Habitat Selection of Raptors in Lot 6 and 7 of the Lower Kinabatangan Wildlife Sanctuary

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Word Count: 5077

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Part A: PTY Reflection

The Danau Girang Field Centre (DG hereafter) presented me with an opportunity to step out of my comfort zone. Undertaking a PTY enabled me to carry out the full process of a research project, from creating and developing a project, through to gathering and analysing the data. Being a genetics student, DG presented me an invaluable chance to learn how to undertake fieldwork, something I had not done before. Living and working in a professional place and challenging environment made me grow as a person, developing skills - particularly communication.

I was keen on undertaking a research project on birds at DG, however, this presented challenges in creating my project. Many tropical bird species can be difficult to study as they often live up in the canopy and are often prey species making them easily spooked. Using river surveys to study raptors gave a means to viewing the forest canopy, working on an interesting group of animals, and utilising skills (surveying and vegetation assessment skills) learnt from assisting PhD and master's students.

Assisting Masters and PhD students has been a major part of PTY life at DG, and the large variation in projects has given me an abundance of fieldwork experience. During my year in the field, I have learnt many methods of conducting fieldwork; trapping, tracking and a variety of different surveying techniques. Projects have been researching on a range of species; from the tiny ants and mosquitoes to the huge and powerful saltwater crocodiles. Many of the projects feature trapping and collaring of animals to understand how these animals utilise the forest and plantations. Deploying a variety of trapping and baiting techniques, fortunately, I have been able to get involved in many trapping procedures; Bornean bearded pigs, Sunda clouded leopards, saltwater crocodiles, Malay civets and monitor lizards. It has been captivating getting involved in these procedures, assisting both the veterinarian and sampling team, learning how to ensure the procedure is done safely while limiting stress for the animal and team, and gathering the required data. Once the animal has been caught and collared, we tracked its movement. Tracking methods varied with the collars, but two types of collars are used at the centre; VHF which requires regular tracking, often done while the animal is asleep (e.g. slow loris), and GPS where we track using VHF until in range to download the data (e.g. civets and monitor lizards).

Throughout the year, there have been many field courses and visitors from all over the world staying at DG, which has given me plenty of opportunities to improve my teaching capabilities such as presenting our research. It is the PTYs responsibility to get students and visitors into the forest to teach them about the amazing wildlife living here along the river and answer any questions they have. Examples of this would be leading river cruises at several times in the day, as well as taking the students on night walks.

Abstract

Raptors are valuable study species in conservation as they are apex predators and typically have large home ranges, subsequently making them useful umbrella and flagship species. Using habitat selection methods provides detailed information about how the organism uses its habitat. Therefore, this information proves valuable in aiding the formation of coherent conservation strategies that more general studies of species richness are unable to provide.

In this study, river surveys are undertaken to find raptors in perching trees. Perching tree variables were measured and compared between raptor species, and against random non-raptor trees. Raptors were found to be selecting certain attributes of perching trees as 7 of the 12 variables were significant. Most notably, raptors were selecting taller trees, greater girth and larger crown spread. Reasons for this are believed to be that these characteristics provide unrestricted flight access, greater vision of the surrounding area and these trees can provide strong branches. Due to past logging activities, ideal perching trees may be limited, hence raptor species may be competing to use the same perching trees. The wildlife sanctuary is also surrounded by oil palm plantations; therefore, raptors may have a greater abundance in forest lots than corridor forest due to less disturbance from human activity. Despite observing more sightings of raptors in forest lots compared to corridor forest, there was not more raptors than expected in forest lots when tested. Coupled with that different raptor species did not use the same perching tree, competition appears to not be an issue. However, this will require a more detailed approach to be certain.

Introduction

Expansion of agriculture and logging are the leading causes of habitat degradation and deforestation in the tropics, particularly South East Asia (Mon *et al.*, 2012; Granados *et al.*, 2016; Prabowo *et al.*, 2016). Lowland tropical forest is under the greatest threat due to its ease of accessibility, timber extraction (especially dipterocarps) and encroachment of plantations (Mon *et al.*, 2012; Prabowo *et al.*, 2016). Borneo's dipterocarps are valuable trees for timber extraction with the principal method being selective logging, which alters the forest structure (Bryan., 2013; Ding *et al.*, 2017). Following selective logging practices, forests are cleared for oil palm plantations. Conversion of forest to oil palm has reduced Borneo's rainforest land cover to 50% with the majority of this forest occurring in the central montane region (Scriven *et al.*, 2015). Oil palm plantations provide unsuitable habitat for avia as oil palm is intensively managed thus preventing any structural complexity forming (Styring *et al.*, 2011; Vergara and Simonetti, 2017). Both expansion of oil palm plantations and timber extraction are having a great impact in one of the world's most biodiverse regions, putting the natural environment in a fragile state (Prabowo *et al.*, 2016).

Large forest fragments can hold a greater diversity of species than smaller fragments however, after logging, a compositional shift in the forest occurs (Lees and Peres, 2008; Osazuwa-peters, Chapman and Zanne, 2015). Many tropical species respond negatively to these human driven impacts (Edwards 2014) as the changes in habitat structure can have a knock-on effect on food resources, microhabitats as well as abundances and richness of species (Peh *et al.*, 2005). An example of a post-logging effect is the removal of the large trees increases the amount of light that can access the forest floor causing the rapid increase in the undergrowth (Iongh, Kustiawan and Snoo, 2014; Osazuwa-peters, Chapman and Zanne, 2015). Changes in habitat structure can lead to an over-abundance of species with generalist traits, which then outcompete specialist species that are typically vulnerable. (Edwards *et al.*, 2013). Forest species will have to adapt to these new habitats as it has been shown that logging activities alone can be imprinted on forest system for over 40 years after logging and the recovery of biomass is estimated to take between 60 to 120 years (Berry *et al.*, 2010; Osazuwa-peters, Chapman and Zanne, 2015; Ding *et al.*, 2017).

The majority of threatened avian species that are at risk from habitat degradation inhabit tropical forest (Gray *et al.*, 2007). Raptors are typically affected by ecosystem threats such as bioaccumulation in the food chain, habitat degradation and fragmentation (Sergio *et al.*, 2008). An example of such a habitat disruption and the resulting rapid declines of raptors occurred throughout Europe and North America in the 1950s-70s caused by DDT and PCB contamination (Sergio *et al.*, 2008). Indicator species such as raptors are considered relatively easy to study, and they are considered a good indicator to habitat quality (Alexandrino et al., 2016; Morelli, Mousseau and Møller, 2017). This is because raptor distributions can mirror biodiversity hotspots, frequently preferring habitat of high complexity (Morelli, Mousseau and Møller, 2017). They are typically sensitive towards variations in habitat structure and composition caused by environmental disturbance (Palomino and Carrascal, 2007; Lemaître *et al.*, 2012; Ferrer-Sánchez and Rodríguez-Estrella, 2015; Morelli, Mousseau and Møller, 2017). This sensitivity is emphasised by that they typically have small population sizes and growth as well as a preference for ecologically complex habitats (Hamer et al., 2015).

