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Use of Drone-Based Technology for Javan Slow Loris (*Nycticebus javanicus*) 3D Habitat Modeling

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Introduction

Globally, human land modification poses one of the largest threats to the survival of primates (Estrada et al., 2017; Galan-Acedo et al., 2019). Although habitat modification has clear impacts on primate populations, such as loss of food resources and fragmentation, it can also have subtle but equally important impacts on the remaining vegetation. Following anthropogenic land modification, vegetation typically becomes structurally simpler, and plant diversity decreases with increasing human impact (Irwin et al., 2010; Bolt et al., 2018). Disturbance can also lead to the encroachment of invasive plant species, which reduces species richness (Mukaromah & Imron, 2020). It is well documented that changes in forest structure impact primates, but responses are often species-specific and related to the type of disturbance (Chapman et al., 2010). Even in undisturbed forests, structure and composition is rarely uniform, and primate habitat use and movement patterns correlate with different attributes (McLean et al., 2016). Given that many primate species exist in a mosaic of habitat types, understanding species-specific flexibility in what structural features support habitat use will be key for understanding how species may persist in light of increasing human land modification and guide both habitat conservation priorities and restoration targets.

Characterizing forest structural variables has traditionally been a time consuming, expensive, and challenging endeavor (Zhang et al., 2016). Remote-sensing via unmanned aerial vehicles (UAVs or drones) offers an appealing alternative because it is more cost effective and can capture a degree of resolution that cannot be achieved via ground surveys or satellite imagery (Koh & Wich, 2012; Wich et al., 2016). Furthermore, LiDAR is a technology that can be mounted on a drone and, unlike satellite imaging, can penetrate the forest canopy and accurately map the canopy and subcanopy in 3D (Lefsky et al., 2002; Vierling et al., 2008). Studies investigating primate behavioral correlates with LiDAR metrics identified previously unknown relationships between habitat structural characteristics and habitat utilization (Palminteri et al., 2012; Singh et al., 2018; McLean et al., 2016; Davies et al., 2019).

The Javan slow loris (*Nycticebus javanicus)* is a Critically Endangered and strictly arboreal nocturnal primate that relies on canopy connectivity to move through the landscape (Nekaris et al., 2014). Endemic to Java (Indonesia), this island also has a large human population and historic deforestation rates, modifying *N. javanicus* habitat into a mosaic (Nekaris & Nijman, 2015). While forest-dependent, this species exhibits habitat flexibility by utilizing human modified landscapes adjacent to forest habitats (Nekaris et al., 2017; Sari et al., 2020) and ranging at higher altitudes than previously observed, altitudes previously thought to be impossible to due to low temperatures (Nekaris, personal communication; Reinhardt et al., 2016). Given the striking compositional differences between these habitats, it is important to understand how *N. javanicus* is utilizing these spaces. Therefore, this study proposed to use UAV (a DJI Phantom 4 V2.0 drone) and LiDAR aerial imagery to generate detailed and 3D habitat data of Cipaganti, West Java across these diverse *N. javanicus* habitats. Imagery will be joined with GPS data from two years of noninvasive focal follows to better understand the structural characteristics facilitate slow loris space use. Determining the consistency or variability between selected features will illuminate the extent of this species' flexibility and ability to persist within diverse habitats.

Original Aims

The original aims of this study proposed to identify the habitat structural characteristics that are associated with *N. javanicus* space use across the gradient of their habitat:
Aim 1: Low altitude forests compared to human modified landscapes.
Aim 2: Low altitude forests compared to the higher altitude forests that they are now known to utilize.

Unfortunately, we cannot characterize habitat structural characteristics because we could not complete the LiDAR survey portion of this study (please see the section on Problems Encountered for more details). However, we were able to collect high-resolution photographs for habitat maps using a DJI Phantom 4 V2.0 drone, and this study is pivoting to now have the revised aims:

Revised Aims

We will characterize slow loris space use based on land-cover land-use types that will be defined from the high-resolution images collected during the DJI Phantom drone surveys of loris home ranges, with the following specific aims.
Aim 1: (a) How does the land-cover composition vary across *N. javanicus* habitats, and (b) how does the characterization of land-cover in *N. javanicus* habitats differ between satellite imagery and drone imagery?
Aim 2: How does *N. javanicus* habitat use differ based on land-cover types?

