How do spider monkeys (*Ateles geoffroyi*) modify their environment? Are they the gardeners of Mexican forests?

Eduardo Jose Pinel Ramos

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Universidad Veracruzana
Instituto de Neuroetología

1. Summary

Habitat loss as a result of deforestation is one of the main threats to biodiversity worldwide. In the case of non-human primates, 60% of the species are under some category of threat, mainly due to the loss of their habitats. The Yucatan Peninsula is one of the regions with the highest rates of deforestation in Mexico. This deforestation may be permanent, for instance, due the construction of human infrastructure (i.e., roads, housing, hotels), while in other cases deforestation is temporary. When deforested lands (i.e., areas used for slash and burn agriculture, and logging), are abandoned a process of forest regeneration can take place through the process of secondary succession. As regenerating forests age, they enter into different stages of succession, which differ in their importance for local primates populations depending on whether the animals can temporarily or permanently use the resources that these forests offer them. Geoffroy's spider monkey (*Ateles geoffroyi*) is listed as Endangered on the IUCN red list and one of the 25 most endangered primate species mainly due to habitat loss throughout its geographical distribution. Regenerating forests in different stages of succession are the most abundant land-cover type within the geographical distribution of Geoffroy's spider monkeys, however, there is very limited information on the use or importance of these types of forests for the maintenance of their populations. Therefore, the objective of my research was to evaluate the use of regenerating forests in different stages of succession by spider monkeys in the Yucatan Peninsula. In order to fulfill this objective, I first developed a land-cover map of the study area using the supervised classification method. Within the land cover map, I classified the following land-cover categories: 1) water bodies; 2) human infrastructure (i.e., roads, cities); 3) agricultural or cattle ranching areas; 4) early (0-15 years of age); 5) medium (16-29 years) and 6) late regenerating forests (30-50 years); and 7) mature forests (> 50 years). Once the land-cover map was completed, I selected 15 5-ha sampling sites in each of the 4 forest categories used (n=60 sampling sites) to conduct spider monkeys surveys. I carried out spider monkeys surveys through flights with a drone equipped with a high-resolution RGB camera. In order to define the flight parameters and to evaluate the detectability of spider monkeys at the time of the flights, I performed a pilot study. The pilot study results showed that spider monkeys can be detected and correctly identified from drone flights performed at a maximum height of 50m above ground level, at

a speed of 2 m/s, and with the drone's RGB camera located at an angle of -90°. Based on these results, I designed and carried out data collection flights to determine spider monkey presence in different stages of succession at 56 of the 60 sampling sites. Data collection is ongoing. I will submit the final results of my research for publication in scientific journals and I will share them with the local communities in which the research is being conducted to help generate knowledge and consciousness about the importance of spider monkey conservation in the area. On a broader scale, the final results of this project will allow us to evaluate the importance of regenerating forests in different stages of succession for the conservation of spider monkeys and will contribute to our knowledge on the distribution of the Geoffroy's spider monkey in the Yucatan Peninsula.

2. Introduction

Primates play an important role in forest maintenance and regeneration (Heymann, 2017). However, there is limited information about the specific role they play in contributing to the floristic composition of regenerating forests in different successional stages. Due to anthropogenic activities, human-modified landscapes, where mature forest patches are surrounded by regenerating forests, croplands, and cattle pastures, are increasingly common. Although regenerating forest is the most common land-cover type inside human-modified landscapes (Arroyo-Rodríguez et al., 2017), there is still little information about its use by primates (Chapman et al., 2020). In many Neotropical forests, primates contribute the highest biomass of frugivorous species, providing vital ecosystem services through seed dispersal (Terborgh, 1992). Primates help in seedling redistribution, dispersing seeds far from their parent plant, thereby increasing their probability of survival (Chapman, 1995). It is important to understand how spider monkeys use modified ecosystems and contribute to forest regeneration, because their local extinction will likely generate an ecological imbalance (Gardner et al., 2019).

Geoffroy's spider monkeys (*Ateles geoffroyi*) are one of the three primate species present in Mexico. They belong to the Atelidae family and range from the south of Mexico to Panamá (Cortes-Ortíz et al., 2021). Throughout the distribution, their populations are significantly decreasing because of deforestation, fragmentation, and forest degradation (Ramos-Fernández & Wallace, 2008). This is particularly the case in the Yucatan Peninsula, where the state of Quintana Roo presents an annual forest loss of 11,300 ha, mainly due to a rapidly expanding tourism industry, subsistence agriculture, and land conversion for livestock agriculture (Ellis et al., 2017). As spider monkeys are large-bodied and charismatic species, they are highly valued as pets (Duarte-Quiroga & Estrada, 2003). Their highly frugivorous diet (fruits represent more than 70% of their diet; González-Zamora et al., 2009), low reproduction rates (long inter-birth intervals and gestation periods: Shimooka et al., 2010), and large home ranges (Ramos-Fernandez et al., 2013) make it difficult for their populations to recover in the short and long term when faced with these threats (Ramos-Fernandez and Wallace, 2008). This species is currently listed as Endangered on the IUCN Red List of Threatened Species (Cortés-Ortiz *et al.*, 2021) and is one of the world's 25 most endangered primate species (Méndez-Carvajal et al., 2019). The aforementioned characteristics and their threat status make Geoffroy´s spider monkeys one of the best study subjects for understanding the dynamics of forest change and regeneration after anthropogenic disturbances.

