# The effects of forest degradation on ranging habits and activities of arboreal primates within Sikundur, the Gunung Leuser Ecosystem, Northern Sumatra

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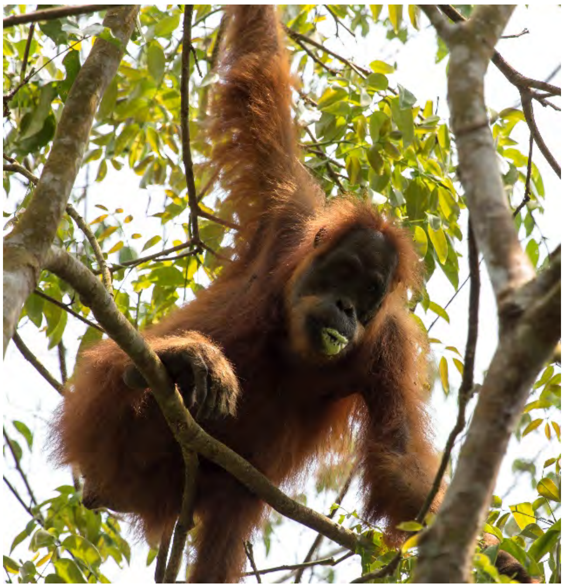

Photo credit: Emma Hankinson

Awarded a PSGB conservation grant in February 2016

**Project background**

Tropical forests are being destroyed at a rate of 1.5 acres every second due to human activities, thereby accelerating climate change through impacts on the carbon cycle, and causing the extinction of species dependent on these habitats. In the face of such immediate and globally significant issues, there is a lack of robust scientific knowledge on how tropical deforestation and degradation affects ecosystem stability and the fauna that inhabit tropical forests.

A rising human population, together with increased affluence in post-industrial economies has caused a rise in the demand for luxury products such as tropical timber. In 2014, the International Tropical Timber Organization exported over 15.8 million tropical non-coniferous logs worth $5.9 billion (ITTO, 2014). As a consequence of this demand for tropical timber, only 18% of tropical nations report more primary than regenerating forest, due to logging events (FOA, 2010). Recent advances in automated monitoring of forest degradation have led to estimates that selective logging, as opposed to deforestation (clear-felling of forest), had approximately 15 times the geographic footprint of deforestation between 2000 and 2005 (Asner et al., 2009). Forest degradation, measured by partial canopy cover loss, effected 185 million ha between 2000 and 2012, with over 156 million ha within tropical forests.

The effects of selective logging on the ecology of tropical forests is still poorly understood, as most studies lack comparable pre and post-logging data (Laufer et al., 2013). Quantative measures of selective logging, also known as forest degradation, are equally challenging; through both the uneven distribution of valuable tree species and the collateral damage caused by “selective” logging. Historically logged forest cannot easily be classified as logged and non-logged, but rather exhibits heterogenous gradients of degradation (Struebig et al., 2013). This form of logging can have a relatively low impact compared with other forms of anthropogenic disturbance, such as fragmentation and fire, in terms of reduced habitat (Chaves et al., 2012, Barlow et al., 2006) with most logged forests containing at least 50% of the biomass and more than 75% of the species compared to undisturbed forest (Berry et al., 2010, Putz, 2012). However, for long lived species, there may be a form of extinction debt hidden by this discrete form of habitat disturbance, the full effects of which have not yet become apparent (Tilman et al., 1994, Vellend, 2006). Though species richness of tropical forests appears resilient to logging events (Edwards et al., 2011), the response of taxa vary widely (Berry et al., 2010, Marsh et al, 2016) with many studies showing clear shifts in species composition (Hall et al., 2003, Ernst et al., 2006), though with few clear discernible patterns between those species most affected (bats, Presley et al., 2009, apes, insectivorous birds, Poulsen et al., 2011, butterflies, Summerville and Crist, 2002).

As anthropogenic disturbance removes available habitat for rainforest species and degrades remaining forests, a multitude of species are threatened. There is a need to develop methods to rapidly assess tropical forest structure and relate this to habitat quality for keystone species, like primates. Only upon understanding the impacts of forest degradation on forests and their inhabiting animals can effective conservation methods be planned. The proposed project aims to investigate the effects of forest degradation on primates over a large study site using innovative data collection methods. This will enable the identification of areas of conservation importance and the modelling of predicted future climate change effects on the well-being of primates inhabiting degraded forests, addressing the possible synergistic effects of forest degradation and climate change on primate species at landscape, as well as community, scales.

**Study Site**

The Sikundur site, within the Gunung Leuser Ecosystem conservation area (Lat: 3.95, Long: 98.07), Northern Sumatra, has been the focus of previous conservation research projects (Knop et al., 2004, Askew, unpublished data) but remains a relatively unstudied area and one of the last remaining lowland forests in Sumatra. The Gunung Leuser Ecosystem conservation area is considered one of the most important bastions of tropical biodiversity, being the only remaining area where Sumatran orangutans (*Pongo abelli*), elephants (*Elephas maximus sumatranus*), tigers (*Panthera tigris sumatrae*), rhinos (*Dicerorhinus sumatrensis*) and sun bears (*Helarctos malayanus*) still co-exist (Hitchcock and Meyers, 2006).