Methods

Study Site & Species

This research was conducted at the Little Fireface Project (LFP) research station in the Garut District of West Java, Indonesia. LFP is a multi-disciplinary conservation-based research project under Oxford Brookes University focused on the ecology and conservation *of N. javanicus* and remains the longest running study of any loris species. *N. javanicus* is one of the 25 most endangered primate species and faces threats from habitat loss and high popularity in the pet trade (Mittermeier et al., 2022). This study utilized the preceding year (2022-2023) of behavioral and ranging data collected by LFP during nightly focal follows, six days a week. GPS points and behavioral data are collected every 5 minutes with notable events collected opportunistically.

Drone Surveys

Eight surveys were conducted July-August 2023 over known home ranges of nine family groups of lorises studied by LFP, two of which heavily overlap (**Figure 1**). Prior to drone surveys, ground control point (GCP) coordinates were marked and recorded across the study area to ensure that the locations of the drone imagery were properly recorded (Martinez-Carricondo et al., 2020). GCP coordinates were recorded with an Emlid Reach GPS unit in the WGS 84 / UTM Zone 48S reference system. Drone surveys to collect photographs for habitat maps were conducted using a DJI Phantom 4 V2.0 drone. This drone was flown via pre-programmed flight paths using the Drone Deploy iPad app that maximizes flight route (Koh & Wich, 2012). The survey area was approximately 80 hectares, which is the cumulative home range of the LFP lorises' and was conducted over three weeks. The drone was flown 70-80 meters above the ground, which is low enough to capture a high level of spatial resolution but high enough to minimize disturbance to animals (Koh & Wich, 2012; Semel et al., 2020). Permission was granted from the local Kantor Desa to fly the drones over the village of Cipaganti.