The aim of this project was to determine the presence of Geoffroy's spider monkeys in regenerating forests in different stages of succession and evaluate their influence on the floristic composition of these forests in the Yucatan Peninsula, Mexico.

3. Methods

The study area is located between the municipalities of Tulum (in the state of Quintana Roo) and Chemax (in the state of Yucatan), covering an area of approximately 1,500 km^2 on both sides of the road between Tulum and Chemax (Figure 1). This area was selected because it presents the necessary conditions to support populations of spider monkeys, but no information on the presence and abundance of spider monkeys exists outside of the Flora and Fauna Protected Area of Otoch Ma'ax Yetel Kooh (Ramos-Fernández & Ayala-Orozco, 2003; Spaan et al., 2019) and from Los Arboles Tulum (a residential development where a long-term project on the behavior and ecology of spider monkeys has been carried out for over 5 years; Spaan et al., 2019). The areas adjacent to these two sites are a mixture of private properties and ejidos (communal landholdings) with no protected status and where different factors are threatening wildlife.

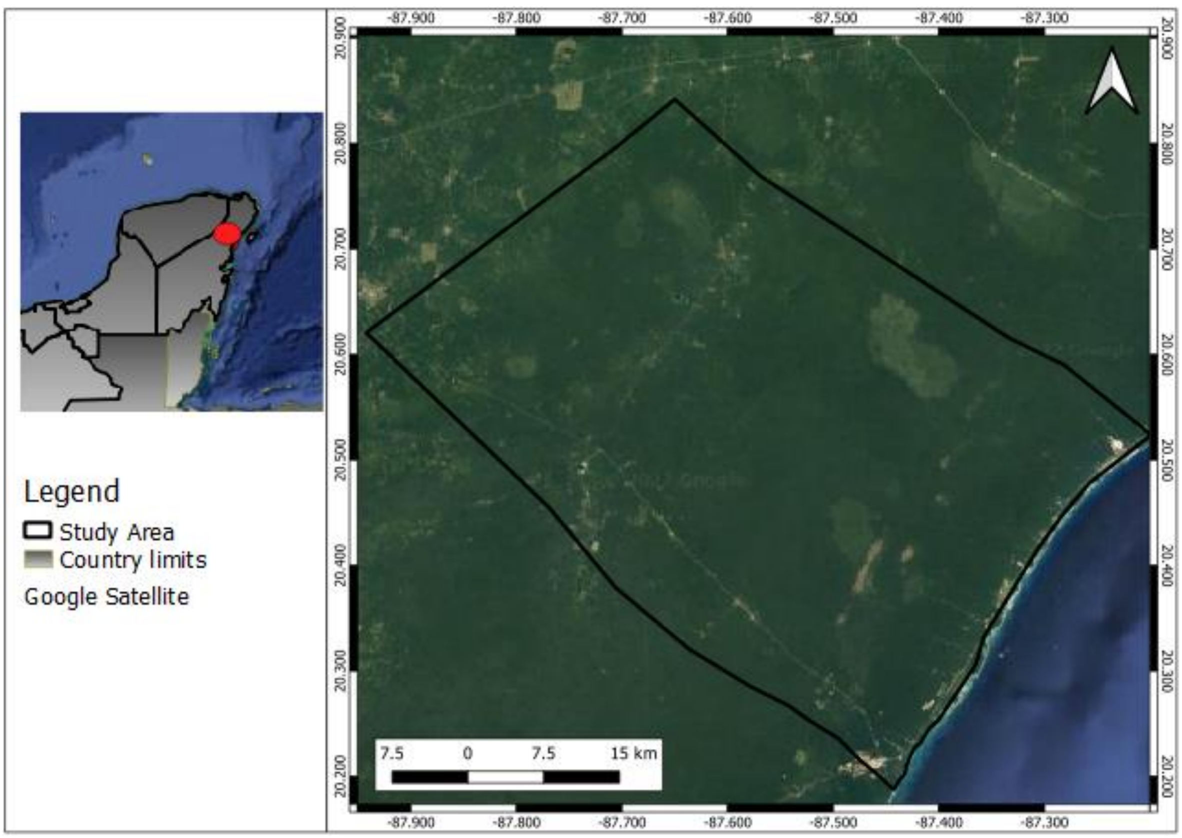

Figure 1. Location map of the study area within the Yucatan Peninsula, Mexico.

3.1 Categorization of forest and others land-cover types

I used a site-landscape approach (Brennan et al., 2002) to determine the presence of Geoffroy's spider monkeys in regenerating forests in different stages of succession and mature forests within the study area. In this approach, the response variables are measured within equally sized sampling sites at the center of each landscape, and predictor variables are measured in the surrounding landscape within a specified radius from the center of each sampling site (Figure 2; Arroyo-Rodríguez & Fahrig, 2014). In this case a landscape is defined as a heterogeneous mosaic composed of fragments of different land-cover types, both natural (i.e., vegetation types, rivers, lakes) and anthropogenic (i.e., agricultural areas, roads, cities; Urban et al., 1987).