The Gunung Leuser Ecosystem conservation area is a significant part of the ‘Tropical Rainforest Heritage of Sumatra’ (TRHS), a UNESCO World Heritage site and a stronghold for Sumatran orangutans. The Sikundur study site covers ca. 15 x 7 km of the Gunung Leuser Ecosystem. The Sikundur area (30–100 m above sea level) consists of diverse mixed dipterocarp lowland forests with rich alluvial forest along the rivers (de Wilde and Duyfjes, 1996). The study site covers both pristine forest and forest that was mechanically logged between 1976-1988 and then again intermittingly in the 1990’s, and then left untouched to recover. During the 1976-1988 logging operations, an average of 11 large trees per hectare were felled (Knop et al., 2004).  Mean temperatures measured in 2016 were 27.8$^{o}$C (max = 41.6$^{o}$C, min = 21.06$^{o}$C), with the average monthly rainfall is recorded as 256.4mm (measured between August 2013-February 2015) with a range of 12.4 – 535.4mm. Since 2013, a permanent ground team from the Sumatran Orangutan Conservation Program (SOCP, a local NGO collaborator) has collected behavioural information on the orangutans in the area. Further study in this area presents a unique opportunity to study the responses of multiple primate species to the effects of a gradient of anthropogenic disturbance over multiple forest types.

