# Assessing the impact of human disturbance on abundance and diversity of wildlife in primary forest around Gaya Island Resort

Charlotte Taylor

Biological Sciences, Zoology (BSc)

Vocational Supervisor: Dr Benoit Goossens / Justin Juhun

Placement Establishment: Gaya Island Resort

Word Count: 4750

**Personal reflection**

During this placement, I gained many invaluable skills. These include practical field skills such as where and how to place camera traps as well as using programmes such as Digikam to tag and organise images from camera traps; experience choosing and measuring habitat variables for habitat analysis; and animal handling and basic treatment of animals (reticulated pythons, Bornean keeled pit viper, egrets and fledgling birds). I also had the opportunity to undertake a Fieldskills course in first aid and search and rescue training which I passed and have received an official certificate for. My communication skills have greatly improved through interactions with staff and guests as part of my job. I also picked up some Malay and was able to have very simple conversations in this language which was useful in helping to integrate ourselves into the community in which we were living.

Spending my placement in a hotel environment had many benefits. The large amount of guest interaction in my customer-facing role as a naturalist/tour-guide gave me a huge confidence boost. I am now much more confident when speaking to strangers and larger groups of people. We were fortunate with the support we received from the resort and were provided amazing accommodation and helped us settle in very quickly. This support helped hugely with the transition from the UK and therefore with my wellbeing and happiness while I was away from home. The other naturalists were supportive and welcoming, we all worked together on both PTY projects, improving our team working skills. Visits to DGFC were useful and memorable experiences during the placement and were definitely highlights of the year.

On the other hand, the small size of the team meant that field work had to be postponed if there were no available naturalists to assist, which was frequently the case. Losing a member of the team slowed project progress due to more responsibility being handed to the only other junior naturalist and the consequent time spent training a new team member. Another con to the placement was the isolation from experienced post-grad staff and students working with DGFC who could have helped with the more technical aspects of our projects that the resort staff didn't know about. This made things like project planning and data analysis hard and communication of project related problems to DGFC staff and students was not always easy. There were also miscommunication problems with our on-site supervisor who was not always easy to work with and often did not understand our projects or our initial skill levels as university undergraduates.

Most minor problems were resolved quickly, and systems were put in place to resolve ongoing issues such as the isolation and problems with the on-site supervisor. Teething problems were expected with this brand-new placement and, overall, I had a really great experience. I have gained so much practical and life knowledge which will be invaluable to me for my future during and after my time at university.

**Abstract**

High levels of human disturbance in natural areas can place pressures on wildlife communities, causing avoidance of these areas by local animal populations. This may alter the behaviour of these populations, causing edge avoidance or attraction and altered feeding patterns especially in sensitive species. This project aims to assess the impacts of human activity in the form of an eco-resort on Gaya Island (Gaya Island Resort) on diversity and abundance of wildlife in an area of primary forest in Borneo. Camera traps were placed in three different areas of the forest assigned by researchers as a high usage trail, low usage trail and low usage off-track. Distance from the hotel was used as an explanatory variable for proximity to human disturbance. After 2063 camera trap days, 14 animal species were recorded. No significant differences were found between diversity values for each survey area. PCA showed significance in the habitat variables measured along the low usage trail. A binomial generalised linear model (GLM) carried out on total individuals captured along each trail

showed no association between habitat variables and capture probability. A negative binomial GLM performed on *Manis javanica* and *Nasalis larvatus* showed significant associations between presence of *N. larvatus* and distance from the resort. No associations were found between *M. javanica* and explanatory variables. Future work needs to include more comprehensive habitat variable measurements and the survey area must be widened to improve understanding of associations between species and their proximity to the resort, as well as increasing the chance of capturing more species.

**Introduction**

The island of Borneo is renowned as one of the world's biodiversity hotspots. It is home to some of the oldest rainforest in the world and has been highlighted as a priority for increased conservation efforts to preserve the many rare and endemic species to which it is home (de Bruyn *et al.* 2014). This means that, with the increasing popularity of eco-tourism (Dioko 2017), it is naturally a hub for those who want to experience this wildlife and make contributions towards ongoing conservation efforts. There is currently very little literature assessing the impacts and effectiveness of eco-tourism on forest conservation worldwide, and no empirical papers addressing this subject in parts of Southeast Asia (Brandt and Buckley 2018).

Gaya Island, Sabah, lies off the northwest coast of Borneo and is a natural tourist attraction due to its beaches, warm weather and a diverse range of wildlife (Said 2008). It is part of the Tunku Abdul Rahman Park (TARP), established in 1974, and is governed by Sabah Parks (Sabah Parks 2019). In recent years, three luxury eco-resorts have been built around the island to accommodate tourists. The presence of these resorts in addition to the water villages which populate the south of the island will have placed pressure on the island's fauna in the form of anthropogenic disturbance. Construction work and development of natural areas like Gaya comes with many risks to the environment, including noise pollution, land contamination and wildlife disruption (Rahman and Esa 2014). Human disturbance has already been found to have had an effect on the island's avifauna (Sompud *et al* 2016), so it is possible that other animal populations may also be affected by human presence on Gaya.

The most recent development on Gaya Island has been Gaya Island Resort (GIR), a resort hotel which opened in 2012. It offers guided nature walks as well as other recreational and educational activities for guests interested in conservation (YTL Hotels 2019). Naturally, the construction and running of the resort may have added to the pressures on the forest's communities of fauna. Over a kilometre of Gaya's eastern coastline has been developed to accommodate guests and staff at the resort, and there are multiple human-made trails that have been cut through the forest for guests to use. Large vans used for transporting food and luggage are a source of pollution, non-biodegradable waste is produced from most departments in the resort, and noise pollution is produced from live music and general noise from residents. The resort places an emphasis on educating guests about conservation in Sabah and on Gaya, but it is important to fully understand the physical impacts that the hotel and its residents may be having on the surrounding environment.