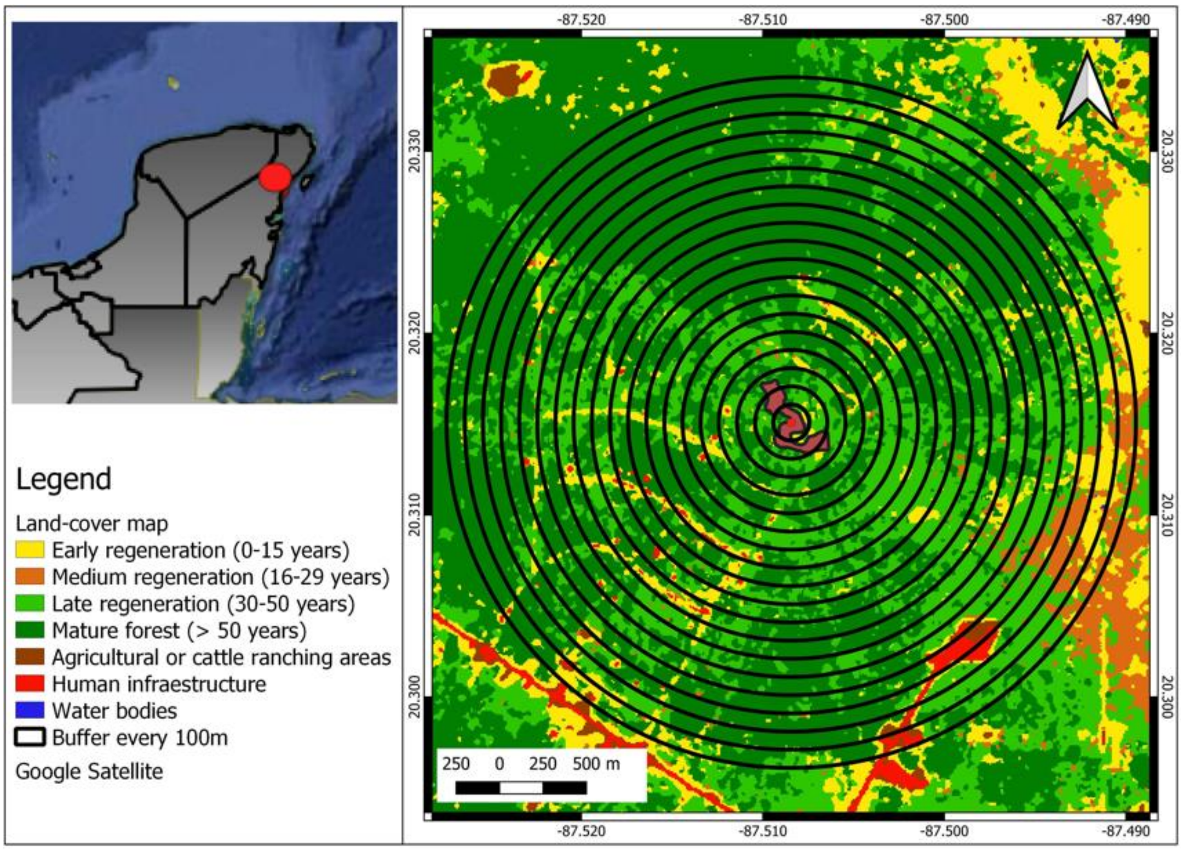

Figure 2. Example of a study landscape within the study area where the heterogeneity of land-cover types and degree of human intervention within each landscape can be observed.

I developed a land-cover map to select the different sampling sites for each of the categories of regenerating forest and mature forest within my study area. I classified the land-cover categories within each landscape as follows: 1) water bodies; 2) human infrastructure (i.e., roads, cities); 3) agricultural or cattle ranching areas; 4) early regenerating forests (0-15 years of age); 5) medium regenerating forests (16-29 years); 6) late regenerating forests (30-50 years), and 7) mature forests (> 50 years). The age-based successional stage categories of regenerating forests are based on categories used in previous studies conducted in the area where land-use history and local community knowledge were taken into account in the classification (García-Frapolli et al., 2007; Ramos-Fernandez et al., 2013; Ramos-Fernández & Ayala-Orozco, 2003). The classification of regenerating forests depending on the years that have passed since the initial disturbance is important as these differences in forest age affect tree species composition, resource availability, forest structure, and canopy height, all of which may influence their use by spider monkeys.

I developed the land-cover map in the JavaScript API Code Editor in Google Earth Engine (GEE) using high-resolution satellite imagery from the Sentinel-2 Multispectral Instrument (MSI). These satellite images have a resolution of 10 m per pixel and are open access (Abdi, 2020; Rapinel et al., 2019). I used a collection of satellite images from the 1st of January to the 31st of October 2021 to create the land-cover map. From these satellite images, I generated a mosaic (i.e., a fusion of several satellite images of the same area) and applied an atmospheric correction to use a clean satellite image without cloud cover. To generate this mosaic of cloud-free satellite images, I created a script to select the satellite images (January to October 2021), excluded their cloud pixels, filtered them by attributes, combined them, and exported the result (Helmer & Ruefenacht, 2005).