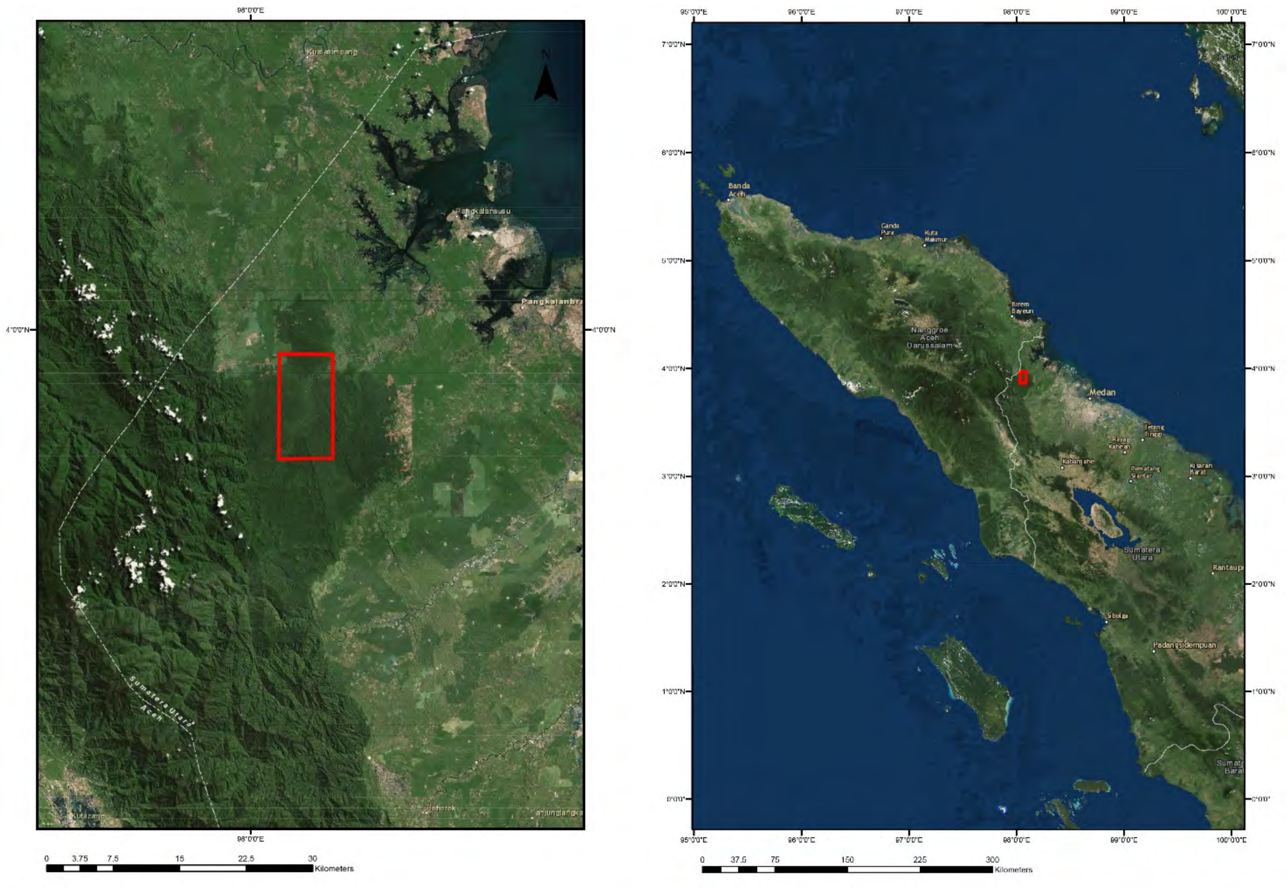


Figure 1. Study site location highlighted in red

**Project Aims**

This project aims to relate gradients of anthropogenic disturbance to relative changes in primate population density and behaviour. To achieve this overall goal, two linked data collection regimes will take place, one at the community scale and one at the landscape scale (see Figure 2). Community-scale data collection will focus on primate behavioural responses to forest structure changes caused by logging events and subsequent alternations in within canopy microclimate in a small 6km$^2$ area. Landscape-scale data collection will focus on primate population densities in relation to forest land-types and gradients of forest degradation over a large 75km$^2$ area.

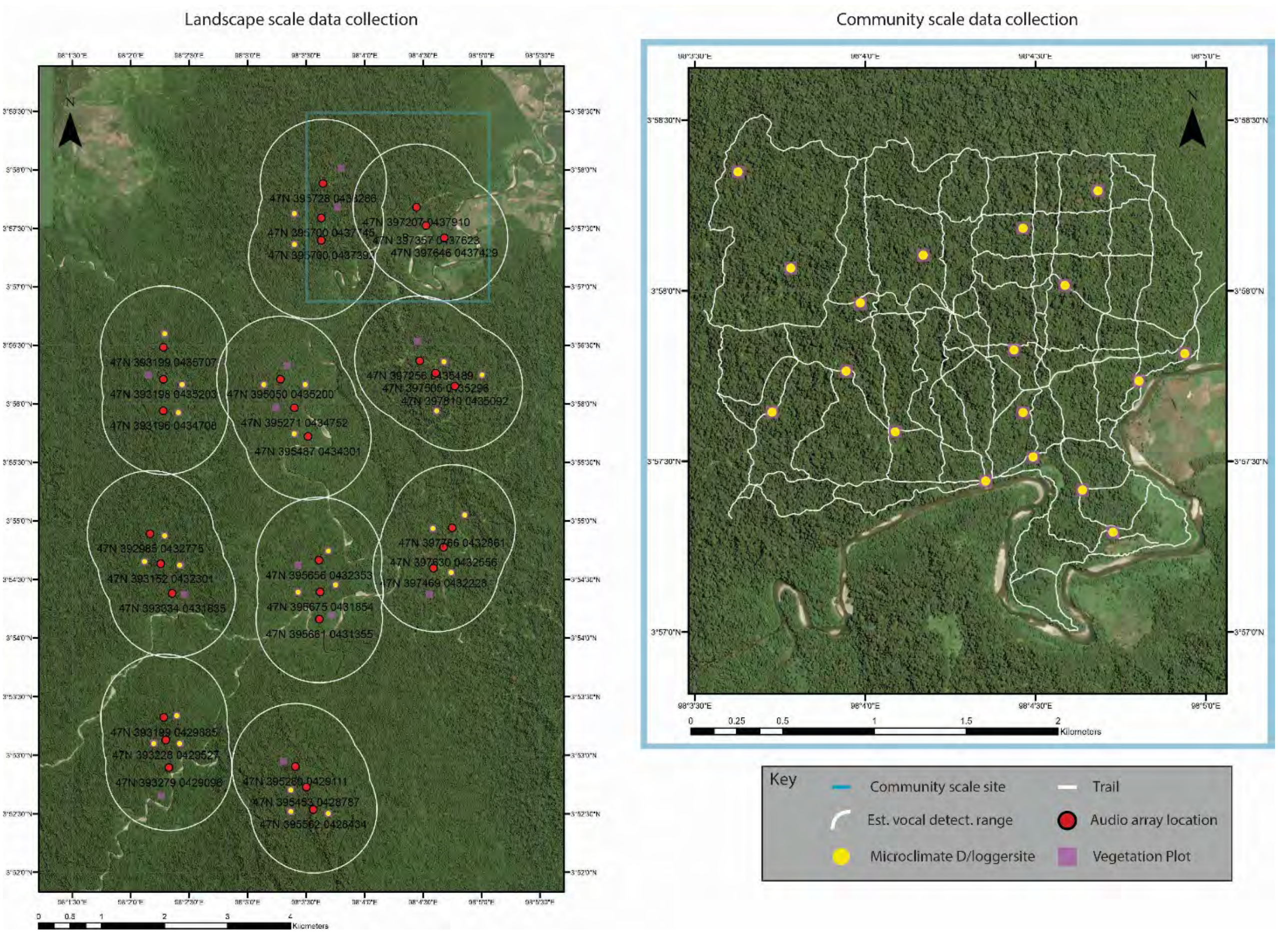


Figure 2. Data collection regime map

Both data collection regimes will provide data to inform a predictive model, allowing a robust understanding of how future predicted climate change and further forest degradation will affect primate behaviour, ranging and survival in a number of differing scenarios. To achieve these goals, the following objectives will be accomplished:

Objective 1. Develop a 3-dimensional vegetation map of the study area. By combining aerial imagery with ground vegetation data, this project will allow the understanding of the 3-dimensional vegetation characteristics that drive primate behaviour, distribution and microclimates below the canopy.

