Evaluating the anthropogenic impact on spider monkeys (*Ateles geoffroyi*) in the inland area of the Riviera Maya, Mexico

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The Northeastern part of the Yucatan Peninsula in Mexico has recently turned into an important region to study the effects of shared habitats between humans and non-human primates. As the environment is undergoing rapid changes due to extreme expansion of the tourism industry and urbanization spreading from coastal regions (the "Riviera Maya") to the inland area, Geoffroy's spider monkeys (*Ateles geoffroyi*) are facing various forms of habitat loss, habitat fragmentation and habitat modification. My project evaluated how anthropogenic factors impact Geoffroy's spider monkeys in this high conservation priority area. Comparing the abundance and occupancy of spider monkeys between areas with different patterns of anthropogenic influence, I evaluated the impact of roads, human settlements, tourist attractions and noise pollution on spider monkey abundance. My findings can provide the basis for evidence-based recommendations from a local NGO to governmental agencies and local stakeholders for the development of effective conservation strategies in the region.

My research was conducted in a semi-evergreen, medium-height tropical forest in the inland area of the "Riviera Maya" at the Yucatan Peninsula, Mexico. The study site stretches for about 400 km^2 from a developing coastal town (Puerto Morelos, 20° 51' 13" N, 86° 53' 55" W) to a rural inland village (Leona Vicario, 20° 59' 20" N, 87° 12' 10" W) (Figure 1). In between these human settlements, a lot of tourist operators provide popular activities from ziplining to ATV tours (Figure 1).

Non-human primate surveys

Point-count sampling and passive acoustic monitoring (PAM) were used to determine the absence or presence of Geoffroy's spider monkeys during repeated surveys, which took place between August 2018 and January 2020. A total of 53 sampling locations were placed systematically in areas which showed different combinations of anthropogenic and environmental characteristics, with a gradient of human impact from pristine forest without habitat disturbances to highly human-impacted environments. Within the course of the study period, two observers conducted six point-count surveys with a waiting time of 20 minutes, leading to a total survey effort of 106 hours during the study. Additionally, six continuous sound recordings of 24 hours length were collected at each sampling location, leading to a total of 7,632 hours. Kaleidoscope Pro software was used to automatically detect spider monkey whinnies on the recordings in order to determine the absence or presence of monkeys during the survey period.

Spider monkeys were sighted during 14 point-count surveys either visually or by their vocalizations. Using PAM, we detected spider monkey whinnies 28 times on the sound recordings. In total, we detected the presence of spider monkeys at 22 out of the 53 sampling locations at least once during the study period using either method.

We calculated an average abundance of $\mu = 0.86$ [Confidence intervals (CI): 0.44, 1.69] spider monkeys per sampling location using Royle-Nichols models and an occupancy probability of $\Psi = 0.53$ [CI: 0.34, 0.69] using single-season occupancy models.

Vegetation survey

Vegetation plots were set up as a circular area of 20 m radius around each point-count centre. With the help of a knowledgeable local assistant, all trees within these plots with a diameter at breast height (DBH) greater than 20 cm were measured and identified at the species level. The density of food trees and the density of large trees (>42 cm DBH) as potential sleeping trees were then calculated. The amount of old-growth forest and regenerating forest at different stages within buffer zones around sampling locations were calculated using a map specifically created for the purpose of my study (Sentinel 2B,

December 2017, supervised classification using the maximum likelihood method). The same map was used to determine the age of the forest (in four classes, Figure 1) within the vegetation plots, which was confirmed by an expert opinion during the vegetation survey. The most common food tree species for spider monkeys found across the study site were *Manilkara zapota* and *Brosimum alicastrum.* The mean density was 124.6 trees/ha (range 7.9 – 294.4) for food trees and 22.1 trees/ha (range 0.0 – 63.6) for potential sleeping trees. Food tree density and sleeping tree density were positively correlated to the forest age class (r = 0.44, p = 0.001 and r = 0.43, p = 0.002). In 14% of all sampling locations we found regenerating forest younger than 30 years in the circular plots, in 42% it was regenerating forest between 30 and 50 years and in 44% it was old growth forest (> 50 years).