The land-cover categories were delimited using the random forest algorithm (Breiman, 2001), which is one of the most efficient machine learning algorithms for digital classification available (Pal, 2005). This algorithm consists of a large number of decision trees that work together to generate a very accurate and efficient classification when working with large volumes of data (Breiman, 2001; Prasad et al., 2006). After collecting the training points corresponding to each land-cover category, I trained the classification program to recognize the different land-cover categories. Training the algorithm involved dividing the data collected into a 70:30 ratio; 70% of the data are used to train the algorithm to recognize each land-cover category and 30% are used to test the model. The final land-cover map was corroborated in the field using a statistically representative sample of verification points. Verification points are locations that I visited in the field to verify that the categories assigned in the land-cover map corresponded to those observed in the field.

3.2 Localizing the study landscapes

During the first months of the project, part of my fieldwork involved visiting different areas to identify sampling sites to fly the drone to determine the presence of spider monkeys. Once a potential site was located, I proceeded to establish contact with the landowner (in the case of private land), with the commissioner in the case of ejidos (Ejido de Manuel Antonio and Ejido de Ruinas de Cobá; communal land holdings), or with the state organizations in charge of the management of protected areas (Tulum National Park and Otoch Ma'ax Yetel Kooh Flora and Fauna Protection Area). During this process, I met with the people responsible for the administration of each site of interest, and after explaining the project methodology and the importance of the study for the conservation of the spider monkeys, I was able to obtain permission to carry out the study in 12 locations. Within these locations, I selected 15 sampling sites for each of the following land-cover categories: early, medium, and late regenerating forests, and mature forest (n=60 sampling sites). In each sampling site, I will survey a sampling area of 5 ha. The 5-ha survey area size was selected because it is difficult to find areas of larger size that consist of only a single forest category, as a consequence of the high heterogeneity in land covers found in the Yucatan Peninsula.

3.3 Spider monkey presence in regenerating forests

To determine spider monkey presence in regenerating forests, I performed drone flights and recorded videos during these flights with an over-the-counter drone with a visual-spectrum (red-green-blue; RGB) camera. Flights were performed with a Mavic 2 Pro (SZ DJI Technology Co.) drone fitted with a 216 Hasselblad L1D-20c RGB camera. This model was selected because it features a high-resolution visual-spectrum camera, is easy to fly, and is simple to program. Drones equipped with RGB cameras have been successfully used for the detection of a wide variety of animal species, including spider monkeys *(Ateles geoffroyi)* (Kays et al., 2018; Spaan et al., 2022). All the flights in my study were performed by a team composed of a Mexican pilot and myself as co-pilot. The pilot is in charge of flying the drone while the co-pilot assists the pilot in everything, they need to successfully perform the flights. We were also accompanied by a local assistant during all visits to the sampling sites for data collection flights. The local assistant is of great importance to guide us in the forest and help us to reach the sampling sites due to the knowledge they have of the forests belonging to their community. We performed surveys in regenerating forest two times during the day (08:00 – 10:30 and 16:00 – 18:30) using the drone with an RGB camera.

Drone flights were carried out in the 5-ha sampling sites located at the center of each landscape. The 5-ha area was sampled on a single day during two consecutive flights, with each flight covering an area of approximately 2.5 ha. The flight paths were configured in Litchi Mission Hub (VC Technology Ltd) in a lawnmower pattern (Figure 3).

Figure 3. Example of the planned flight path for the RGB drone (yellow line) in a 5-ha sampling site of late regenerating forest as seen in the Litchi Mission Hub. Yellow arrows represent the flight route and the direction in which the drone will fly. The blue balloons represent the boundaries of the sampling site.

3.4 Pilot study

We performed a pilot study in Los Arboles Tulum (20°17’50” N, 87°30’59” W) to evaluate the different parameters that could influence the detectability of spider monkeys in drone

RGB footage. It is important to evaluate detectability to ensure that spider monkeys that are present in regenerating forests at the time of flights will be detected (and therefore recorded as present). As such this pilot study laid the basis for the data collection of the project.

Los Arboles Tulum (LAT) was chosen for this pilot study because a long-term study of wild spider monkeys is being conducted there, and thus information on the location of sleeping trees and areas of frequent use by spider monkeys is available. We performed 21 test flights evaluating the height and speed at which to fly the drone, as well as the angle to position the camera during the flight. The height is important because the ground sampling distance (GSD) increases as the altitude increases. The GSD is the distance between the center points of each pixel; this means that the lower the GSD value the better the accuracy of the measurement and the greater the detail of the image (Hodgson et al., 2018). In the case of my study the GSD is important because the lower the value, the easier it is to differentiate the spider monkeys in the video recorded during the flight. I evaluated the altitudes 50, 60, and 70 m above sea level (Figure 4), based on recommendations by Spaan et al. (2022).