Method 1a. Aerial images: 3-dimensional vegetation data will be obtained using Unmanned-Aerial-Vehicles (UAVs) using a number of flights (n=12 to date) at both community and landscape scales (n=~20 additional flights required). These data will be processed using structure-from-motion (Pix4D) software with support from Conservation Drones and the Landscape Ecology and Primatology research group (LEAP).

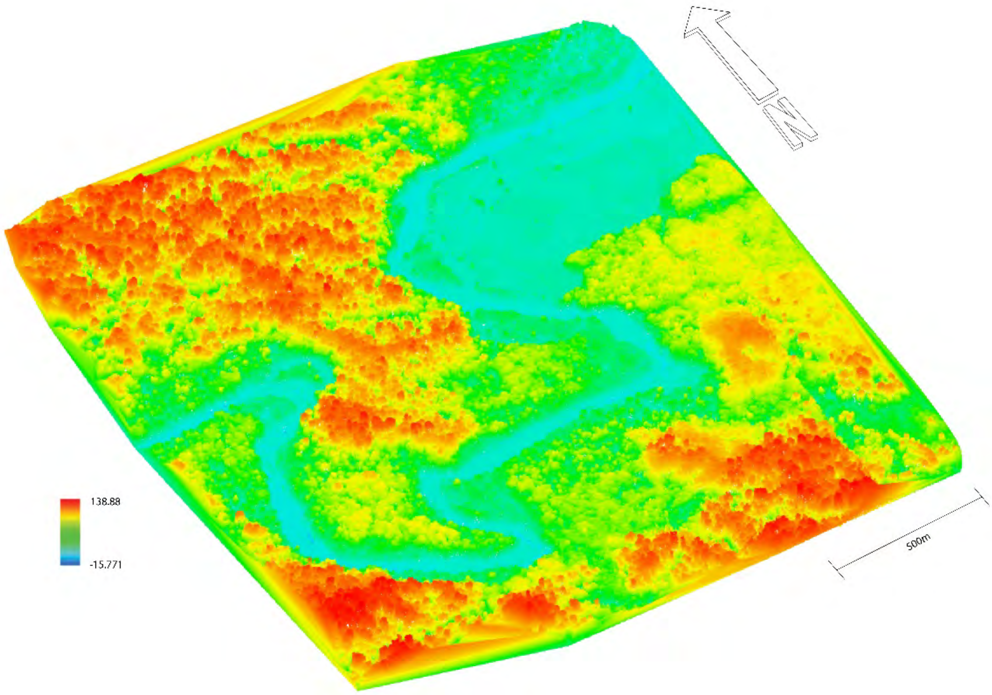


Figure 3. a section of the Sikundur 3-dimensional canopy model

Method 1b. Ground vegetation data: landscape-scale vegetation surveys have been conducted at 10 sites within differing land-types (4/5 vegetation plots per land unit) to calibrate aerially captured data for these areas. Community-scale vegetation surveys (n=17) will consist of vegetation plots conducted around randomly determined points (see M2). 49 vegetation plots across both landscape and community scales have been conducted to-date.