There is currently little scientific literature about Gaya island. Most existing studies focus on the marine environment around the islands in the TARP (e.g. Waheed *et al* 2007). Notable work on Gaya Island's terrestrial fauna includes the recent and only status review of the Sunda pangolin population conducted by Sompud *et al* (2019). The Sunda pangolin (*Manis javanica*; critically endangered, Challender *et al* 2014) is one of two large mammal species of interest on Gaya. The other is the proboscis monkey (*Nasalis larvatus*; endangered, Meijaard *et al.* 2008). This project will use camera traps to conduct a multi-species survey, but any captures of these two species in particular will be of special interest to the researchers due to their population vulnerability. Camera traps have been used for multi-species studies elsewhere in Borneo (e.g. Brodie *et al.* 2015, Evans *et al* 2016) but never on Gaya Island. Camera traps are a non-invasive, effective way of observing wildlife, especially nocturnal and elusive species (Sunarto *et al.* 2013). It is a more efficient and ethical method than live trapping as it reduces the amount of manpower required for studies and the levels of stress caused to animals (Villette *et al.* 2016). Hence, camera trapping will be used as the sole method to conduct this preliminary survey.

This study will use camera traps to assess the effects of human disturbance and various habitat variables on the biodiversity and distribution of animals in the forest around GIR, focusing on the man-made trails used by the resort guests. A comparison will be made between species diversity and abundance along a highly used trail, a rarely used trail and in areas never used by tourists. Furthermore, comparisons will be made between distance from the resort and species abundance to find if there are any correlation between the two factors. This study aims to discover whether there is an association between species abundance and diversity and proximity to areas with high levels of human disturbance.

**Methods**

*Study site*

The study was conducted on Gaya Island, west Sabah (figure 1). The region experiences a tropical climate with wet and dry seasons lasting on average from November to February and from March to October respectively. This survey was carried out between 29$^{th}$ January and 16$^{th}$ May 2019. Gaya Island's average annual temperature is between 24°C and 28°C (WorldWeatherOnline, 2019). Gaya island is roughly 15km$^2$ – the largest of the five islands included in the Tunku Abdul Rahman Marine Park. The island has been designated as a forest reserve since 1923 and is mostly primary dipterocarp forest. It is home to 12 recorded species of mammal – three bat species (*Rhinolophus sedulous, Emballonura monticola* and *Megaderma spasma*), four small mammal (*Suncus murinus, Chiropodomys gliroides, Rattus norvegicus* and *Sundasciurus lowii*) and five large mammal species. All the small mammals (< 500g (Colyn *et al.* 2018)) are from the order Rodentia. The large mammals (> 500g) include two primate species (long-tailed macaque – *Macaca fascicularis* – and proboscis monkey – *Nasalis larvatus*), Sunda pangolin (*Manis javanica*), bearded pig (*Sus barbatus*) and red giant flying squirrel (*Petaurista petaurista*). Large reptile species such as water monitor lizard (*Varanus salvator*) and reticulated python (*Malayopython reticulatus*) also inhabit the forest. This information has come from previous surveys carried out by naturalists who work at the resort, not using camera traps but by recording any animal encounters and reports they experience on the island.

There are three resorts currently on Gaya, of which Gaya Island Resort (GIR; N6°01'07" and E116°02'50") is the most recently constructed. Small water villages are also located on the south side of the island. GIR is the closest inhabited area to the study region and the anthropogenic disturbance from this resort is the focus of this report. The hotel conducts nature walks for guests and has therefore constructed a number of trails through the forest. The most highly used trail (area 1: the Hill trail (1.5km long) with an average of 12 people walking it per day between December 2018 and June 2019 (a total of 2490 people over six months)) and one of the least used trails (area 2: the Loop trail (2.2km long) which had fewer than 10 people total walk it during the research period) were surveyed during this project alongside off-track areas where tourists and resort staff do not go (area 3: off-track transects). The Hill trail is maintained by GIR staff; maintenance includes regular sweeping of leaves and debris from the path, removal of obstructing vegetation and upkeep of step structure, wooden handrails and bridges. Neither the Loop trail nor off-track areas are altered by trail maintenance.