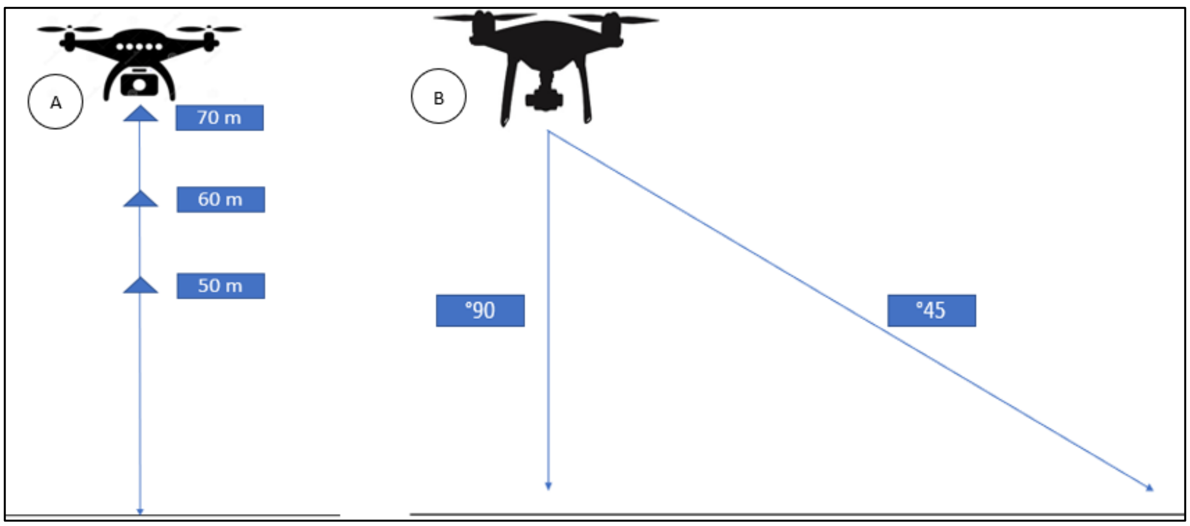

Figure 4. A) shows the 3 different heights and B) the 2 camera angles evaluated during the pilot study.

I also evaluated flight speed, because the faster the drone is flying, the more difficult it is to detect the movements of the monkeys in the videos or to distinguish them from the movement of branches caused by wind. Flight speed was tested on the first flight where the presence of spider monkeys was confirmed. In this case, I evaluated speeds of 2, 4 and 6 m/s by flying the drone (straight lines) over the location of a spider monkey subgroup at each of the three speeds. I also evaluated two camera angles (45° and 90°, Figure 4) to understand which of these two positions facilitates the detection of spider monkeys. If the camera is placed at an inclined angle to the ground (e.g., 45°) the area observed in the image will be larger (Burke et al., 2019). Once I detected monkeys in the videos, I noted down the flight parameters (height and camera angle) and the minute of the video where the monkeys were detected. Once I finished reviewing each video, I evaluated how feasible it was to detect movement or the presence of the spider monkeys in the videos recorded during the flights depending on the flight height and camera angle. In addition, I evaluated how accurately I could reliably determine that the individual or individuals detected were spider monkeys.

I evaluated different percentages of overlap and sidelap to determine which percentage would guarantee full coverage of the sampling polygon while optimizing sampling time. Overlap refers to the degree of frontal overlap between the images and sidelap is the degree of lateral overlapping between images (Elhadary et al., 2022). I performed flights with side and overlap percentages of 35%, 40%, 50% and 60%, and calculated the Dw (width of single image footprint on the ground in meters) and the distance between lines in each case (Figure 5). I performed these calculations using the Ground Distance Sampling calculator tool from the company Pix4D.

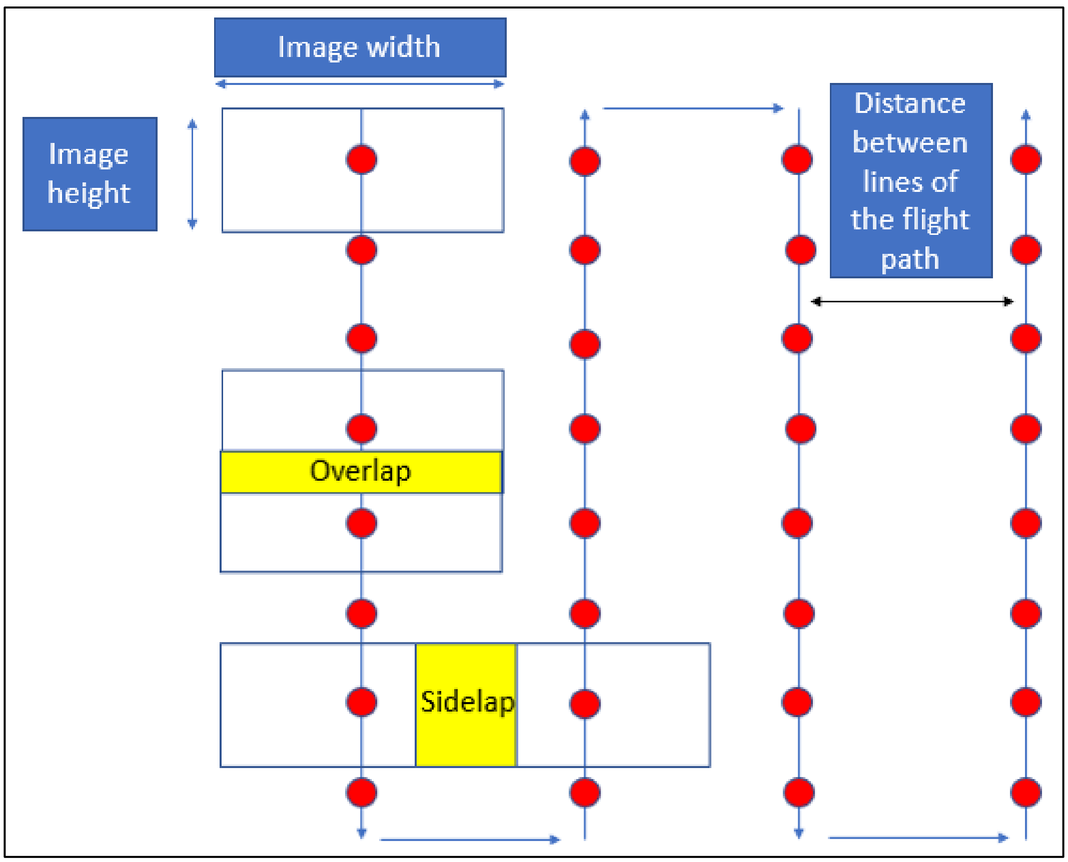

Figure 5. Diagram showing an example of the degree of overlap and sidelap as well as the height and width of the image taken during a drone flight. The red circles represent the points where the photographs are taken during the flight.

