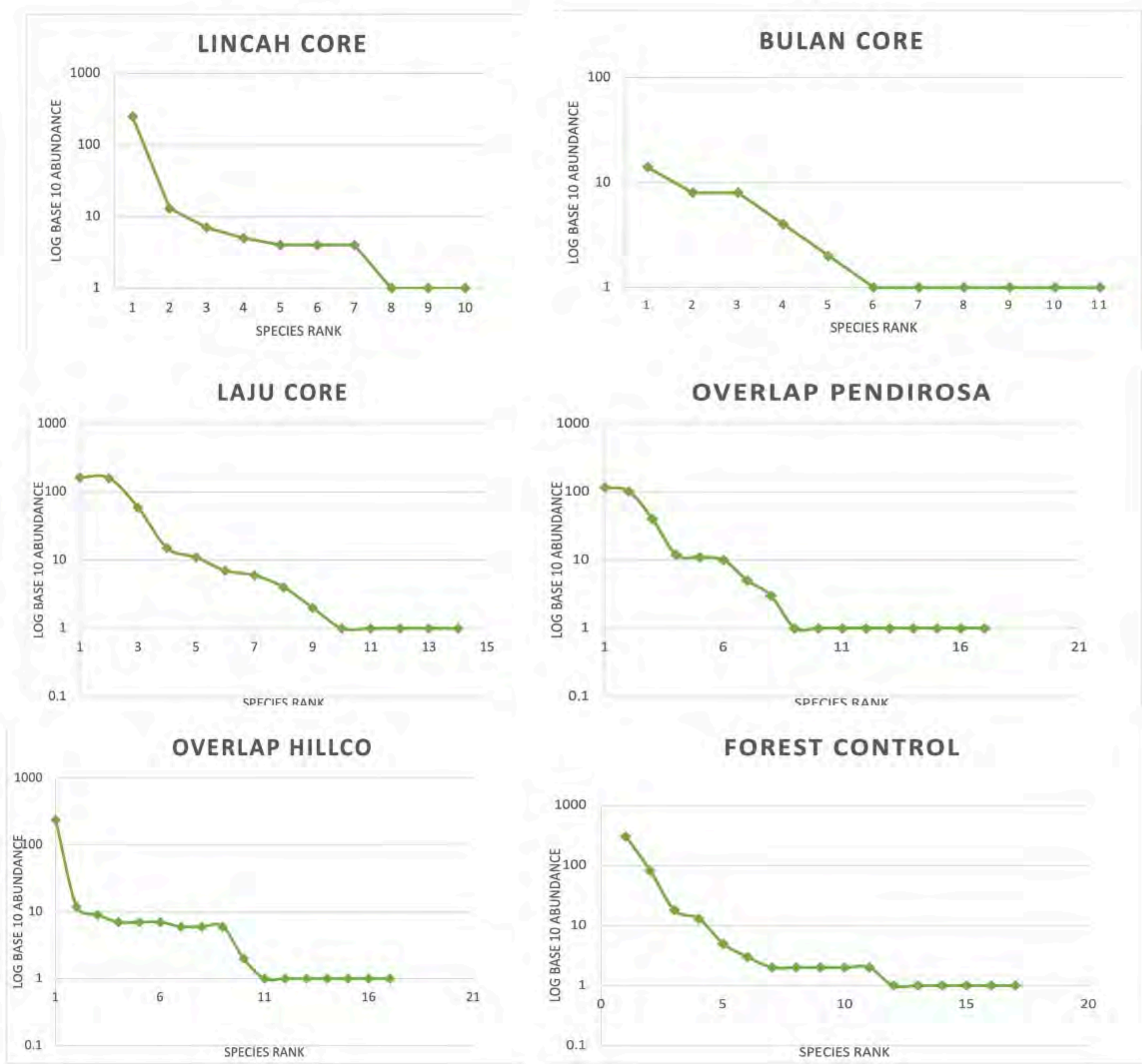
8. Supporting information

Appendix 1. The small mammal traps used in this study. These traps work by placing a bait on a hook inside the trap, the hook is attached the top of the trap and the door is placed under the top hook. When the trap is triggered by slight pressure on the hook, the door is released, and a spring brings the door to close with the horizontal bar falling and keeping the door closed.



Appendix 2. Rank abundance curves for each location. Species rank were calculated for the presence of each species in each site and plotted against the abundance (log10) of that species observed.

Appendix 3. Table showing the data collected at each site for the habitat assessments. Environment variables measured include canopy cover, understory depth, understory and midstory density, leaf litter cover, ground vegetation cover, and presence of water bodies. There are 3 categorised for trees based on cm at DBH (0-20, 20-40 and 40+).

Site	Canopy cover (%)	Understory depth (m)	Understory density (%)	Midstory density (%)	Leaf litter cover (%)	Ground veg cover (%)	No. of trees 0-20 cm DBH	No. of trees 20-40 cm	No. of trees 40+ cm DBH	Presence of water

								DBH		
Lincah	83.29	1.14	34	18	76.15	12	13	12	4	Y
Bulan	12.3	2	16	0	0	14.4	0	0	0	Y
Laju	2.3	0.84	24	0	0	49	0	0	0	Y
Overlap Pendirosa	12.81	0.55	0	0	0	24.4	0	0	0	Y
Overlap Hillco	26.95	1.24	32	26	9.45	56.2	3	1	0	Y
Forest control	73.28	0.8	38	32	46	44.4	38	4	0	N