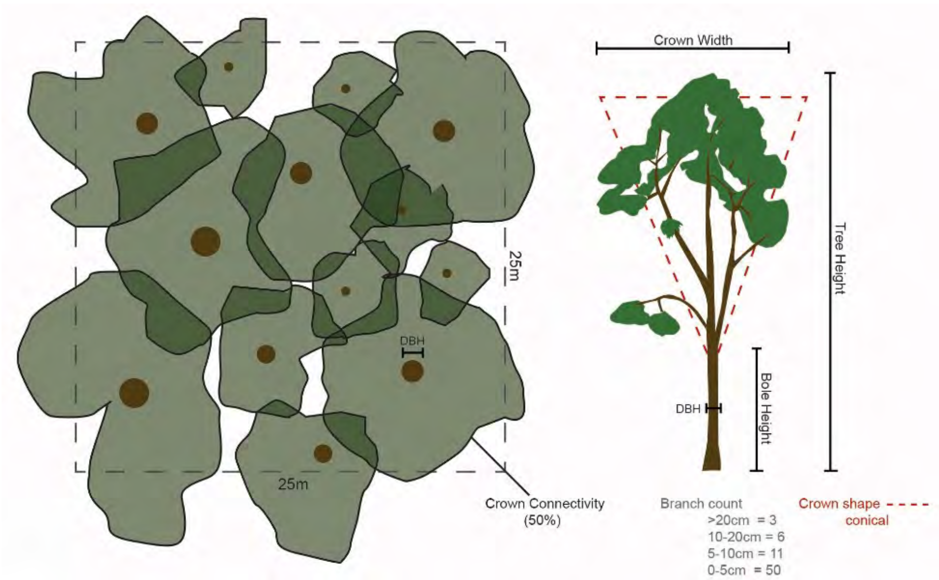


Figure 4. Illustrative diagram of vegetation plot measurements

Objective 2. Determine microclimate and soil characteristics across varying levels of degradation and land-types.

Method 2a. Microclimate: 42 data loggers, recording temperature and luminosity, have been placed in the canopies of multiple trees (n=17) throughout the community-scale area. Together with M1b, these will measure the effects of forest structure on microclimate. 10 microclimate data loggers will be used to record similar data in 4-day vegetation studies at 10 sites (400 data logger days) across the Landscape-scale area.

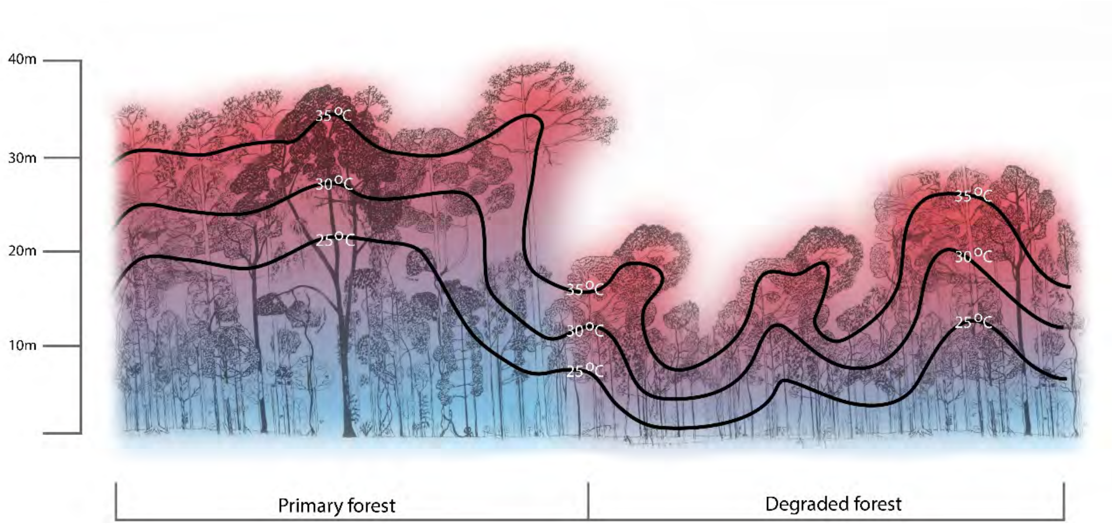


Figure 5. Illustrative hypothesis of the effect of forest degradation on microclimate

Method 2b. Soil:  pH measurements have been taken at every vegetation plot (both community and landscape scales) to determine how soil conditions correlate with forest structure variation and primate densities. 300 pH values taken to-date.

Objective 3. Determine variation in primate densities, ranging and behaviour relative to forest characteristics (as measured in O1 and O2) and soil-based geological surveys (O3) (Wich et al., 2004).

Method 3a. Passive auditory surveys: using Spatially-Explicit Capture-Recapture (SECR) methods and traditional point sampling methods, the origins of primate early morning vocalisations have beeen triangulated and their frequency and detection distance used to calculate population density based on 4-day auditory surveys across the landscape-scale site. Additionally, primate calls have been recorded with specialist long-range audio equipment to enable the statistical analysis of vocalisations, allowing the individuality of primate calls to be assessed and home-ranges of individual groups to be estimated.

Method 3b. Behavioural data: All-day follows of orangutans and siamang will be conducted in the next field phase within the community-scale site, recording ‘coarse-grain’ activity states and location of primate behaviours, which can then be interpreted in terms of ecological variables

Objective 4. Data from Objective1-3 will be combined to show how differences in forest structure affects microclimate, soil moisture and pH values and, in turn, primate species spatial distribution, densities, behaviour and habitat use. These data will be used to develop a predictive model simulating how the primate community within the lowland Leuser Ecosystem will be affected by further forest degradation and future climate change. This will aid in the development of targeted conservation plans.