3.5 Vegetation plots

In order to assess the impact of spider monkeys on seedling and juvenile tree (saplings) species composition in each of the regenerating forest categories, I worked with a local botanist to learn to correctly determine the species used by spider monkeys. We conducted a survey of adult trees, seedlings and saplings of 10 species that are important in the spider monkey diet (Table 1). I photographed each developmental stage of the species of interest to develop a personal field guide which I will use to identify species in all sampling sites.

However, since the search for the sampling sites, the development of the land-cover map, and the development of the pilot study with the drone took longer than expected, the establishment of the mini-plots was delayed and I am still collecting the data.

Table 1. The 10 most important spider monkey feeding tree species in the Yucatan Peninsula based on a literature review (Ramos-Fernández and Ayala-Orozco, 2003; Gonzáles-Zamora et al., 2009; Chavez et al., 2012).

Species	Family	Maya name	Feeding time %
Brosimum alicastrum	Moraceae	Ramon	25
Manilkara zapota	Sapotaceae	Zapote	15
Guazuma ulmifolia	Malvaceae	Pixoy	5
Coccoloba sp.	Polygonaceae	Boob	4
Metopium brownei	Anacardiaceae	Chechen	4
Spondias mombin	Anacardiaceae	Jobo	3
Oxandra lanceolata	Annonaceae	Botox	3
Astronium graveolens	Anacardiaceae	K'ulinche'	2
Vitex gaumeri	Lamiaceae	Ya'axnik	1
Pouteria campechana	Sapotaceae	K'aniste	1

4. Results and Discussion

4.1 Categorization of forest and others land-cover types

I visited 170 verification points distributed randomly across the study area. Of the 170 verification points that I visited, 147 points were correctly assigned by the algorithm to the seven land-cover categories, resulting in an overall accuracy rate of 86.47 % (Table 2).

Table 2. Results of the verification process, including the number of correct and incorrect points for each land-cover category.

Category	Number of points	Correct points	Incorrect points	Percentage accuracy
Human infrastructure	18	18	0	100
Agricultural/ cattle ranching areas	17	14	3	82.4
Water bodies	15	12	3	80
Early regenerating forests	34	30	4	88.2
Medium regenerating forests	31	25	6	80.6
Late regenerating forests	28	23	5	82.1
Mature forest	27	25	2	92.6
Total	170	147	23	86.5

I used different values to evaluate the accuracy percentage of the final land-cover map. Overall accuracy compares how each of the pixels is classified versus the definite land-cover conditions obtained from their corresponding ground truth data. Producer accuracy is a measure of how well real-world land cover types can be classified (errors of omission), and consumer accuracy represents the likelihood of a classified pixel matching the land cover type of its corresponding real-world (errors of commission; Sari et al., 2021). The land-cover categories of "human infrastructure", "agricultural or livestock areas" and "water bodies" had the highest precision values (Table 2). These high values are a product of the conditions of the study area, since most of the area corresponds to regenerating forests and mature forests, making the characteristics of these three land-cover types easy to differentiate from other land-cover types. It is therefore logical that the accuracy values for both producer and consumer accuracy were high for these land-cover categories. The lowest consumer accuracy values were obtained for the categories that showed higher similarity in their characteristics, i.e., the four forest categories (Table 3). The overall accuracy of my land-cover map was 91%, which is a very good value and indicates that the resulting map is reliable.

The Kappa coefficient is an index of the coincidence rate that does not depend on chance; therefore, as this value increases, the accuracy of the classifications also increases (Kitada & Fukuyama, 2012). The value of the Kappa coefficient can be categorized as follows: Poor = < 0.21; Weak = 0.21 - 0.40; Moderate = 0.41 - 0.60; Good = 0.61 - 0.80; Very good = 0.81 - 1 (Kitada & Fukuyama, 2012; Rwanga et al., 2017). Many researchers have proposed that a value of > 0.8 for the Kappa coefficient is of high quality (Islami et al., 2022; Mohd Hasmadi et al., 2009; Souza et al., 2013). The Kappa coefficient accuracy for the land-cover map was 0.89. The final land-cover map of my study area obtained is shown in Figure 6.

Table 3. Consumer and Producer accuracy results for the 7 land-cover categories.