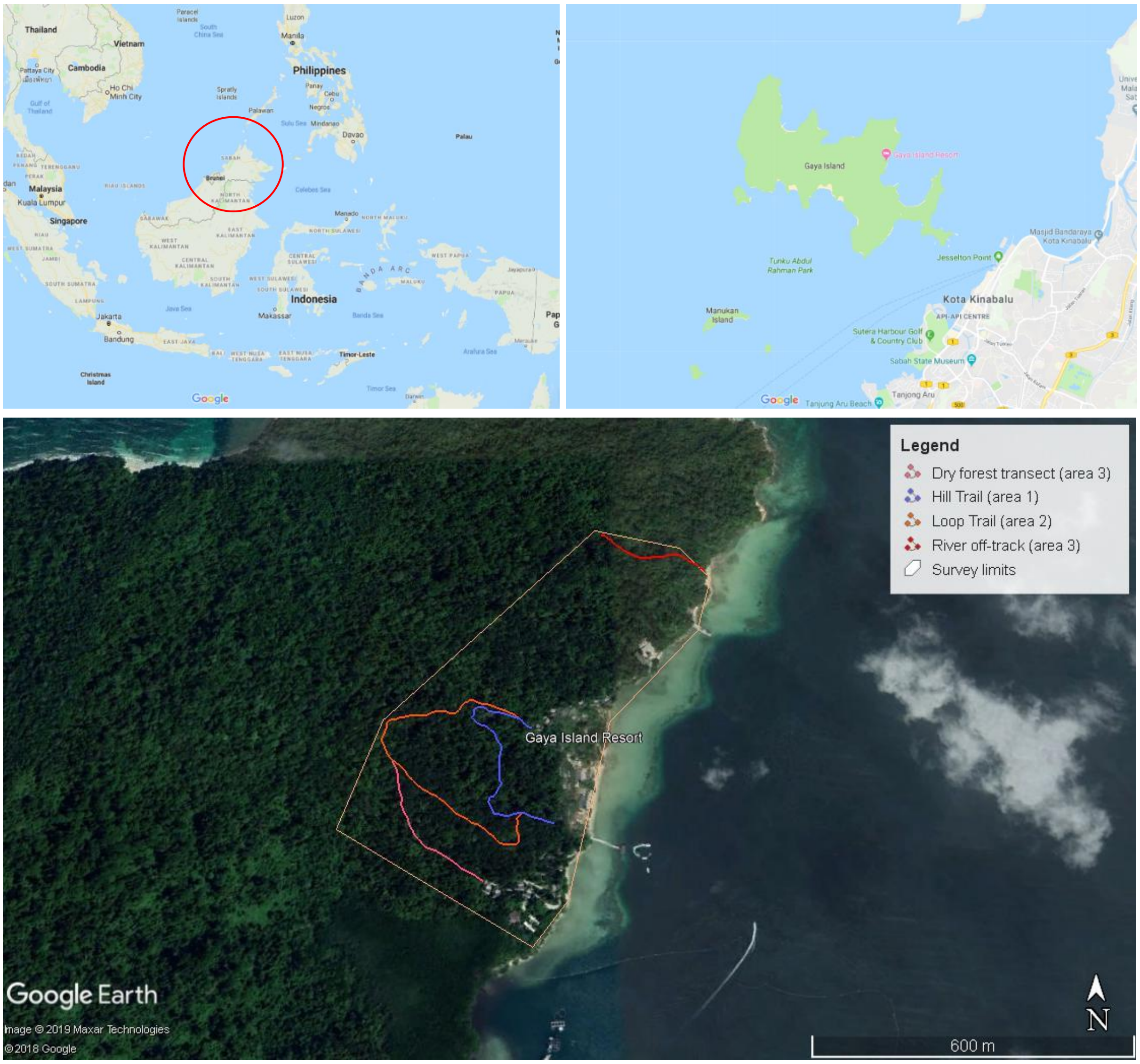


**Figure 1. Maps showing area around Gaya Island Resort which was included in the survey.** Clockwise from top left: Borneo, South-East Asia; Gaya Island, off the west coast of Sabah next to the capital city Kota Kinabalu; Gaya Island Resort and the area where cameras were placed around the hotel. The total area surveyed was 0.5km x 1km which is shown by the polygon. Seven cameras were placed in area 1, six were placed in area 2 and eight were placed in area 3.

*Camera spacing and placement*

A total of 21 camera traps (17 Reconyx Hyperfire PC800 and four HC500) were used in this study. The cameras were set in the forest areas described above (high disturbance area 1, low disturbance area 2 and low disturbance off-track area 3). Seven cameras were placed in area 1, six in area 2 and eight were used in area 3. Each trail was measured using Garmin Basecamp (Hill trail: 614m; Loop trail: 921m) and GPS points were chosen at equal distances along each trail for camera placement (every 87m along the Hill trail, every 154m along the Loop trail). These points were located in the field using a handheld Garmin GPS and cameras were placed on the nearest suitable tree which was considered close enough to the trail. One camera site in area 1 was deliberately placed on a permanent freshwater stream which crossed the trail 177m away from the resort in an attempt to account for bias caused by using another permanent freshwater stream as an off-track transect. This is why there is one extra camera used in area 1. One camera was placed in a small valley between the two trails and counted as part of area 3.

For area 3 camera placement, two areas of forest were chosen which were not accessed by tourists but were easy for researchers to get to. Due to the steep elevation of Gaya Island, many areas of the forest are not easily accessible. A 310m transect was measured using Garmin Basecamp in an area of dry forest. GPS points were made every 78m along this transect for camera placement. The other transect was chosen to be along a permanent freshwater stream and was close to 300m long, similar in length to the first transect. GPS points were made every 100m along this stream for camera placement, but there were few suitable trees to which cameras could be attached which affected the distance between each final camera placement. One camera was placed 100m from the first, the third was placed 200m from the second.

Each camera trap was placed between 50cm and 72cm above the ground on each tree, with the on-trail cameras facing diagonally towards the trail and the off-track cameras towards the largest open space. Cameras along the stream transect were faced towards the stream. The area in front of each camera was trimmed of obstructing vegetation within a 3m radius in an effort to reduce false trigger events and obscuring of passing animals. If necessary, the camera was angled towards the ground using sticks and twigs. No bait was used.

*Data collection and analysis*

Cameras were set to trigger after motion detection and set at the highest sensitivity. Cameras were active 24 hours a day and when triggered would take three photos, leaving one second between each movement detection. Non-rechargeable batteries were used which were changed at one to two-month intervals depending on how often the camera captured images. Images were stored on SD cards. Cameras along the Hill trail were visited for SD card collection and battery checks once a week due to the high volume of human traffic, whereas cameras in other survey areas were visited once per month for SD card collection and battery checks.