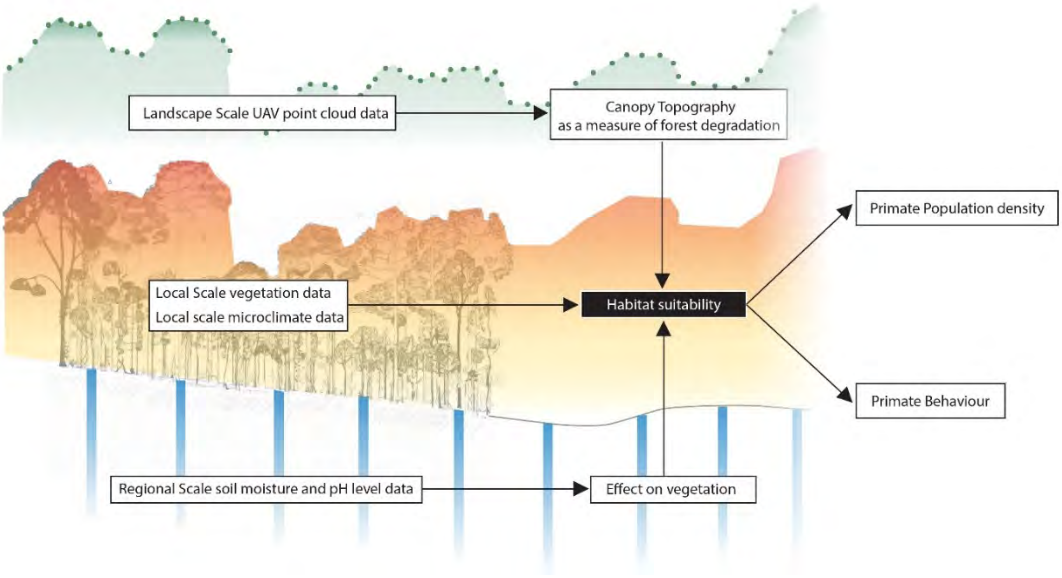


Figure 6. Flow diagram of data collection regime

Between March 2016 and August 2016 I have collected data for Objective 1, Objective 2, and Objective 3 within both community and landscape-scale studies within the Leuser Ecosystem, Northern Sumatra. Primate ranging and behavioural data (Objective 3) will be supplemented by data collected by collaborators, the Sumatran Orangutan Conservation Programme (SOCP) and other LEAP researchers. The second phase of fieldwork, spanning 2017, will build upon the established methodological framework from the first phase, resolving uncompleted data sets from Objective 1, 2, 3, and 4.

**Results to date**

**Community Scale behavioural study**

To investigate the ability of UAV data and microclimate dataloggers to measure the synergistic effects of canopy structure on climate and its impact on arboreal wildlife, these technologies were used in conjunction with long-term behavioural recordings of Sumatran orangutans (*Pongo abelii*) in the Gunlung Leuser National Park, Northern Sumatra. Sumatran orangutans are large-bodied, predominately arboreal and mainly solitary (Fleagle, 2013). As the largest arboreal mammal, canopy structure is of primary importance in their continued survival, enabling them to locomote to obtain food resources, reach sleep sites, and avoid predation (Morrogh-Bernard et al., 2009). Similarly, as arboreal large bodied mammals, orangutans are sensitive to fluctuations in temperature. Travel in high temperatures and direct sunlight increases energetic expenditure (Levesque et al., 2016) and increases the secretion of sweat (King and Farner., 1961), which may in turn limit which areas of forest orangutans utilise at the hottest part of the day, effectively reducing daily range size over in the long term.

**Orangutan behavioural data**

10 orangutans were habituated and systemically followed between 2007 and 2016, their behaviours recorded using scan samples every 15 min (Altman, 1974) during which their locations were recorded using GPS units (Garmin GPSMap 60CSx, 62, 62s). Behavioural follows took place between 6am and 7pm. For this study, behavioural data between 2014 and 2015 were used and behaviours were classified as either “active” or “passive”. “Active” behaviours were classified as behaviours in which focal animals were engaged in an activity which required movement, such as locomotion, feeding and foraging. Behaviours were classified as “Passive” if they did not require movement and included resting, sleeping, and social contact with an infant. We overlaid a 25 m x 25m grid upon the 600ha study site and counted the number of ‘active’ or ‘passive’ behaviours that occurred within each cell, as well as the hour at which they occurred.

**Data analysis**

Using multiple linear regression, readings from data loggers were compared with their position and the characteristics of the individual tree in which they were placed and the surrounding vegetation plot. Mean values of tree variables (DBH, Height, etc.) were used as vegetation plot variables in statistical analysis. Similarly, variables produced from three-dimensional canopy mapping using UAVs were compared with data logger readings using multiple linear regressions. Orangutan behavioural data was processed using the GPS locations of behaviours and the times in which they occurred. These were then plotted as the sum of behaviours, active or passive and the time of their occurrence, that fell within each quadrat, ultimately displaying the sum of behaviours, active or passive, that occurred in each quadrat over a 12-month period.