In a fragmented landscape, restricted and endemic species have been shown to be precursors to local extinction with this being shown in avian species (Lees and Peres, 2008; Alexandrino *et al.*, 2016; Vergara and Simonetti, 2017). Forest-dwelling raptors displaying a low tolerance towards anthropogenicity means that the loss of habitat leads to the replacement of endemics and specialists with a less diverse community of generalist species (Palomino and Carrascal, 2007; Robinson, 1994). Specialists are often to first to be impacted in habitat degradation with many endangered species being specialists. An estimated 46% of all tropical raptors are threatened by habitat loss and fragmentation, particularly affecting endemic and specialist species negatively (Ferrer-Sánchez and Rodríguez-Estrella, 2015). These trends have been seen in Cuba where endemic and specialist species were more associated with forests despite species richness being highest in areas of moderate human activity (Ferrer-Sánchez and Rodríguez-Estrella, 2015). Raptors are ideal indicator and umbrella species as they typically have large home ranges, occur at low population densities and are apex predators (Robinson, 1994; Palomino and Carrascal, 2007; Sergio *et al.*, 2008). This is seen in the majority of forest-dwelling raptors and conservation strategies based upon the requirements of a raptor population will benefit other (less demanding) species (Sergio et al., 2008). The presence of a species may facilitate resources that are essential to other species of which would otherwise be unavailable, an example of this is breeding associations (Sergio et al., 2008; Burgas, Byholm and Parkkima, 2014). It has been shown that raptors will select forest patches with a higher biodiversity than other patches available (Burgas, Byholm and Parkkima, 2014). For tropical forests, Thiollay 1989 deduced that raptors were good indicators of environmental change, with most tropical raptors being forest specialists that have a low tolerance towards human impacts.

Raptors have been doubted as indicators as some raptors are generalists and opportunists (Sergio et al., 2008). They are known to be able to swap between prey sources, featuring a few primary prey species with a wider range of secondary prey sources (Sergio *et al.*, 2008; Nadjafzadeh, Hofer and Krone, 2016). In addition to this, many raptors can readily adapt to human-modified landscapes (Rodríguez-estrella, Donázar and Hiraldo, 1997). Generalists may provide an abundance of data although due to their high plasticity in habitat and foraging selections, they can prevent robust predictions of their occurrence (Lemaître et al., 2012). Subsequently, raptors can be considered less tightly linked to a specific environment (Ferrer-Sánchez and Rodríguez-Estrella, 2015; Morelli, Mousseau and Møller, 2017). It is typically in temperate regions that these generalist raptors are found whereby the impact of human development promotes heterogeneity providing an increase in resource diversity (Palomino and Carrascal, 2007). In degraded habitats however, studying generalists can provide predictions in the structural and compositional change that will occur, and the persistence of a raptor population can in fact be linked to a diverse array of prey species (Sergio *et al.*, 2008). Raptors are also valuable flagship species, capturing the attention and educating the public in ecological system processes (Sergio et al., 2008).

With raptors being used as environmental indicators, it is important to understand how species utilise and respond to their habitats and any impacts on it. Models showing this greater ecological detail can be beneficial over highly summarized biodiversity measures (E.g. species richness) cannot give (Lemaître et al., 2012). Linking animal behaviour to the environment therefore enables conservation of these environments at a species level (Lemaître et al., 2012; dos Anjos et al., 2015; Heinrichs et al., 2017). Using habitat selection techniques to establish an indicator or umbrella species is ideal as comprehensive data on a majority of species is rarely available (Cao and O'Doherty, 1999). From habitat records assembled, species distributions based on potentially suitable habitats can be mapped (Thuiller, Arau and Hirzel, 2004). This provides a cost-effective method to map species in large regions where environmental factors are known but species have not yet been sampled. When using habitat selection methods, the selected study species is crucial in the establishment of an indicator species.

It is vital to understand the requirements of target species, as the presences or absence from an area alone does not always reflect the suitability of fragmented or degraded habitats for viable populations (Verboom et al., 2001; Thuiller, Arau and Hirzel, 2004). For example: endangered species may be restricted in the area they occupy which may not be due to their relation to the habitat but outside pressures (e.g. hunting). Therefore, one may underestimate the quality of habitat outside of the species range (dos Anjos et al., 2015). Areas may not be occupied in all years but may still be important to retain for species such as non-territorial individuals or spill-over from surrounding areas. In heterogenic landscapes created by human driven impacts, preferred habitats are likely to be further away. It is paramount to recognise species selection cues in this increasing anthropogenic landscape as populations often require time to adapt to habitat changes and lag behind landscape changes (Verboom et al., 2001).

The use of perching sites is a major hunting technique used by raptors. This hunting technique is typically a low cost, low profit technique and, enables greater access to habitat occupied by prey animals (Askham, 1990; Wolff et al., 1999). This access that perch sites provide may impact prey species populations and demography due to an increase in raptor foraging efficiency and predation pressure (Kay *et al.*, 1994; Wolff *et al.*, 1999). It has been shown that foraging sites significantly differ to nesting sites indicating that species may avoid homogenous habitats in favour of habitats with a variety of features capable of satisfying multiple demands (Petit et al., 1988). Habitat degradation and the increased development of agricultural land has resulted in the reduction in natural perching sites (Kay et al., 1994). The importance of perching sites for raptors has been shown via the introduction of artificial perches. In agricultural landscapes, artificial perches attract a greater number of raptors to an area and also increases visitation times of these raptors (Kay et al., 1994; Wolff et al., 1999). Limited perching sites may cause a shift in raptors behaviours, causing flight techniques to become dominant or an avoidance of the area completely (Kay *et al.*, 1994). Reinert (1984) showed that large raptors preferred erected dead trees over artificial perches. Tall, bare, or dead trees are favourited by raptors (for example buteos, hawks, bald eagles) as the lack of vegetation provides unobstructed vision and flight paths (Stalmaster and Newman, 1979).

In this study the habitat use of raptors was assessed, specifically focusing on the perching sites that they occupy. By conducting surveys along the Kinabatangan River, raptors were able to be spotted at varying heights of the canopy. An environmental survey was then carried out on raptor-occupied trees and randomly chosen trees. It is expected that raptors are choosing trees non-randomly, selecting for characteristics such as increased height, less dense crowns and ground vegetation. Raptors may be selecting for trees with such characteristics for improved vision and access when hunting or guarding territories. Due to the Lower Kinabatangan Wildlife Sanctuary having been selectively logged, the amount of ideal perching sites may be limited and therefore it is expected that different raptor species may be competing to use the same trees. Also, raptors are predicted to be present more often in the forest lots than corridor forest.