Individual detection events were determined to be images of the same species taken more than one hour apart; this is a common approach (Tobler *et al.* 2008). Images from camera traps were tagged and organised using the image organising software Digikam. Sampling effort was determined to be number of cameras multiplied by the number of days which they effectively sampled (camera trap days; Ancrenaz *et al.* 2012). EstimateS (Colwell 2013) was used with 100 randomisations and classic formulas for Chao indices to produce diversity index values for capture data. Rarefaction curves were not extrapolated, and Shannon and Simpson's indices were calculated in diversity settings. All other statistical analyses were carried out using R studio (R Core Team 2018).

*Habitat variable analysis*

Habitat variables were measured within a 5m$^2$ area in front of each camera trap. These variables consisted of the number of large trees, percentage canopy cover, vine score (0-5, 0 being no vines, 5 being a large number of vines) mid-story and understory density, number of logs, substrate depth, distance from water and hotel and elevation above sea level. Canopy cover was measured using the image processing and analysis software ImageJ (Schindelin *et al.* 2012) and elevation above sea level was measured using a Garmin handheld GPS. Due to the high number of counts of 0 for number of logs, number of large trees and vine scores, however, at each camera station, these variables were excluded from statistical analyses.

To find correlations between habitat variables at each camera trap site and between survey areas, a principal component analysis (PCA) was carried out. Habitat variables included in the PCA were percentage canopy cover, mid-story and understory density, substrate depth, distance from water and elevation above sea level. Principal components (PCs) from this were compared using ANOVA testing to establish if there were significant associations between habitat variables for each site.

To test for an association between habitat variables and total counts of individuals at each camera trap site, an initial Poisson generalised linear model (GLM) was carried out. This revealed an overdispersion parameter value of > 15 and, therefore, the standard errors were corrected using a negative binomial GLM with a log link function. Variables included in this model were individuals captured at each camera, area number of each camera, percentage canopy cover, mid-story and understory density, substrate depth, distance from water, elevation above sea level and distance from hotel.

Binomial GLMs were used to attempt to predict occurrences of *M. javanica* and *N. larvatus* based on habitat variables, especially looking at distance from hotel. Stepwise deletion was then carried out with a $Chi^2$ test (using the drop1 function in R) to eliminate non-significant variables and improve the model fit. McFadden's pseudo-$r^2$ value was used to determine goodness of fit of each model and then graphs of predictions were made from variables. Variables included in these models were those used for the binomial GLM mentioned above, but using presence-absence data of *M. javanica* and *N. larvatus* at each camera rather than total individuals

**Results**

*Camera trapping*

Sampling effort was 2063 camera trap days after a loss of 245 trap days due to camera faults and batteries losing charge before they were checked. By the end of the study, 1150 individuals were detected across all species and a total of 52885 photographs were collected during the time period. Most individuals were captured in area 3 (526 individuals compared to 208 for area 2 and 415 for area 1; table 1). Areas 1 and 2 captured nine species whereas area 3 captured 11. A total of 14 species were captured across the whole survey region These included six large mammal species (*Canis lupus familiaris, Felis catus, Macaca fascicularis, Manis javanica, Nasalis larvatus* and *Sus barbatus*), three small mammal species (*Sundasciurus lowii, Rattus* spp. and *Suncus* spp.) and five bird species (*Copsychus stricklandii, Ketupa ketupu, Megapodius cumingii, Stachyris grammiceps* and *Treron vernans*). Individuals of both *Rattus* and *Suncus* genera were unable to be identified to species level. The most commonly photographed animal (excluding humans) was *S. barbatus,* but there were more total individuals of *M. fascicularis* captured. Human captures made up more than 60% of total photographs tagged during the survey and were excluded from diversity analyses.

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**Table 1. Total individuals captured by 21 camera traps for a multi-species survey in three different area types.** Area 1 = high usage trail, area 2 = low usage trail, area 3 = low usage off-track. Detections were counted over a five-month period (2063 camera trap days). Individuals of *Rattus* and *Suncus* genera were not able to be identified down to species level. Species were identified by researchers using the image organiser and tag editor software Digikam. Detections of the same species were considered to be separate individuals if they were sighted > 1hr apart.

| **Species** | **Total individuals per survey area** | | | |
|---|---|---|---|---|
| | **Area 1** | **Area 2** | **Area 3** | **Total** |
| *Canis lupus familiaris* | 2 | 2 | 0 | 4 |
| *Copsychus stricklandii* | 0 | 1 | 1 | 2 |
| *Felis catus* | 14 | 1 | 2 | 17 |
| *Ketupa ketupu* | 0 | 0 | 1 | 1 |
| *Macaca fascicularis* | 265 | 102 | 135 | 502 |
| *Manis javanica* | 3 | 2 | 4 | 9 |
| *Megapodius cumingii* | 9 | 7 | 8 | 24 |
| *Nasalis larvatus* | 0 | 1 | 5 | 6 |
| *Sundasciurus lowii* | 0 | 0 | 5 | 5 |
| *Treron vernans* | 0 | 0 | 1 | 1 |
| *Stachyris grammiceps* | 1 | 0 | 0 | 1 |
| *Sus barbatus* | 117 | 18 | 308 | 443 |
| *Rattus spp.* | 4 | 74 | 56 | 134 |
| *Suncus spp.* | 1 | 0 | 0 | 1 |
| Total | 416 | 208 | 526 | 1150 |