Spatial assessment of further variables

The amount of forest loss was calculated within buffer zones of 100 m, 500 m and 1000 m around each point-count centre based on available data from a project using remote sensing data to monitor global forest loss and gain from 2000 – 2018 at a high spatial resolution of 30 meters (Hansen et al., 2013; http://earthenginepartners.appspot.com/science-2013-global-forest). The mean forest loss was 3% (1052.5 m^2; range 0.0 - 13,066.0 m^2) for 100 m-buffer zones, 4% (29,953.7 m^2; range 0.0 - 179,483.0 m^2) for 500 m-buffer zones and 4% (121,522.7 m^2; range 0.0 - 812,667.0 m^2) for 1000 m-buffer zones.

I calculated he overall size of all recreational areas with low and high tourist abundance and the length of paved and unpaved roads within buffer zones. Recreational areas with low tourist abundance covered more area than recreational areas with high tourist abundance throughout all buffer zones (mean 3,299.5 m^2 versus 178.4 m^2 within 100 m-buffer zones; 38,913.6 m^2 versus 4478.2 m^2 within 500 m-buffer zones; 108,463.6 m^2 versus 20,983.1 m^2 within 1000 m-buffer zones). Unpaved roads covered more length than paved roads within 100 m-buffer zones (mean 43.3 m versus 8.7 m) and within 1000 m-buffer zones (1,313.5 m versus 932.3 m), but not within 500 m-buffer zones (443.2 m versus 454.4 m).

I calculated the Euclidean distances to small and large human settlements (>10 houses / ha) from each sampling location. The mean distance to the closest small settlement was 4.17 km and to the closest large settlement 15.11 km.

Anthropogenic noise pollution

Wildlife Acoustic SM4 recording devices were used to record the sound of the environment during six continuous 24-hour periods at each point-count location. Noise intensities were measured as the z-standardized mean Sound Pressure Levels of the 1,000 – 2,000 Hz frequency band from each recording file compared to the Sound Pressure Levels of the remaining soundscape (400 – 6,500 Hz). Values were then averaged across the six repetitions at each sampling location.

The mean anthropogenic noise intensity at my study site was z = -0.92, indicating that the noise produced by human activities creates amplitudes almost 1 SD lower than the sound of the natural environment (range: -1.33 - 0.17). Noise intensities positively correlate with the length of paved roads within buffer zones around the sampling locations ($r = 0.77$; $p < 0.001$ for 100 m buffers, $r = 0.49$; $p < 0.001$ for 500 m buffers, $r = 0.46$; $p < 0.001$ for 1000 m buffers) and show a negative correlation with the distance of both small ($r = -0.34$; $p = 0.014$) and large human settlements ($r = -0.36$; $p = 0.008$). No significant correlation was found for noise intensities with the amount of area that is covered by recreational activities within buffer zones around the sampling locations.

Conclusions

The overall few detections of monkeys during point-count surveys and during the passive acoustic monitoring across the study site suggest a low density of Geoffroy's spider monkeys in the inland area of the Riviera Maya of the Yucatan Peninsula of Mexico. Whether their density has always been low or whether it decreased within the last few years is unknown as no spider monkey surveys have been carried out in the region before my study. My preliminary results indicate that the presence of paved roads and areas for recreational activities with high tourist numbers affect the spider monkey abundance, but that these effects are not explained by the anthropogenic noise pollution.

The complete preservation of continuous mature forest as a conservation strategy might not always be a realistic approach, especially in regions where the economic benefit of

modifying natural landscapes is as great as in the inland area of the Riviera Maya. Therefore, detailed knowledge on how different types of anthropogenic disturbance impact animal populations is necessary to find ways of combining primate conservation efforts and economic interests. This study aimed to gather such detailed knowledge. Once preliminary results are confirmed, appropriate conservation strategies will be developed and recommended to ensure the viability of Geoffroy's spider monkey in the inland area of the Riviera Maya.