Methods

Study Site

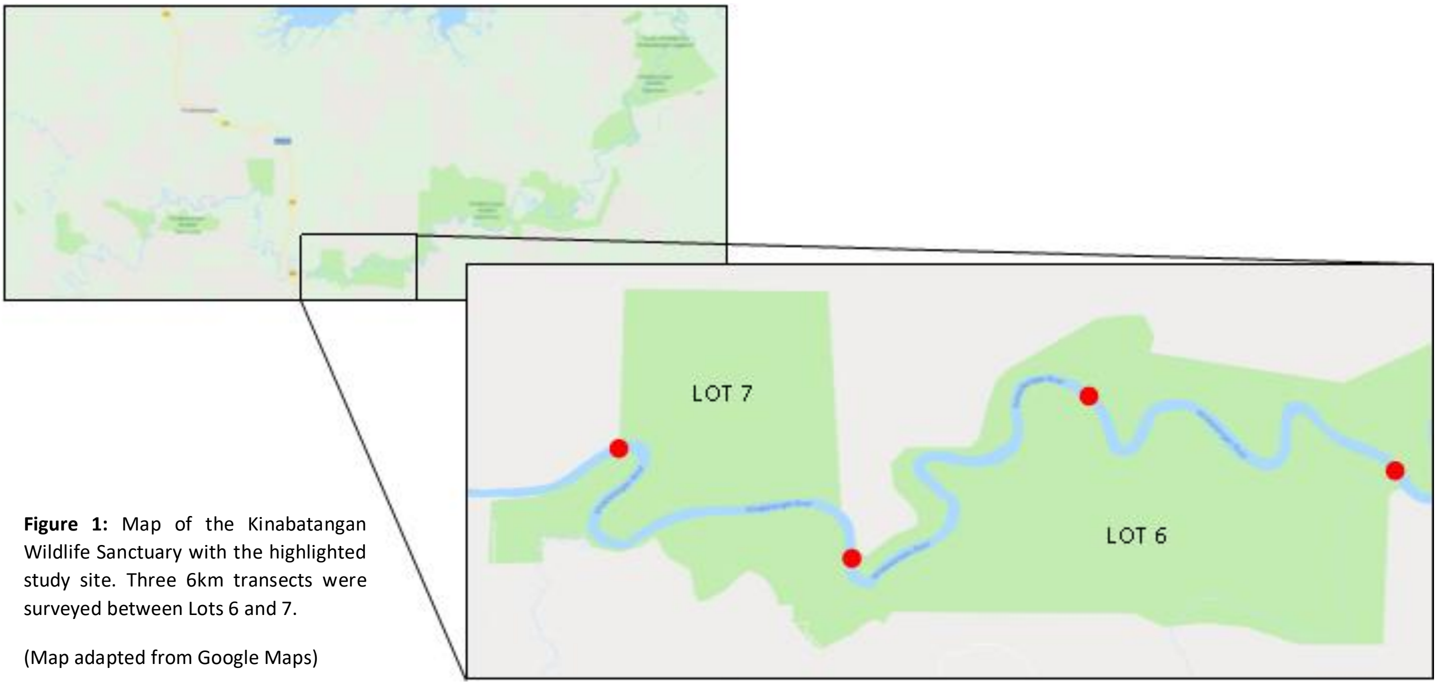


Figure 1: Map of the Kinabatangan Wildlife Sanctuary with the highlighted study site. Three 6km transects were surveyed between Lots 6 and 7.

(Map adapted from Google Maps)

The Kinabatangan river (Sabah, Malaysia) is the largest river in Sabah, featuring a wildlife sanctuary comprising of 10 Lots stretching from the coast to the interior forest. The study was conducted along a 18km stretch of river (N5° 24.763' E117° 59.145' - N5° 24.503' E118° 04.954') of Lots 6 and 7 of the Kinabatangan Wildlife Sanctuary. The forest present in the wildlife sanctuary is composed of a variety of habitat types however, the habitat surveyed in this study was riparian edge forest. The Kinabatangan Wildlife Sanctuary has been previously selectively logged and is surrounded by oil palm plantations. Surveys took place from January - June 2018, with daily temperature and rainfall recorded throughout. Mean rainfall was 7.53mm with highest temperature recorded as 34.5 and lowest temperature of 22.5ºC. River level fluctuated throughout, and an estimation of was taken at the start of each survey.

Data Collection

River Surveys

Raptors use perches as resting sites or a low energy cost method of hunting and will remain inactive for an extended period. Along with being inactive, plumage colour often allows them to be camouflaged against the surrounding forest making them difficult to see (Thiollay, 1989). River surveys were used to locate raptors over forest transects as the river provides an open area where the forest canopy can be observed from distance. The 18km stretch of river was split into three 6km transects with surveys conducted after sunrise, between 06.00 and 08.00 hrs, where raptors are at their most numerous before declining to a stable level later in the morning (Kay *et al.,* 1994). Forest on both sides of the river were surveyed for raptors (Nikon 8x42 binoculars). Upon locating a raptor, the species was identified, photographs taken (Nikon D3100), GPS point taken (Garmin GPSMAP 64S) and the tree physically tagged. One transect was completed on a given day and the study site was completed once in a week.

Tree Characterisation

In addition to characterising raptor trees, non-raptor trees were selected for comparison at random by generating points on a grid along the length of the study site. Non-raptor trees were chosen at the end of the study to ensure that raptor trees were eliminated from selection. Both raptor and non-raptor trees were characterised using the same variables (excluding perch height) and these variables along with methods of measurements are outlined in the Table 1 below.

Variable	Method of Measurement	Unit of Measure
Diameter at Breast Height	Measuring Tape	Nearest cm
Maximum Crown Spread	Measuring Tape	Nearest m
Distance to Riverbank	Measuring Tape	Nearest m
Height	Clinometer	Nearest 0.1m
Perch Height	Clinometer	Nearest 0.1m
First Branch Height	Clinometer	Nearest 01.m
Crown Density	Visual Estimation	Categorical
Crown Shape	Visual Estimation	Categorical
Canopy Cover	Image J	%
Ground Vegetation Density	Density Pole	%
Presence of Vines	Categorical	Present/Absent

Table 1: Variables of the tree that were measured along with the method of taking measurements.