Results from Abundance-based Coverage Estimator (ACE) estimated higher diversity in area 3 (ACE mean = 12.5) compared to areas 1 and 2 (ACE mean = 9.5 and 10 respectively). Conversely, rarefaction performed using S(est) values predicted highest diversity in area 2 (figure 2; S(est) = 9, 95% confidence interval (CI) lower bound = 6.38, CI upper bound = 11.62) compared to area 1 (S(est) = 7.56, 95% CI lower bound = 5.16, CI upper bound = 9.97) and area 3 (S(est) = 8.51, 95% CI lower bound = 5.35, CI upper bound = 11.68) at 208 individuals. Results from Shannon's and Simpson's diversity indices also showed highest diversity and evenness in area 2 (D (Shannon) = 1.21, D (Simpson) = 2.66) compared to area 1 (D (Shannon) = 0.98, D (Simpson) = 2.05) and area 2 (D (Shannon) = 1.15, D (Simpson) = 2.38). These differences were not found to be significant (Shannon: P ($Chi^2$) = 0.9876; Simpson's: P ($Chi^2$) = 0.9613).

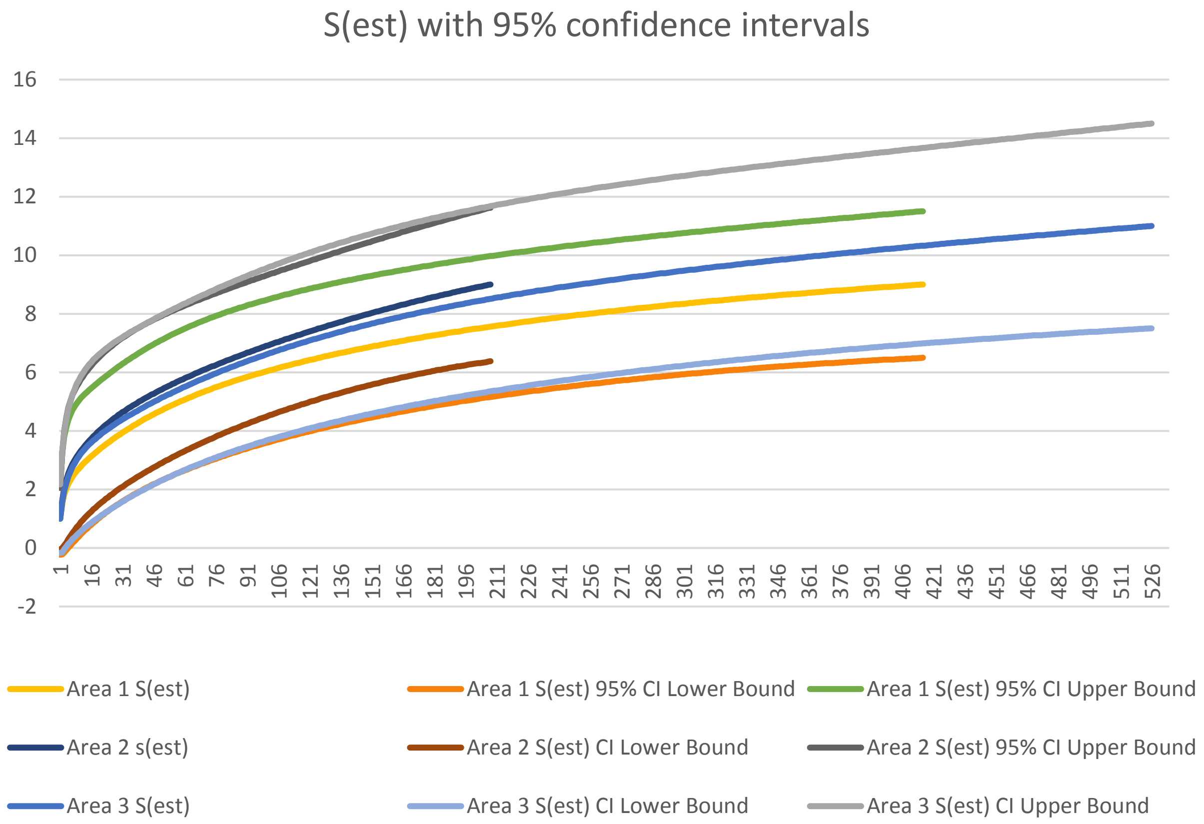


**Figure 2. Rarefaction curves showing estimated number of species present in each survey area – high usage trail (area 1), low usage trail (area 2) and low usage off-track (area 3).** Also shown are upper and lower bound 95% confidence intervals (CI). At 208 individuals: area 1 S(est) = 7.56 (95%CI lower bound = 5.16, 95% CI upper bound = 9.97), area 2 S(est) = 9 (95% CI lower bound = 6.38, 95% CI upper bound = 11.62), area 3 S(est) = 8.51 (95% CI lower bound = 5.35, 95% CI upper bound = 11.68). Graph uses data produced using EstimateS (Colwell 2013).

*Habitat variable analysis*

The first three PCs explained 76.8% of variance between sites (table 2). ANOVA testing on PCs produced from PCA showed a significant result for PC1 (P = 0.003966). To find differences between each survey area, a Tukey Multiple Comparison test was performed using results from this ANOVA and showed significant differences between area 1 and area 2 (P = 0.0352657), and between area 2 and area 3 (P = 0.0032513). ANOVA testing showed no statistical significance for PC2 and PC3 (P = 0.2428; P = 0.3017 respectively). Residuals were normally distributed.