**Temperature and vegetation**

To establish if a relationship existed between vegetation variables and mean temperature, multiple linear regression tests were used to compare plot level vegetation characteristics to mean temperatures recorded by data loggers collected over a 4-month period, including all time periods. Multiple linear regression showed that single tree vegetation variables (variables of the tree in which the data logger was placed; logger height from canopy, DBH, connectivity) were significant in determining 47% of the data variability of mean temperature recordings (n=39, $R^2$ =0.467, p=<0.001). Logger height alone accounted for 34% of the variation in mean temperatures (n= 39, $R^2$ = 0.339, p=<0.001). Plot wide vegetation variables (logger height from canopy, mean DBH, mean tree height, Moristia's index, canopy density) accounted for 51% of data variability of mean temperature (n=39, $R^2$ =0.513, p=<0.001). To explore the relationship between vegetation variables captured using UAVs, variables for each quadrat in which a data logger was placed were extracted from UAV data. Logger height from canopy, maximum elevation subtracting the mean elevation, standard deviation of elevation and relative elevation with neighbouring cells (5x5) accounted for 60% of the variation in mean temperature measured by data loggers (n=39, $R^2$= 0.598, p =<0.001) (Table 1). Comparing vegetation characteristics as measured by UAVs of the sites in which vegetation plots took place (n=39) with relative use by orangutans displayed a trend, but was not statistically significant (n=39, $R^2$=0.373, p=0.065). Given that temperatures varied during the time of day, mean temperatures for three hour periods (5am-7am, 8am-10am, 11am-1pm, 2pm-4pm, 5pm-7pm) were compared to each form of vegetation variables (individual tree variables, vegetation plot variables, UAV variables) (Table 1). UAV variables were found to be the most accurate predictor of microclimate measurements across the most time periods.

| | Mean Temperature | | 5am-7am mean temps | | 8am-10am mean temps | | 11am-1pm mean temps | | 2pm-4pm mean temps | | 5pm-7pm mean temps | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27.83 ± 0.55 | | 24.15 ± 0.58 | | 29.43 ± 1.86 | | 33.28 ± 1.41 | | 32.68 ± 1.26 | | 28.19 ± 0.32 | |
| | $R^2$ | p | $R^2$ | p | $R^2$ | p | $R^2$ | p | $R^2$ | p | $R^2$ | p |
| Ind. Tree variables | 0.467 | <0.001 | 0.122 | 0.202 | 0.250 | 0.017 | 0.431 | <0.001 | 0.305 | 0.005 | 0.212 | 0.037 |
| Veg plot variables | 0.513 | <0.001 | 0.069 | 0.783 | 0.327 | 0.018 | 0.550 | <0.001 | 0.473 | 0.001 | 0.278 | 0.047 |
| UAV variables | 0.598 | <0.001 | 0.200 | 0.175 | 0.541 | <0.001 | 0.421 | 0.002 | 0.366 | 0.008 | 0.422 | 0.002 |

Table 1. Results of multiple linear regression comparing mean microclimate temperatures with differing methods of vegetation surveys, most accurate form of measurements highlighted

Given that UAV variables strongly correlated with microclimate, microclimate temperatures could be modelled throughout the range of UAV data collection using equations produced by the results of multiple linear regression. Temperatures were modelled as means of each three-hour period (5am-7am, 8am-10am, 11am-1pm, 2pm-4pm, 5pm-7pm) giving the mean temperatures of all areas covered by UAV data over a 5-month period at various distances from canopy top.

Using the equations produced by general linear models, modelled mean temperatures for all areas covered by UAV flights were produced for two-hour time periods. When compared the accuracy of these equations with actual data logger readings;

| | **5am -7am** | **8am - 10am** | **11am - 1pm** | **2pm - 4pm** | **5pm - 7pm** |
|---|---|---|---|---|---|
| Data Loggers Max. Temp. | 27.56 | 35.44 | 36.07 | 35.80 | 28.98 |
| Data Loggers Mean Temp. | 24.16 | 29.34 | 33.28 | 32.68 | 28.19 |
| Data Loggers Min. Temp. | 23.81 | 25.84 | 29.63 | 29.55 | 27.39 |
| Data Loggers Temp. Range | 3.75 | 9.61 | 6.44 | 6.25 | 1.59 |
| Modelled Max. Temp. | 24.84 | 32.79 | 35.28 | 34.44 | 28.62 |
| Modelled Mean Temp. | 24.16 | 29.41 | 33.25 | 32.69 | 28.20 |
| Modelled Min. Temp. | 23.70 | 26.86 | 31.17 | 30.81 | 27.69 |
| Modelled Temp. Range. | 1.14 | 5.93 | 4.11 | 3.63 | 0.93 |
| $R^2$ of MLR | 0.20 | 0.54 | 0.42 | 0.37 | 0.42 |
| Root Mean Square Error | 0.53 | 1.29 | 1.03 | 0.88 | 0.25 |

Table 2. detailing comparisons of recorded microclimate temperatures and modelled microclimate temperatures

This produced site-wide temperature maps which could be compared with orangutan behavioural data (Fig 7).