Category	**Consumer accuracy**	**Producer accuracy**
Human infrastructure	0.98	0.98
Agricultural or cattle ranching areas	0.99	0.93
Water bodies	1	0.94
Early regenerating forests	0.88	0.95
Medium regenerating forests	0.87	0.87
Late regenerating forests	0.85	0.85
Mature forest	0.83	0.86

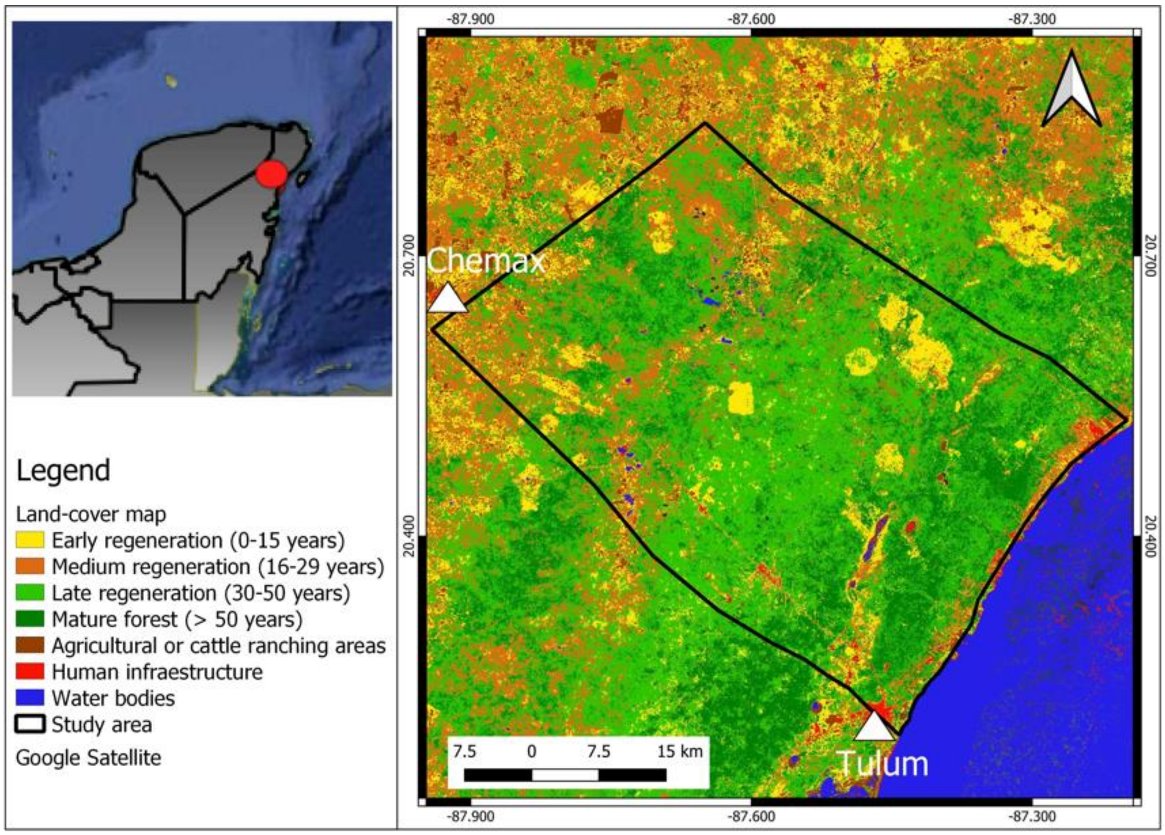

Figure 6. The final land-cover map of the study area with the seven land-cover categories developed through the supervised classification method.

4.2 Spider monkey presence in regenerating forests
4.2.1 Pilot study

We performed 21 test flights evaluating the height, speed and camera angle of the drone during the flight (Table 4). Of the 21 test flights, 16 were conducted at times when spider monkeys were known to be present in the area. Spider monkeys were detected in 7/16 flights (44% of flights) (Table 4). Although I could detect movement and even the silhouette of an animal moving in the 7 videos taken from a height of 70 and 60 m, it was more difficult to reliably determine that the individuals were spider monkeys than in the video taken from a height of 50 m (Figure 7). This observation is congruent with what was mentioned above that at lower altitudes the GSD value is lower, making it more feasible to determine that the moving individual is a spider monkey.

Table 4. Number of flights made at each altitude, camera-angle, speed, and the percentage of overlap and sidelap for each flight.

Flight height (m)	Camera Angle (°)	Flight speed (m/s)	Overlap and sidelap (%)	Number of flights	Number of flights with monkeys detected
50	90	2	40	6	2
60	90	2	40	3	1
70	90	2	40	3	2
50	45	2	40	2	1
60	90	2,4,6*	40	1	1
60	45	2	40	1	0
70	45	2	40	1	0
50	90	2	35	1	0
50	90	2	50	2	0
50	90	2	60	1	0

* All three flight speeds were evaluated during the same flight.

Figure 8. Examples of spider monkeys (in red circle) recorded from the drone at different heights from the ground. A) Spider monkey photograph taken with the drone at 50 m, B) 60 m and C) 70 m above the ground.

Flight speed: When I reviewed the video taken during this flight, I realized it was increasingly more difficult to detect the spider monkeys as the speed of the drone increased. Thus, I decided that all data-collection flights to determine spider monkey presence in different forest categories would be made at a speed of 2 m/s.

I also evaluated two camera angles (45° and 90°) to understand which of these two positions facilitates the detection of spider monkeys. If the camera is placed at an inclined angle to the ground (e.g., 45°) the instantaneous image coverage area will be larger (Burke et al., 2019). When I compare videos recorded at the same height, it was easier to detect and determine that the individuals were spider monkeys with the camera at a 90° angle than at a 45° angle (Figure 7). This is because when the video is recorded at a 90° angle, the drone is exactly over the location of the monkeys, and they appear closer and larger than when the video is recorded at 45°.