**Table 2: Principal Component Analysis (PCA) loadings of habitat variables from 21 camera trap sites surveyed on Gaya Island.** The first three principal components of the PCA explain 76.8% of total habitat variance.

| Habitat Variable | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
|---|---|---|---|---|---|---|
| % Canopy Cover | 0.231 | 0.00 | 0.798 | -0.473 | -0.273 | 0.109 |
| Understory Density | -0.607 | 0.00 | 0.00 | 0.00 | 0.133 | 0.771 |
| Mid-story Density | -0.569 | 0.00 | 0.203 | -0.326 | 0.445 | -0.575 |
| Average Substrate Depth | 0.439 | -0.512 | 0.00 | 0.00 | 0.718 | 0.151 |
| Distance from Water | 0.233 | 0.542 | -0.404 | -0.644 | 0.208 | 0.175 |
| Elevation Above Sea Level | 0.00 | 0.660 | 0.386 | 0.496 | 0.389 | 0.00 |

**Table 3. Summary of values produced from GLM with a negative binomial family comparing abundance data of all species captured at 21 camera trap sites to habitat variables measured at each site.** Threshold for P-value taken to be > 0.05. Final two columns are from using drop1 function (test = Chi). Stepwise deletion did not show any significant associations between abundance and habitat variables.

| Coefficients | Estimate | Std. error | Z value | P (> \|z\|) | AIC | P (Chi) |
|---|---|---|---|---|---|---|
| **(Intercept)** | 3.2371957 | 5.7834430 | 0.560 | 0.576 | 218.74 | -- |
| **Canopy cover** | 0.0156355 | 0.0622872 | 0.251 | 0.802 | 216.80 | 0.7971 |
| **Understory density** | -0.0242007 | 0.0168533 | -1.436 | 0.151 | 218.28 | 0.2139 |
| **Distance from water** | -0.0001417 | 0.0019153 | -0.074 | 0.941 | 216.74 | 0.9473 |
| **Elevation** | -0.0002350 | 0.0091832 | -0.026 | 0.980 | 216.74 | 0.9804 |
| **Distance from hotel** | 0.0004493 | 0.0021018 | 0.214 | 0.831 | 216.78 | 0.8409 |

For abundance data, no significant associations were found between abundance and other explanatory variables after using a GLM with a negative binomial family (table 3). This model was created to find if there were any associations between survey area and abundance. The other habitat variables were added to the model to see if they were causing bias.

The binomial GLM used to look at occurrences of *M. javanica* showed no significant associations between habitat variables and presence-absence of individuals (table 4). No further modelling was done using this data. The binomial GLM used to look at occurrences of *N. larvatus* did show a significant association between distance from the hotel and presence-absence of individuals (P = 0.01432; table 5). This model was used to create predictions of *N. larvatus* presence compared to distance from the resort (figure 3). Predictions of presence of individuals is positively correlated with distance from the resort.

**Table 4: Summary of values from GLM with negative binomial family comparing presence-absence data of *M. javanica* with habitat variables measured at 21 camera trap sites.** Habitat variables used for modelling were % canopy cover, understory density, distance from water source, elevation above sea level and distance from hotel.

| Model explanatory variables | AIC | Std. error | Z value | P (> \|z\|) | Residual deviance (df) | McFadden $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept) Can cov + Und dens + Dist water + Elevation + Dist hotel** | 37.862 | $2.061e^1$ | -0.574 | 0.566 | 21.862 (13) | 0.1822338 |
| **Null** | 28.734 | 0.2829 | -1.522 | 0.128 | 26.734 (20) | -- |

**Table 5: Summary of values from GLM with negative binomial family comparing presence-absence data of *N. larvatus* with habitat variables measured at 21 camera trap sites.** Habitat variables used for initial model were % canopy cover, understory density, distance from water source, elevation above sea level and distance from hotel. Final model only used distance from hotel.

| Model explanatory variables | AIC | Std. error | Z value | P (> \|z\|) | Residual deviance (df) | McFadden $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept) Can cov + Und dens + Dist water + Elevation + Dist hotel** | 25.098 | 40.023524 | 0.423 | 0.673 | 13.098 (15) | 0.359139 |
| **Null** | 22.45 | 0.3153 | -2.779 | 0.00545 | 20.45 (20) | -- |
| **Dist hotel** | 18.452 | 2.055288 | -2.255 | 0.0241 * | 14.452 (19) | 0.2932956 (2) |

## Discussion

*Species diversity and abundance*

The PCA highlighted some correlation between habitat variables between sites, suggesting the habitat variables which made up PC1 were significantly different between the three areas (specifically area 2 was most different from areas 1 and 3). This may have caused a bias in abundance of species between survey areas. This is important to consider when looking at differences in diversity and evenness between each survey area.

Across the survey duration, 14 different species were captured. These included the endangered and critically endangered *N. larvatus* and *M. javanica*. The only large mammal not captured during this research which is known to inhabit the island was *Petaurista petaurista* (red giant flying squirrel). This is an arboreal species which glides between trees to forage and find mates (Krishna *et al.* 2016) so was unlikely to be seen during this terrestrial survey. Smaller mammals were hard to identify to species level due to quality of camera trap photos, but individuals of *Rattus* spp. made up a significant amount of total captures. The only previously recorded species of *Rattus* on Gaya is *R. norvegicus,* but as an island-wide species survey has not yet been conducted it could not be assumed that all captures of *Rattus* individuals were of *R. norvegicus.* Camera traps are usually best suited for observing medium to large-sized ground-dwelling mammals (Ancrenaz M. *et al.* 2012) and, therefore, other small mammals may have been missed by the cameras' sensors even when highest sensitivity settings were used, especially if they moved at high speed (Alistair *et al.* 2013). Supplementing the survey with other methods of recording wildlife such as live-trapping or bio-acoustic localisation (Wilson *et al.* 2014) may give more reliable results for abundance of smaller mammal species in the region. This would also help create a full record of Rodentia species present on Gaya.