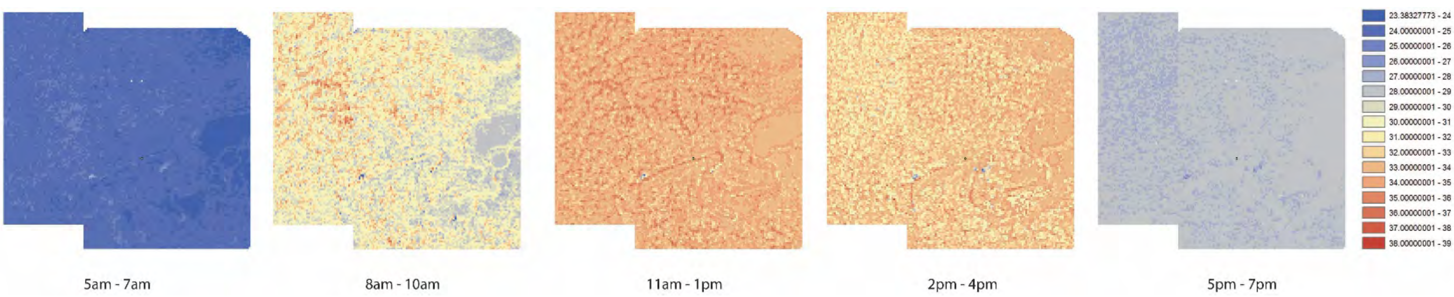


Figure 7. Temperature maps of modelled microclimate data loggers at seven meters height

No clear statistical relationship between orangutan behavioural data and modelled microclimate was apparent (n= 2904, $R^2$=0.02, p = <0.001). However, quadrats used by orangutans at specific time periods showed a trend for avoiding areas of high canopy rugosity during periods when temperatures are highest (Fig 8). Median vegetation values ("UAV Range") for quadrats used by orangutans during the hottest hours of the day (12pm-2pm) are significantly lower than those used (Mann-Whitney U test, Z = 5.329, p =>0.05, n = 12).

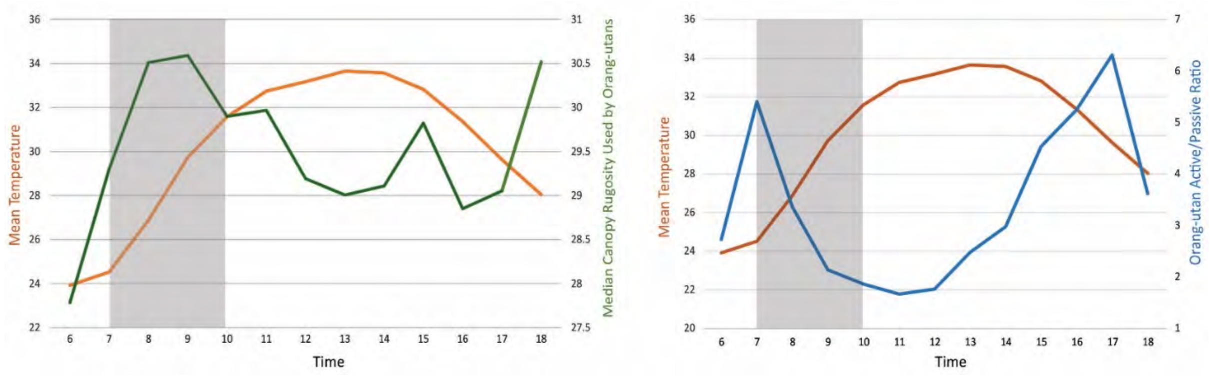


Figure 8. Line graphs displaying mean temperature across hourly time periods compared to median canopy rugosity used by orangutans and orangutan ratio of active and passive behaviours

This initial analysis of orangutan behavioural shows that 'active' behaviours occur in areas with high canopy rugosity early and late in the day, when temperatures are low, and 'passive' behaviours occur in areas of low canopy rugosity during parts of the day which are the temperature is high. This suggests that orangutans avoid areas that would involve greater energetic costs due to greater variation in height during the hottest times of the day. This shows orangutans are sensitive to microclimate differences produced by vegetation structure variability, a product of selective logging . Rising global temperatures may affect ranging and behaviours of orangutans inhabiting degraded forests, possibly pushing them toward more crepuscular activity patterns.

**In Progress**

Addtional data collection from the community scale area (soil pH values, population density of siamang, gibbon and langur species) have been collected, but have yet to be analysised fully.

Additional UAV flights will be conducted in April 2017 to provide greater detail on the 3-dimensional vegetation structure of both the community scale and landscape scale study areas, allowing more precise modelling of microclimates.

Data in the landscape scale area has been collected (population densities of siamng, gibbon and langur sepecies, vegetation surveys, soil pH surveys) but has yet to be analysed fully.

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