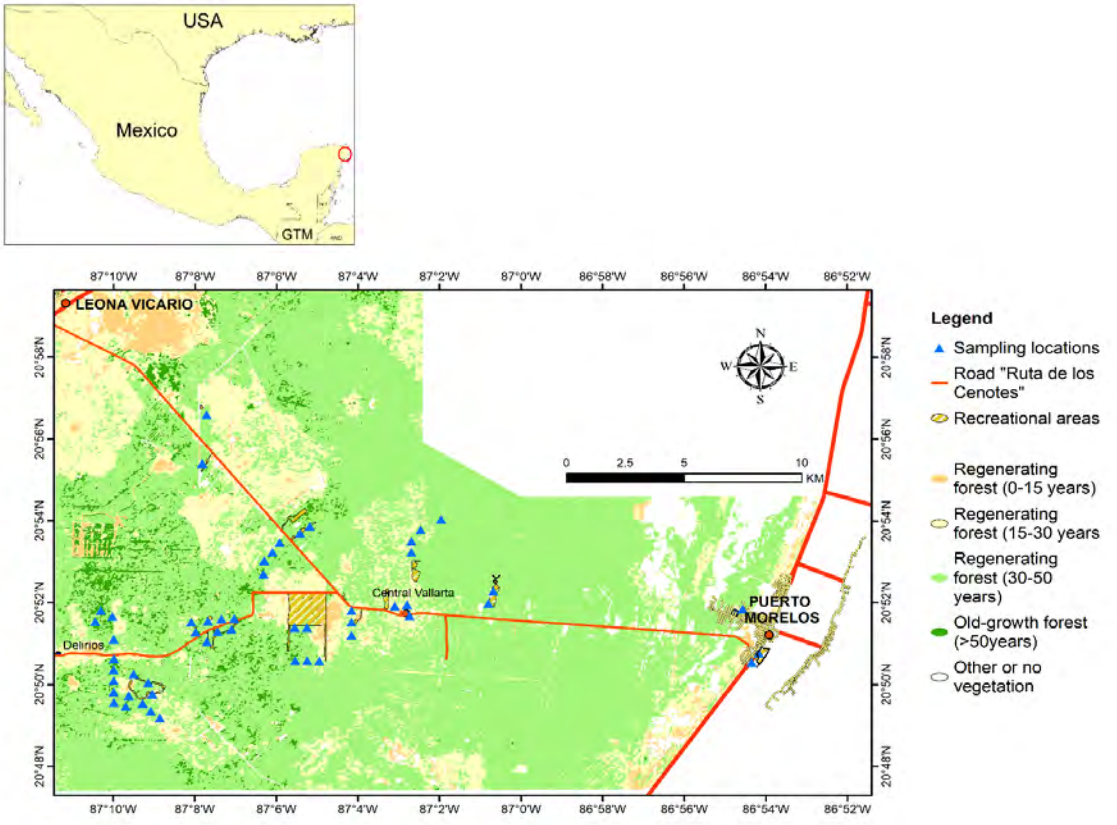

Figure 1. The study in the inland area of the Riviera Maya, Quintana Roo, Mexico. The site stretches across the municipality of Puerto Morelos between the town of Puerto Morelos and the village of Leona Vicario.

Spider monkeys live high up in the tree canopy of the tropical forests between Mexico and Bolivia. Geoffroy's spider monkey is the northernmost species of them.

The main threats to Geoffroy's spider monkeys in the Yucatan Peninsula include deforestation, forest fragmentation and forest degradation. Often, areas are clear-cut or burned for the expansion of settlements or the constructions of road.

By the use of point-count sampling and passive acoustic monitoring we estimated the occupancy and relative abundance of Geoffroy's spider monkeys in the forests of the inland area of the "Riviera Maya".

A typical forest path that would lead us to the next sampling location.

Sometimes, we would find signs of illegal activities such as hunting or logging on the way.

During the project, we came in contact with several local people who were interested in our work. Whenever I had the chance, I informed them about the conservation state of spider monkeys in the region. For example, in a lecture for a primary school or in an interview for the local radio.

Over the project period, I had the pleasure to work with many amazing people who helped me to find monkeys, identify trees, create vegetation maps and who made field work a whole lot of fun.

Thank you PSGB for supporting the conservation of Geoffroy's spider monkeys at the Yucatan Peninsula of Mexico!