Data Analysis

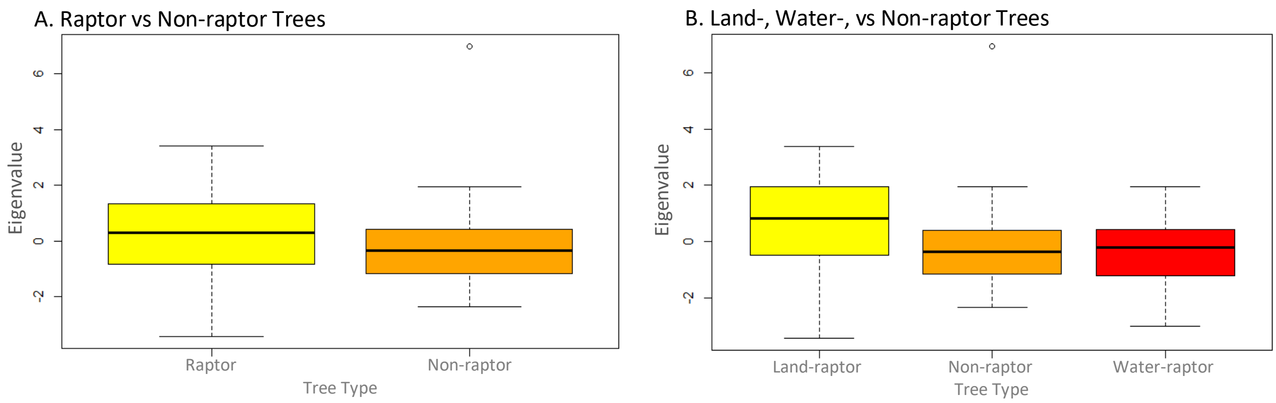
Initially, the interactions between the continuous variables was investigated via a principal component analysis. The resulting principal component was tested between sets of data by a one-way ANOVA. The tests were; raptor vs non-raptor trees, between land-raptor, water-raptor and non-raptor trees and between trees of different raptor species.

The variables measured were primarily tested via one-way ANOVAs for continuous data, and Chi-square test for categorical data. All statistical analysis was undertaken using R Statistics, version 3.5.1. Due to low occurrences of many of the raptors, the data was grouped together in two ways: All perching trees group together as 'raptor' trees and compared against the random 'non-raptor' trees sampled, with the second option being perching trees from terrestrial - or water-associated ('Land' or 'Water' respectively) raptors being grouped together. A random sample of 50 trees were generated for each variable for 'raptor vs non-raptor' however, for 'Land and Water' analyses only non-raptor trees were randomly generated.

The continuous variables Height, DBH, Average Crown Spread, First Branch, Vegetation Density and Canopy Cover were all tested for both grouping methods. Canopy cover was tested via the Kruskal-Wallis test as normal distribution of the data could not be achieved despite attempted transformations. The rest of the variables were tested using a one-way ANOVA and any non-normally distributed variables were transformed. Normal distribution of the variables was verified using Q-Q plots and Shapiro-Wilks test along with confirmation that there was an absence of heteroscedascity of the residuals via the Levene test (R package 'car'). Distance to riverbank and perch height were tested just between the 'land' and 'water' group using the same statistical analyses.

For the categorical variables; crown class, crown density, crown shape and vines, chi-square test was utilised. Post Hoc analysis of the variables categories was shown using a mosaic graph displaying the standardized residuals (R package 'vcd'). Any categories with a residual value of above or below +/-1.96 respectively was considered significant.

Results



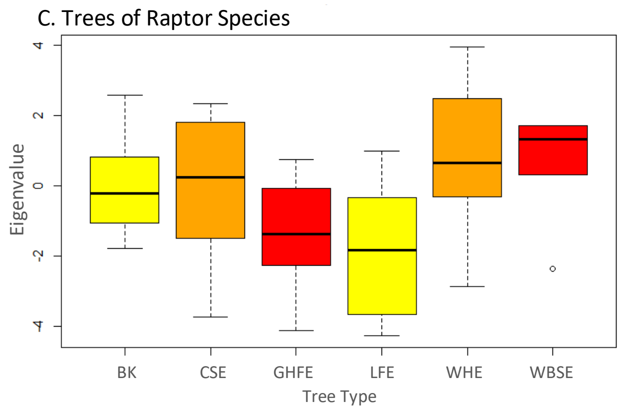


Figure 2: Boxplots showing the comparison of PC1 between the different groups of trees. (A) Bird trees had a significantly greater PC1 value than non-bird trees. (B) Land bird trees showed a significantly greater PC1 value than both non-bird and water bird trees. (C) Almost all species showed over with each other in PC1 values, the exception being WHE and LFE. All the variables contributed positively to PC1.

Key: BK Brahminy kite, **CSE** Crested serpent eagle, **GHFE** Grey headed fish eagle, **LFE** Lesser fish eagle, **WHE** Wallace's hawk eagle, **WBSE** White bellied sea eagle

Interactions between the continuous variables was looked at via a principal component analysis. The test was carried out at three resolutions; raptor vs non-raptor trees, between land-, water- and non-raptor trees, and between trees used by different raptor species. In each of the tests, one principal component was found with all the variables contributing positively to the principal component. Principal component one (PC1) was able to capture 29% of the total variation when non-raptor trees were included and 46% of the total variation when just raptor trees were tested. PC1 of each of the different groups were tested by using an ANOVAs shown in Figure 2.

Raptor vs non-raptor trees gave a significance difference ($F_{1,161}$ = 4.0997, P = 0.045) with raptors selecting larger trees. Between land-, water- and non-raptor trees, the significance of the previous test is due to land raptors selecting larger trees as water raptors did not significantly differ to non-raptor trees. Land-raptor trees differed to both water- (P = 0.0029) and non-raptor (P = 0.0014) trees. Looking at the differences between the raptor species, almost all species overlap with only a significant difference being between Wallace's hawk eagle and lesser fish eagle (P = 0.026).

Out of the 10 variables that were tested for raptor vs non-raptor analysis, 6 gave significant results (summarised in Table 2).

Variable	Statistical Test	Result	Outcome
Height	One-way ANOVA	P<0.01	Taller raptor trees
DBH	One-way ANOVA	P<0.001	Raptor DBH greater
Average Crown Spread	One-way ANOVA	P<0.05	Raptor crowns larger
First Branch	One-way ANOVA	P<0.05	Higher raptor first branches
Vegetation Density	One-way ANOVA	P>0.05	No significant difference
Canopy Cover	Kruskal-Wallis	P>0.05	No significant difference
Crown Density	Chi-square	P<0.001	Random: More 'full' crowns Less 'little' crowns Raptor: Less 'full' crowns More 'little' crowns
Crown Class	Chi-square	P<0.01	Random: Less 'above canopy' trees Raptor: More 'above canopy' trees
Crown Shape	Chi-square	P>0.05	No significant difference
Vines	Chi-square	P>0.05	No significant difference

Table 2: Statistical analyses results of variables for a randomly generated sample of raptor trees against non-raptor trees. One-way ANOVAs were used for testing of continuous variables that were normally distributed (with or without transformations) and Kruskal-Wallis test was used for canopy cover that was not normally distributed. Chi-square test was used for categorical variables to find any preferences in subcategories.

The significant results were; Height ($F_{1,98}$ = 9.05, P<0.0033) which found that raptors were selecting taller trees. The mean height of raptor trees was 25.72m compared to 20.60m of non-raptor trees. Raptors were found to be selecting trees with larger diameter trunks ($F_{1,98}$ = 29.28, P<0.001) with raptor trees featuring a mean diameter of 69cm in comparison to 39.90cm for non-raptor trees. Raptors were found to be selecting larger crown spreads ($F_{1,98}$ = 4.18, P = 0.044 – Raptor mean of 10.4m, Non-raptor mean of 8.7m) and trees featuring higher first branches ($F_{1.98}$ = 5.20, P = 0.025 – Raptor mean of 14.4m, Non-raptor mean of 11.6m).