Although there were two more species recorded in area 3, diversity indices suggested similar diversity and evenness scores across all areas with none significantly more diverse than the others. Overall, the results suggest that area 1 is the least diverse, but this is not a statistically significant finding. This suggests that the diversity and species richness seen in areas with low levels of human disturbance is mostly retained in areas of higher human disturbance. The low scores for Shannon and Simpson's diversity indices for area 3 may be explained by the high number of individuals of *S. barbatus* that were captured by one camera on the stream off-track transect. A bearded pig family is known to inhabit the stream area and is frequently observed by guests and staff at a beach very close by – it is thought that this family made up a large proportion of the species' captures on the stream transect. This may have reduced the evenness of the total captures in area 3 and caused a lower diversity score than expected from the area with the highest number of species. The overall results from these diversity estimators suggest that human disturbance levels do not have a negative effect on the diversity of megafauna inhabiting the forest. This is a positive result and suggests that the wildlife has adapted to the presence of humans near the forest.

The only species showing significant associations with any explanatory variables was *N. larvatus.* Presence of this species was positively correlated with distance from the resort, suggesting a level of avoidance of areas with high anthropogenic activity. Individuals were captured on both off-track transects and only once on the Loop trail. The individual captured on the Loop trail was identified and thought to be a known rescued male translocated from mainland Borneo. This male had been subject to a higher level of human interaction than the rest of the population on Gaya Island due to time spent in a mainland zoo and his home range being close to the resort compound. This may be the reason he was the only individual sighted on a man-made trail occasionally used by tourists. Otherwise, the native population is known to be elusive and individuals are rarely seen near the resort. There is a mangrove forest to the east of the hotel, relatively far from the main resort compound in which proboscis monkeys are occasionally sighted. Proboscis monkeys are known to inhabit mangrove swamps and feed on foliage (Matsuda *et al.* 2011), and a lack of a food source close to the main resort may therefore be the reason they avoid this area rather than the higher levels of human activity. Further investigation into the home ranges of the *N. larvatus* groups on Gaya Island may give more insight as to whether it is proximity to human disturbance or food sources that is the limiting factor to their movements. A species-specific project to observe the island's population would be more appropriate to allow conclusions to be made about these factors.

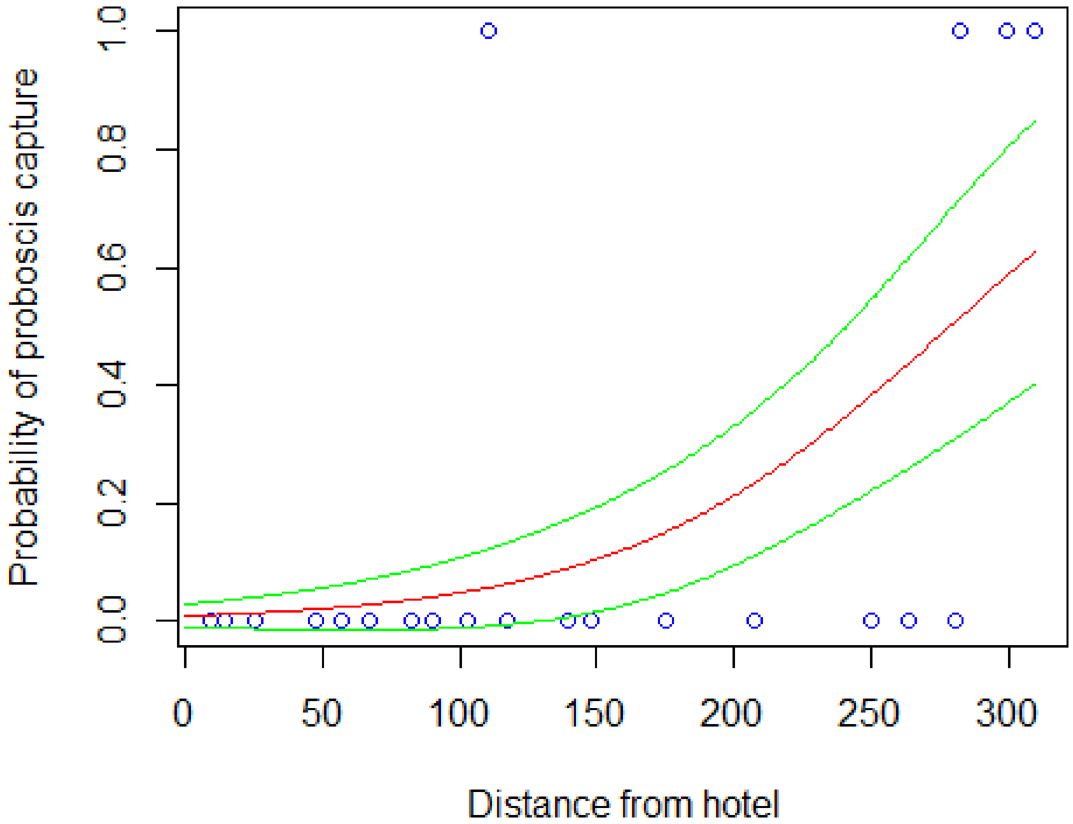


**Figure 3. Graph of predictions for capture probability of *N.larvatus* on Gaya Island relative to distance from Gaya Island Resort.** Trend (red) with +/- standard errors (green). Predictions based on results from binomial GLM using presence-absence data of *N. larvatus* captures across 21 camera traps. Furthest camera trap was placed 309m from the resort. Values from final binomial GLM: AIC = 18.452; P (> |z|) = 0.0241; McFadden $R^2$ = 0.2932956.