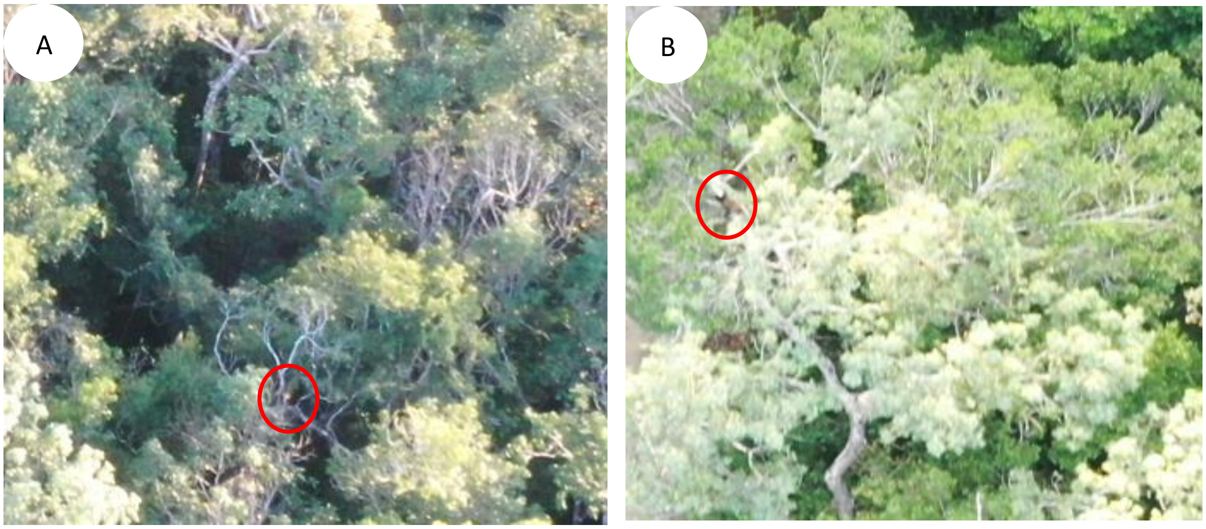

Figure 7. A) Spider monkey in red circle recorded from the drone at a height of 50m from the ground and with the camera positioned at an inclination of 45°. B) Spider monkey in red circle recorded from the drone at the same height but with the camera at a 90° angle.

I performed 5 test flights to evaluate the percentage of overlap and sidelap adequate for the execution of the flights (Table 4). From these test flights, I was able to verify that with 40% overlap and sidelap I covered the entire sampling area. Performing the flights with 40% overlap and sidelap allowed me to have a shorter flight time compared to values of 50% and 60% because as the percentage of overlap and sidelap increases, the number of flight lines that the drone needs to perform to cover the same survey area increases. I performed one flight with a 35% overlap and sidelap, but the distance between the flight lines and the DW value were very similar, so I judged it was preferable to keep a higher overlap and sidelap margin to guarantee a better probability of detection. Thus, I decided that all data-collection flights would be performed with an overlap and sidelap of 40%.

Based on the results of the pilot study, I decided that all data-collection flights would be performed as follows: overlap and sidelap would be kept constant at 40% at the canopy level, and the drone would be flown at 2.0 m/s, 50 m above ground level (0.50 centimeters/pixel ground sampling distance) and with a camera inclination of -90°.

Up to now I have conducted one flight at 56 sampling sites to determine the presence of spider monkeys with the drone equipped with an RGB camera. Of these, 15 have been conducted at sampling sites corresponding to mature forest, 15 in late regeneration forest, 14 in medium regeneration forest and 12 in low regeneration forest. I have identified 4 other sampling sites for flights. Of these, 1 site for medium and 3 for low regeneration forest. Although, I had anticipated to have completed data collection by July 2022, the construction of the land-cover map and identification of sampling locations took longer than expected and therefore data collection remains ongoing.

Full financial summary

The total funds of £1500 granted were used as follows:

ITEM	DESCRIPTION	Amount (£)
Transportation		
	Bus tickets to move around the study area (12 months)	18
Gasoline	Petrol for cars to move around the study area (12 months)	500
Field work		
Field assistant	Local assistant salary (180 days at 300 pesos per day)	932
Other		
	Covid-19 PCR test	50
Total		**1500**

The grant funds awarded by PSGB and Born Free Foundation (£1500) were used to cover the costs of public transportation and gasoline to travel between the different sampling sites (bus tickets to move around the study area: £18; gasoline for cars £500). In the budget proposed in the grant application, a larger amount had been requested for bus tickets to travel between the different sampling sites, however due to the difficulty and lack of public transportation to visit the more isolated sampling sites, I decided to buy a used car and the funds destined for the bus tickets were used to pay for the gasoline to travel between sampling sites. Additionally, I used the awarded funds to take a Covid-19 PCR test before going to the field and the purchase of masks and disinfectant gel (£50) and to pay part of the local field assistant's salary (75 days at 300 pesos per day = £932). The local assistant helped me in the field guiding me through the forest and helping me to reach the different sampling sites.

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