When looking between land- and water-raptor groups, 7 out of 12 variables proved significant (summarised in Table 3). The additional variable being significant was distance to riverbank where water-raptors were perching closer to the river than land-raptors ($F_{1,72}$ = 16.04, P<0.001). Land-raptors perched at a mean of 20.63m from the riverbank edge whereas water-raptors perched 5.16m away.

Variable	Statistical Test	Result	Outcome (With Post Hoc analysis)
Height	One-way ANOVA	P<0.001	Land- and water-raptor trees taller than non-raptor trees
DBH	One-way ANOVA	P<0.001	Land- and water-raptor trees have a larger DBH than non-raptor trees
Average Crown Spread	One-way ANOVA	P<0.05	Land-raptor trees have larger crowns than water-raptor trees
First Branch	One-way ANOVA	P<0.01	Land-raptor trees higher than non-raptor trees
Vegetation Density	One-way ANOVA	P>0.05	No significant difference
Canopy Cover	Kruskal-Wallis	P>0.05	No significant difference
Crown Density	Chi-square	P<0.001	Non-raptor trees: More 'full' crowns Less 'empty' crowns Water-raptor trees: More 'empty' crowns
Crown Class	Chi-square	P<0.01	Non-raptor trees: Significantly less 'above canopy' trees Land-raptor trees: Significantly more 'above canopy' trees
Crown Shape	Chi-square	P>0.05	No significant difference
Vines	Chi-square	P>0.05	No significant difference
Distance to Riverbank*	One-way ANOVA	P<0.001	Water-raptors trees closer to river than land-raptor trees
Perch Height*	One-way ANOVA	P>0.05	No significant difference

Table 3: Statistical analyses results of variables for land- and water-raptor trees against a randomly generated sample non-bird trees. One-way ANOVAs were used for testing of continuous variables that were normally distributed (with or without transformations) and Kruskal-Wallis test was used for canopy cover that was not normally distributed. Chi-square test was used for categorical variables to find any preferences in subcategories. Distance to riverbank and perch height were only tested for land against water birds and did not involve any non-bird trees. After tests were run, Tukey's post hoc analysis was used to look at the differences between groups.

The remaining 6 variables were the same variables as the analysis for raptor vs non-raptor trees however, using Tukey's post hoc analysis, significance between land- and water-raptors was tested. Height and DBH showed no difference between land- and water-raptor trees. For average crown spread, land-raptors were shown to select trees with larger crowns than water-raptors (P = 0.084). First branch displayed that land-raptors selected trees with significantly higher first branches than non-raptor trees (P = 0.0014) however, there were no significant differences for water-raptors between land- or non-raptor trees. Out of the categorical variables, crown density and crown class displayed significance. For crown density, there was an abundance of ‘full’ crowned trees and less ‘empty’ crowned trees observed than expected. Land-raptors did not select any category more than expected whereas water-raptors were selecting ‘empty’ crowned trees more than expected. Crown class displayed that there were less ‘above canopy’ trees than expected and that land-raptors were selecting these trees more than expected. Water birds did not deviate more than expected for any crown class.

Whether raptors were choosing to perch more in forest lots than corridor forest was also tested using chi-square. Both individual species and, land and water groups were tested and neither test produced significant differences resulting in raptors not selecting certain forest more than expected. During the surveys, 21 observations of the same tree being used was recorded, this entailing 9 individual trees. Statistical analyses on this was not done however it was noted that different raptor species did not use the same tree.

Discussion

Food resources and competition are factors which effect the type of habitat that an individual chooses (Styring *et al.*, 2011). Perching sites are important to raptors as a method of accessing these food resources, and subsequently is a low expense hunting method (Wolff *et al.*, 1999). The presence of raptors in an area will, for example, affect the demography of the prey populations. If there is an absence of ideal perching sites hunting will be restricted to flight or raptors will avoid the area entirely (ASKHAM, 1990; Wolff *et al.*, 1999). As a threatened group of birds, knowledge of raptors ecological requirements is vital for conservation purposes (In, Hills and Nadu, 2012). In this study, surveys were carried out to determine whether raptors along the Kinabatangan River were selecting certain habitats or not, specifically their perching trees. The lack of information available on raptors living in tropical environments is an issue which needs to be addressed. Most of the information currently available on tropical raptors is focused in South America. The importance to understand how these birds utilise their environments is required as they are apex predator, hence they are involved in ecosystem processes and influence the trophic levels below (Sergio *et al.*, 2008). In addition to this, their large area requirements make them an ideal indicator and umbrella species for the vast biodiversity that is present in tropical environments (Morelli, Mousseau and Møller, 2017). Our data showed that raptors were selecting for certain tree characteristics, with 7 of the 12 variables showing significance. These variables were: Height, DBH, crown spread, first branch, crown density, crown class and distance to riverbank. The remaining variables: vegetation density, canopy cover, crown shape, vines and perch height displayed no significance. Our study also determined that raptors do not choose to perch in forest lots or corridor forest more than expected. Out of the 9 trees where raptors had been sited on multiple occasions, no two-raptor species used the same tree.

The Lower Kinabatangan Wildlife Sanctuary provides an ideal location to study how species utilise disturbed habitat. The typical features of logged forests are that they have greater light intensity, lower stem density and are mainly composed of small trees (Iongh, Kustiawan and Snoo, 2014; Osazuwa-peters, Chapman and Zanne, 2015). The impacts of selective logging should be short term if a low proportion of the canopy is removed, however, these impacts can be imprinted upon a forest system for at least 40 years (Berry *et al.*, 2010; Osazuwa-peters, Chapman and Zanne, 2015; Ding *et al.*, 2017). For the rehabilitation of the forest, it is vital that large trees are left in previously logged areas, as the microenvironment is more comparable to the primary state of the forest (Ding *et al.*, 2017). Large trees appear to play an important role for raptor as from our data, it is seen that raptors are generally selecting for larger trees. The trees that raptors were selecting were on average 5.12 m taller and 16.19cm greater in height and girth respectively than non-raptors trees. Therefore, raptors selecting larger trees may be showing intolerance towards the habitat disturbance caused by logging. This appears unlikely as many species of raptors, for example: red-tailed, red-shouldered hawks (*Buteo jamaicensis* and *Buteo lineatus* respectively) and buteos will use man-made structures as perching sites such as fence posts and telephone poles (Bohall *et al.*, 1984; Short *et al.*, 1975). However, it is known that raptors which live in tropical forests are typically sensitive to human disturbance (Thiollay, 1989), and may require natural perching sites. It has been reported previously that raptors select tall trees, and in addition to this the trees are often bare of foliage, or dead altogether (Stalmaster and Newman, 1979; Bohall *et al.*, 2013). This is concurrent with what was observed in this study, not only the selection of taller trees, but also that raptors were selecting for trees with less dense crowns. These trees may be ideal for several reasons; the larger trees have branches which are strong enough to support the weight of these large birds, trees that are taller than the surrounding canopy provide unrestricted flight access and the tallest trees will provide the greatest amount of vision for hunting or territorial behaviour (Stalmaster and Newman, 1979). The visual reasoning may be most prominent, as forest edges are often an important area for hunting raptors. These sites typically provide high perching sites and overlook an open area to hunt in (Stalmaster and Newman, 1979; In, Hills and Nadu, 2012). Crested serpent eagles (*Spilornis cheela*) have frequently been observed at forest edges, this may explain why, despite not being water hunting raptors, crested serpent eagles and Wallace's hawk eagles (*Nisaetus nanus*) were regularly at the forest edge bordering the river (In, Hills and Nadu, 2012).