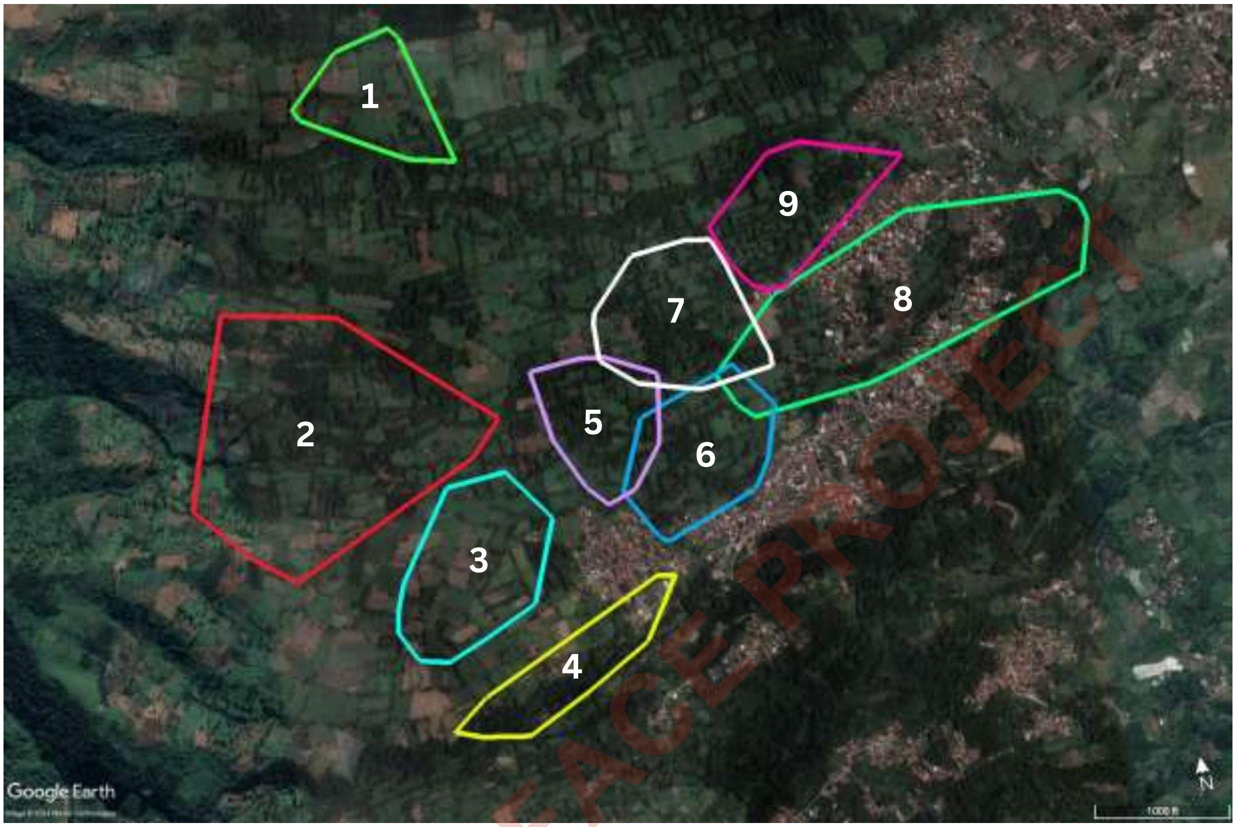

Figure 1. Survey area with loris family group home ranges which were the areas surveyed by the drone represented via polygons in Cipaganti, West Java.

Drone Data Processing

Aerial imagery from the phantom drone surveys was processed in AgiSoft Metashape. GCP coordinates were manually entered, identified in the software, and then the software aligned the images to create an image of the landscape. These maps were imported into a software called Catalyst where the land-cover types present in the imagery were classified using object-based image analyses. Land-cover types were "dot crops" (coffee, tea), "row crops" (chilies, tomatoes, cabbages), labu (*Sechium edule*), developed (e.g., houses, etc.), and forest patches.

Loris Space Use

LFP's long-term behavioral data from the last year from 2022-2023 was used for nine family groups. Estimates of home range size and habitat utilization were calculated for each group using the minimum convex polygon function in ArcGIS which is an estimate of total space use. Within ArcGIS, these home range estimates were mapped onto our classified land-cover maps to relate loris space use to habitat type.

Results

Eight areas were surveyed across the study site that are used by nine loris family groups two of which heavily overlap, resulting in eight high-resolution orthomoasic maps (**Figure 2**). The resolution of these maps ranges from 5 centimeters per pixel to 7 inches per pixel depending on how high the drone needed to be flown and changes in the landscape elevation. These maps were then classified into land-cover types, with labu, forest patches, and row crops (chilies, tomatoes, cabbages) being the most prevalent land-cover types (**Figure 3**). These surveyed areas were then trimmed down to represent only the 100% minimum convex polygon home ranges of each loris group in order to determine the habitat composition (**Figure 4**). Preliminarily, many of the lorises have home ranges that are mainly comprised of forest patches, row crops, and labu, but there is variation between each group (**Figure 5**).