Amongst the species captured were the domestic species *C. lupus familiaris* and *F. catus*. Both species are present in the water villages on Gaya Island and are frequently seen in and around GIR. Cats and dogs pose significant threats to wildlife and have been known to cause extreme adverse effects on endemic species (Medina *et al.* 2011; Hughes and Macdonald 2013). All captures of *C. lupus familiaris* and over 80% of captures of *F. catus* were on made-made forest trails, suggesting populations may favour being close to the resort and areas with high levels of human presence. This may be due to the resort providing a food source through waste disposal from restaurants. The non-native *R. norvegicus* is one of the previously recorded mammal species on Gaya Island and is assumed to make up a proportion of the *Rattus* individuals identified from camera trap images during this survey. As shown in the nearby capital city of Sabah, Kota Kinabalu, and the surrounding forest, invasive rat species can replace endemic small mammal species (Wells et al. 2014). The presence of invasive and potentially harmful species such as rats, cats and dogs could have similar effects on the endemic wildlife populations of Gaya. They are potentially another source of disturbance in addition to human activity, reducing species diversity in the forest close to the resort. Conducting an island wide survey for the presence of rats and feral cats and dogs and implementing methods to reduce their ranges, as suggested by Plaza *et al.* (2019) may help future efforts to conserve wildlife populations on Gaya.

It was not possible to predict capture probability for *M. javanica* based on habitat variables included in this survey. Proximity to areas of higher anthropogenic disturbance did not have a significant effect on capture rate of *M. javanica*. In fact, one individual was recorded less then 10m from the resort compound and one third of all captures of this species occurred on the high usage trail. It is encouraging to see that Gaya's pangolins include the resort area in their home ranges. It suggests a degree of adaptability to anthropogenically disturbed areas. It was not possible to identify specific individuals from camera trap images, but one individual had a distinctive marking on its tail leading researchers to believe there were at least two individuals inhabiting the range of the camera traps. This survey corroborates conclusions from Sompud *et al.* (2019) who found that pangolins on Gaya Island were strictly nocturnal – all individuals recorded in this survey were captured between 22:28 and 03:57. The status review of *M. javanica* on Gaya Island conducted by Sompud *et al.* (2019) covered the whole island using ten camera traps across 69 sites, totalling 2545 camera trap days. The total of nine captures of *M. javanica* during that survey matches the number of captures during this survey and the number of camera trap days in both surveys is similar. These reports in conjunction suggest that the population on Gaya may be small and elusive to researchers, but widespread across the island. Another, longer-term species-specific survey for pangolins would help determine population size and home ranges, adding to the dearth of literature concerning this species. Little is known about the ecology and home ranges of *M. javanica*, although they and other pangolin species are thought to be shy and elusive (Hasitha *et al.* 2018) and are hunted extensively due to their high value on the black market (Newton *et al.* 2008; Zhou *et al.* 2014). The pangolin population on Gaya Island has no natural predators save for potential human poachers and the island is protected under TARP, meaning there is potential for future species-specific conservation projects to protect Gaya's pangolin population.

*Conclusion*

From this research, human disturbance from GIR cannot conclusively be said to be affecting wildlife populations adversely or otherwise. It is possible that the populations of *N. larvatus* are avoiding the resort and man-made trails, although other factors may be involved in explaining this pattern. It is encouraging that this research did not show extreme significant effects on the wildlife observed, but more work should be done to attempt to record more species and their population sizes to form a more comprehensive view of the forest's wildlife communities. Future work on Gaya should involve a wider range for surveys. There may be more significant correlations found between species abundance and explanatory variables if the survey area was to be extended deeper into the forest or compared with different transects around the island. As mentioned above, more species-specific research on the vulnerable species inhabiting Gaya Island would help wider conservation efforts. Furthermore, comparing results from this survey with similar surveys conducted in primary forest near anthropogenic disturbance on mainland Borneo may expand on conclusions from this report. Tourism in natural areas has been found to have had effects on fauna in areas all over the world (e.g. Oberosler *et al,* 2017) so it is important to continue future studies in Borneo in order to establish if the results from this research are significant.

Gaya Island's primary forest plays host to an important community of fauna, including the endemic species *N. larvatus* (Matsuda et al. 2018) and critically endangered *M. javanica* (Challender 2014) and research should be continued into the future to preserve these communities. Collaboration with GIR and other eco-resorts for any future work done on the island would help increase awareness of conservation efforts through education of resort guests and staff. This would also encourage involvement from the public in efforts to conserve the wildlife on Gaya Island and in the rest of Borneo. Human disturbance comes in many forms but can have many adverse and devastating effects on the wildlife it disturbs (Cuaron 2000). It is important that we continue to do research in areas at risk of being negatively affected by humans, especially with the rise in popularity of eco-tourism, in order to protect the vulnerable populations of wildlife which depend on the surrounding natural areas.

While it is important to consider any negative effects that rise of eco-tourism may be having on the environment, it is also an important opportunity to advance conservation efforts through education and increased public awareness. Eco-tourism can provide economic growth, funding for conservation efforts and increased awareness of the threats which face many species today (Brandt and Buckley 2018), helping to preserve unique ecosystems like the one found on Gaya Island for future generations.

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