Bird diversity has been shown to be strongly associated with structural complexity of the environment (Styring *et al.*, 2011). However, we found that raptors show no preference over the density of the canopy and vegetation, or the presence of vines. Bird community structure has also previously been correlated with the forest canopy (Styring *et al.*, 2011). Due to logged forests having less dense canopies, it could be expected that raptors would select for areas with denser canopies, that would be more similar to primary forest. However, as no difference was seen in comparison to non-raptor trees, the less dense canopies are potentially beneficial for raptors, for similar reasons that they selected for the tallest trees; unrestricted access and an unobscured view of the river. Raptors showed no preference towards vegetation density or to the presence of vines as well. This is unsurprising for the water-associated raptors as they are primarily hunting in the river, or along the riverbanks. However, it would be expected that terrestrial raptors in general would prefer less dense vegetation, in order to improve the probability of hunting success (Wolff *et al.*, 1999). This is because logged forests allow higher levels of light to the understory, thus vegetation density will be greater than that of primary forests (Osazuwa-peters, Chapman and Zanne, 2015). The presence of vines may not hold any significance for raptors, however, they can contribute indirectly to raptor habitat. The rehabilitation of forests involves the removal of vines to improve tree regrowth (Putz *et al.,* 2001). This would benefit raptors as trees would grow larger at a faster rate, reaching ideal sizes for raptors to use as perching sites or nesting trees. However, vines can provide food and protection for many prey animals, and the removal of these will impact the distribution of prey species to an extent (Edwards *et al.*, 2009; Ansell, Edwards and Hamer, 2011). Hence, the distribution of predators would change.

Distribution and competition of raptors along the river was also observed. Raptors may be territorial, against both the same species or different, over ideal perching trees. For the species present in the study, the crested serpent eagle has been shown to be tolerant to overlap in territories with other individuals and species (Chou, Walther and Lee, 2012). However, Brahminy kites are known to be territorial, and white bellied sea eagles' populations are affected when their habitat overlaps with the larger wedge tailed eagle (Olsen *et al.*, 2013; Khaleghizadeh and Anuar, 2017). Raptors can also be non-territorial, undertaking long range movements until they locate an available territory (Shephard, Catterall and Hughes, 2005). It was expected that there would be a greater number of raptors observed in the forest lots, when compared to the corridor forest. Although this was true (49 compared to 34 in total), when a chi-square test was run, raptors were not using either forest type outside of their expected use. Forest lots are larger, and therefore can accommodate a greater number of individuals. An overabundance of individuals wasn't seen in forest lots, suggesting there may not be that much of a difference in quality to forest corridors for raptors. Also, less competitive individuals (e.g. juveniles) are often forced away from the higher quality environment into worse territories (Loehle, 2012). This could be a reason why raptors weren't observed clumped in a certain area. Adding to the competition for raptors, it was expected that there would be interspecific competition for perching trees, due to the removal of the large trees by logging, restricting the number of ideal trees available. Results suggest otherwise, as no two raptors were observed occupying the same tree. This result would need to be investigated further as only 9 trees were repeatedly used, likely by the same individuals. Lack of interspecific competition is likely due to numerous ideal trees available, or the territorial behaviour of raptors.

For future studies on habitat selection of raptors, establishment of raptor home range and movement patterns would reveal previously unknown details about these apex predators' lifestyles. In temperate raptor species, the development of heterogenous landscapes, via agriculture for example, have proven beneficial to generalist species (Palomino and Carrascal, 2007; Prabowo *et al.*, 2016; Vergara and Simonetti, 2017). In contrast, forest-dwelling raptors are typically sensitive to human disturbance, with habitat loss being detrimental to resident populations (Palomino and Carrascal, 2007; Lemaître *et al.*, 2012; Robinson, 1994). It has been shown that birds use different habitats for foraging and nesting (Vergara and Simonetti, 2017). Therefore, to set up valuable conservation strategies, it is required that the protected area contains essential habitats for raptor populations. Oil palm plantations could be made to be more habitable for raptors via the introduction of artificial perching trees. Artificial perching trees have been used previously to entice raptors into agricultural land, facilitating ecological functions such as population control of pest species (Kay *et al.*, 1994; Wolff *et al.*, 1999). Raptors utilise the canopy, such species are the most disturbed in oil palm plantations as the canopy level is disturbed for harvesting (Prabowo *et al.*, 2016). Introducing artificial perching trees designed in line with what has been found may make plantations for hospitable for raptors, creating a hunting area. Artificial perches are known to be an important management tool for raptor conservation, by attracting and increasing the visitation of raptors to an area (Kay *et al.*, 1994; Wolff *et al.*, 1999). In addition to making anthropogenic environments more hospitable, understanding how species utilise their environments contributes to protecting further habitats. Studying different populations extensively requires a lot of work however, being able to map the habitat requirements of a species provides a more cost-effective method of conservation (Thuiller, Arau and Hirzel, 2004).

Here, it has been shown that raptors are selecting certain characteristics of trees for their perching sites. Larger trees with a lack of crown were favoured by raptors, whereas surrounding vegetation appeared to be unimportant. As apex predators, raptors are involved in ecological functions such as prey population demography, and are valuable indicator species for ecosystem health (Sergio *et al.*, 2008). Typical for apex predators; large home ranges and low population densities make them vulnerable to anthropogenic effects (Sergio *et al.*, 2008). The Kinabatangan Wildlife Sanctuary is a forest which has undergone habitat degradation, being selectively logged throughout, and is surrounded by oil palm plantations. This creates an ideal study area for how species utilise their environment. Logging in the forest has removed the majority of large trees, possibly creating competition between raptors for ideal perching trees. Competition between raptors will need to be investigated further, but from observations, different raptor species do not use the same trees. In addition to this, raptors do not appear to use forest lots more than expected, when compared to corridor forest.