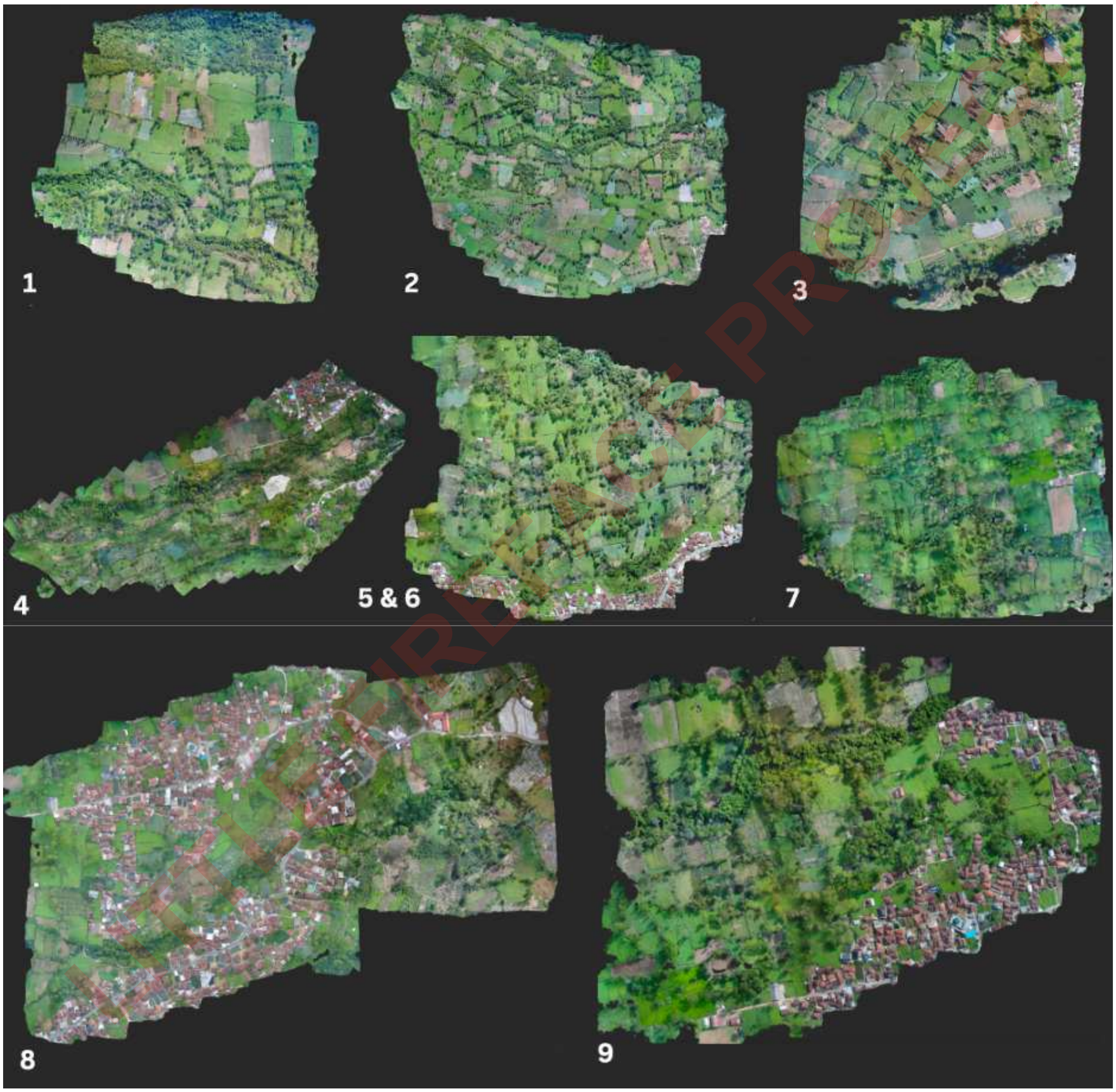

Figure 2. Imagery from the Phantom drone surveys of the loris home ranges. Image resolution ranges from 5 centimeters per pixel to 7 inches per pixel. Numbers correspond to different family groups (home ranges for groups 5 and 6 were surveyed together).

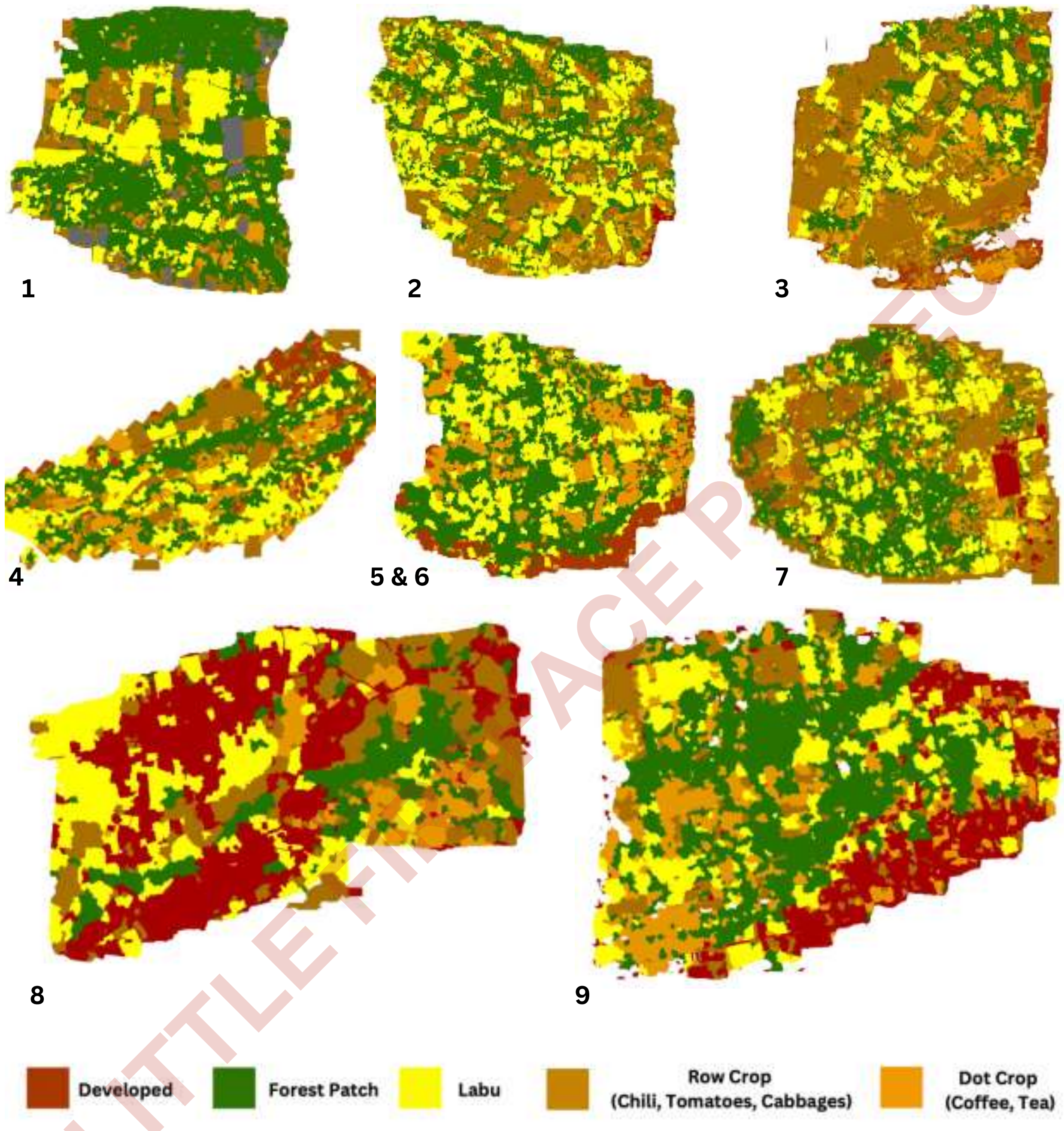

Figure 3. Classified land-cover types in survey areas. Numbers correspond to different family groups (home ranges for groups 5 and 6 were surveyed together).