Acknowledgement

Thank you to Dr Benoit Goossens, Dr Milena Salgado, Dr Sergio Guerrero, Dr Luke Evans, Dr Danica Stark and Meaghan Evans for giving me the opportunity to complete this placement. Thank you to all the PTYs, researchers (special thanks to Dr Miriam Kunde and Richard Burger), staff and volunteers involved with DGFC. Their support with my project throughout its entirety and the skills they taught me are greatly appreciated.

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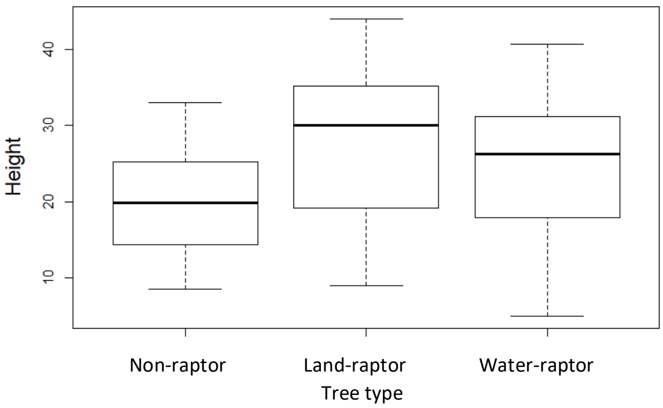
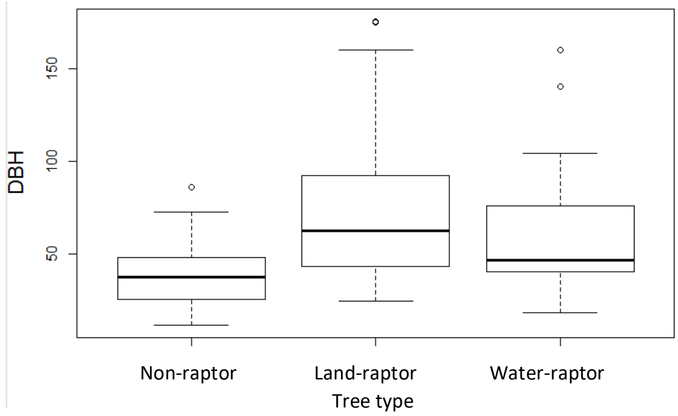
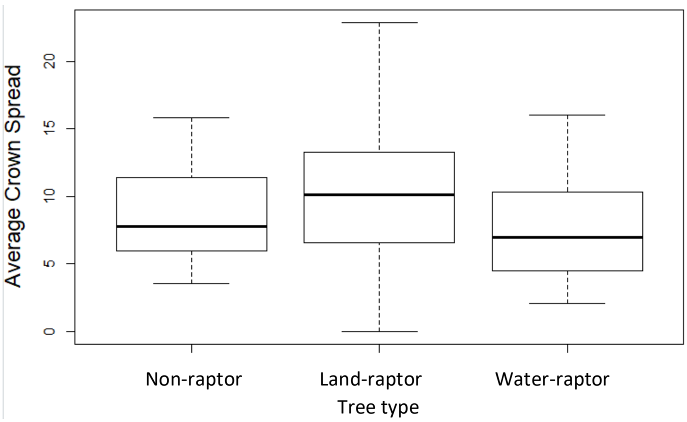
Appendices



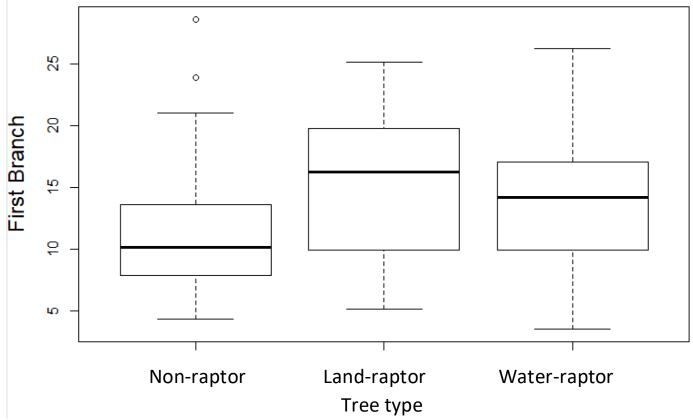
Boxplot displaying heights of the different tree types. Land-raptor and water-raptor trees were both significantly taller than non-raptor trees.



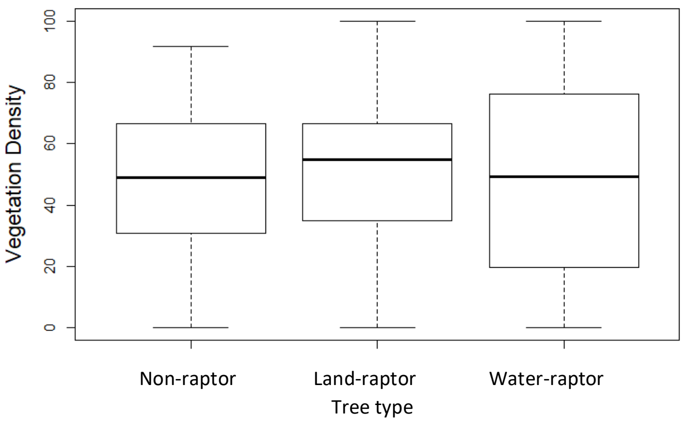
Boxplot displaying DBH of the different tree types. Land-raptor and water-raptor trees were both significantly larger in girth than non-raptor trees.



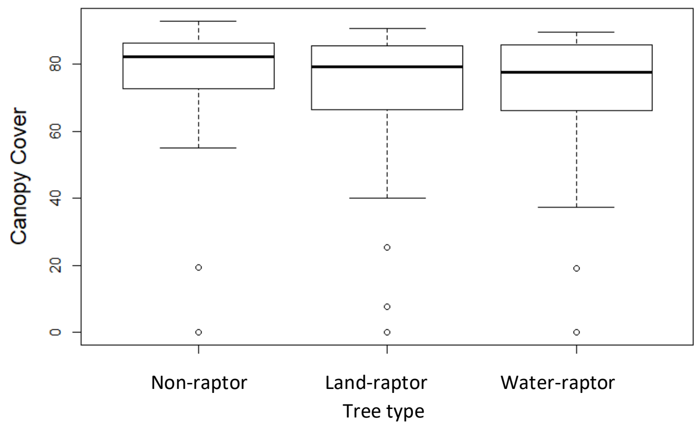
Boxplot displaying crown spreads of the different tree types. Land-raptor trees were significantly taller than both water-raptor and non-raptor trees.