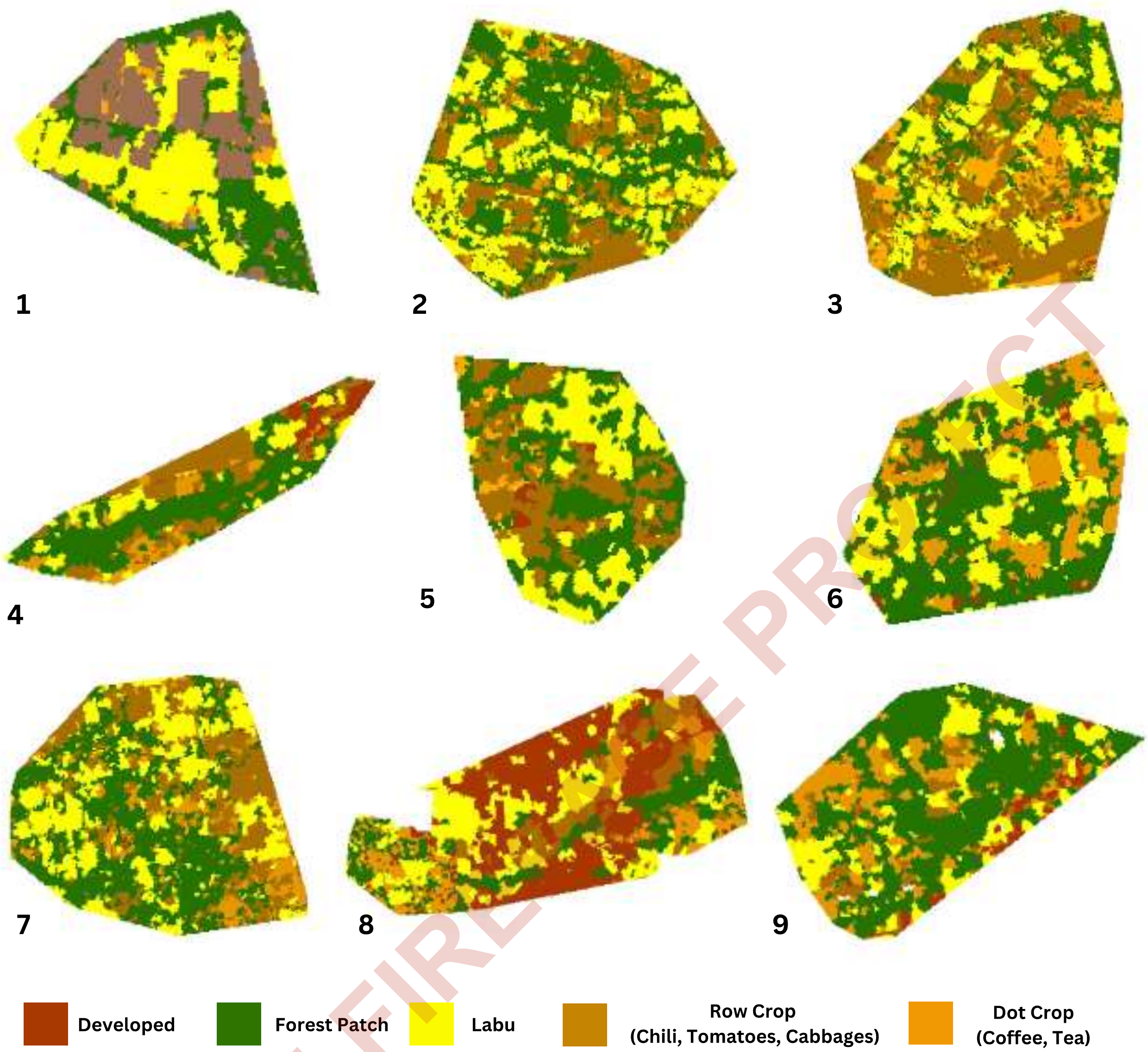

Figure 4. Classified land-cover types in the 100% minimum convex polygon home ranges of *N. javanicus*.

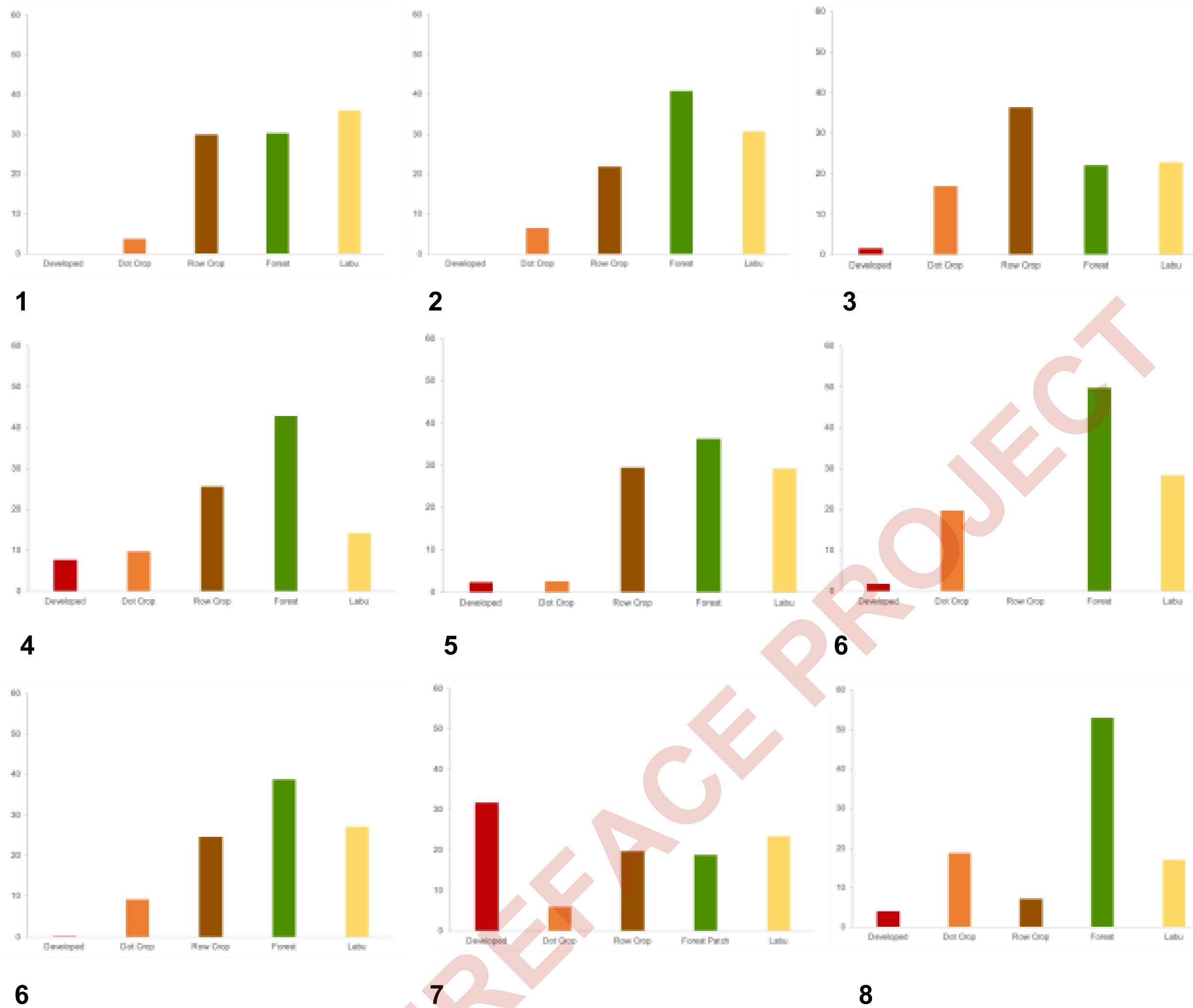

Figure 5. Bar graphs representing the percentage of land-cover types present in each *N. javanicus* 100% home range.

Conclusions

The high resolution of the imagery taken with these drones allowed for finely classifying the home ranges of these lorises. Lorises are found across a diversity of habitats that vary in percentage of land-cover land-use classes, but there appears to be a preference for having home ranges comprised of mostly forest patches, row crops, and labu. This habitat selection is consistent with this species being strictly arboreal. Additionally, classification of labu is critical because *N. javanicus* can utilize areas where labu is present due to this crop being grown on an elevated trellis system, enabling this species to persist in extensively human-modified landscapes. These preliminary trends will be explored in future work to better understand the ecological flexibility of these species when it comes to habitat selection. In addition to the scientific benefits of detailing this species habitat selection, the improved classification, and aerial imagery of these areas, can aid the Little Fireface Project in their conversation planning.

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