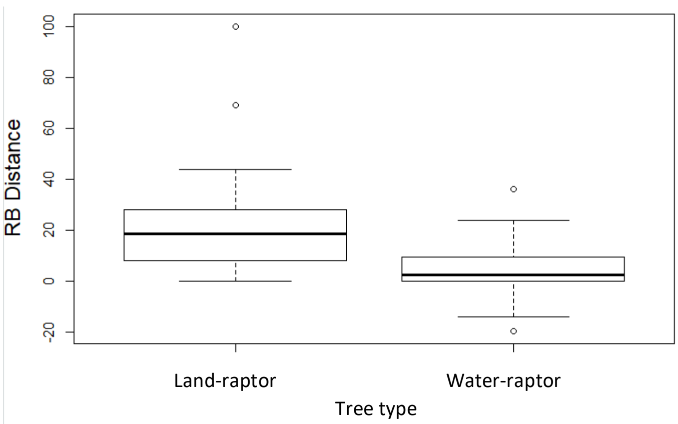
Boxplot displaying heights of the different tree types. Land-raptor trees had a significantly higher first branch height than non-raptor trees.



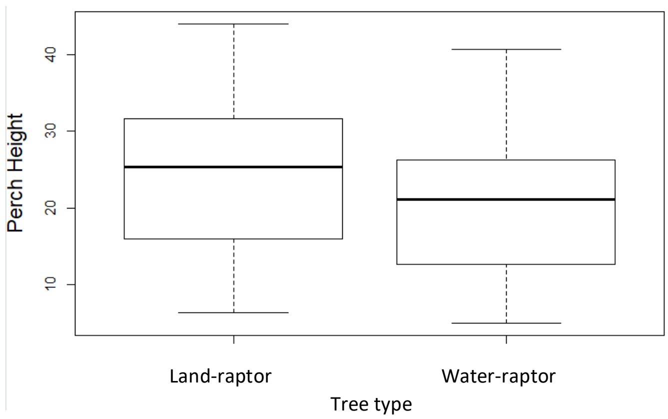
Boxplot displaying vegetation density surrounding the different tree types. There was no significant difference between the tree types.



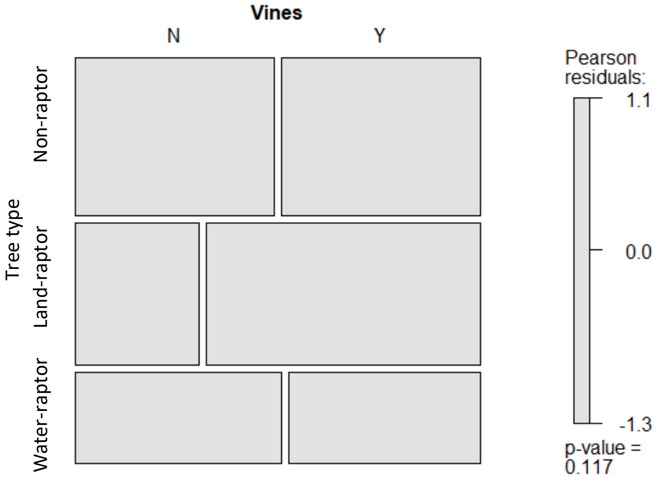
Boxplot displaying canopy cover surrounding the different tree types. There was no significant difference between the tree types



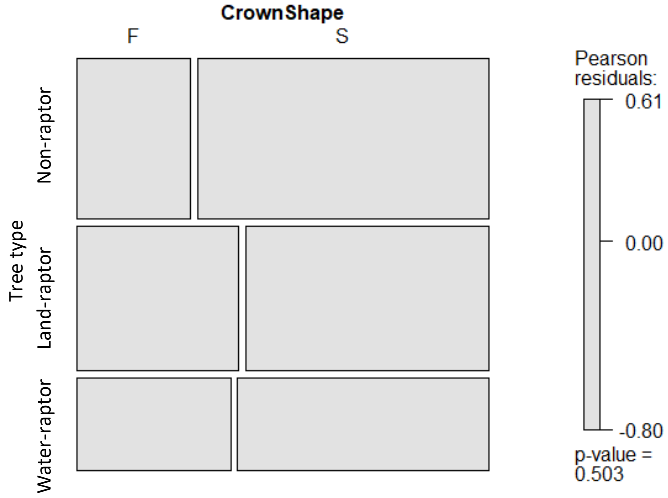
Boxplot displaying the distance to the riverbank of land-raptor and water-raptor trees. Water-raptors perched significantly closer to the river than land-raptors.



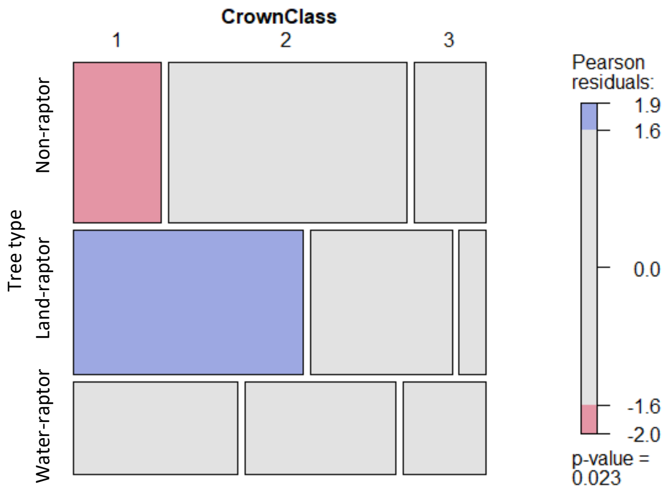
Boxplot displaying the perching heights of the different raptor types. There was no significant difference between the perching heights.



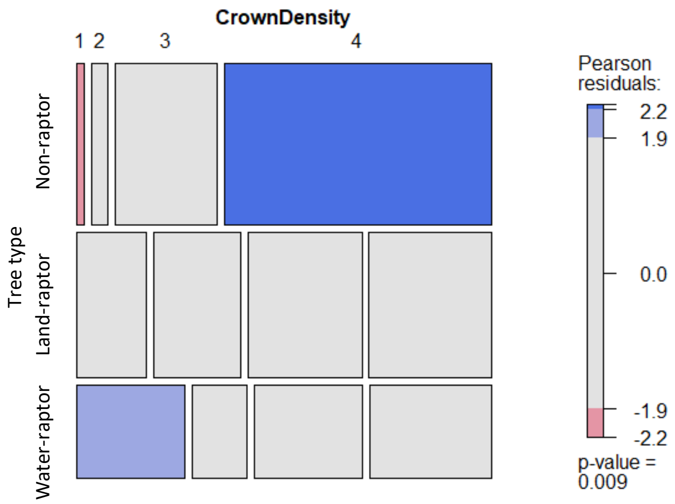
Mosaic graph displaying Pearson's residuals of a chi square test for presence of vines. No tree type showed a significance for vines or not.



Mosaic graph displaying Pearson's residuals of a chi square test for the crown shape of trees. No tree type showed any significance of a free formed or structured crown.



Mosaic graph displaying Pearson's residuals of a chi square test for the crown class of trees. Non-raptors trees had less trees featured above the surrounding canopy with the opposite occurring for land-raptor trees.



Mosaic graph displaying Pearson's residuals of a chi square test for the crown density of trees. Non-raptor trees featured more crowns full of leave than expected.