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Detecting spider monkeys from the sky using a high-definition RGB camera: a rapid-assessment survey method?

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ABSTRACT

Commercial, off-the-shelf, multirotor drones are increasingly employed to survey wildlife due to their relative ease of use and ability to cover areas quicker than traditional methods. Such drones fitted with high-resolution visual spectrum (RGB) cameras are an appealing tool for wildlife biologists. However, evaluations of the application of drones with RGB cameras for monitoring large-bodied arboreal mammals are largely lacking. We aimed to assess whether Geoffroy's spider monkeys (*Ateles geoffroyi*) could be detected in RGB videos collected by drones in tropical forests. We performed 77 pre-programmed grid flights with a DJI Mavic 2 Pro drone at a height of 10m above the maximum canopy height covering 45% of a 1-hectare polygon per flight. We flew the drone directly over spider monkeys who had just been sighted from the ground, detecting monkeys in 85% of 20 detection test flights. Monkeys were detected in 17% of 18 trial flights over areas of known high relative abundance. We never detected monkeys in 39 trial flights over areas of known low relative abundance. Proportion of spider monkey detections during drone flights was lower than other commonly employed survey methods. Agreement between video-coders was high. Overall, our results suggest that with some changes in our research design, multirotor drones with RGB cameras might be a viable survey method to determine spider monkey presence in closed-canopy forest, although its applicability for rapid assessments of arboreal mammal species´ distributions seems currently unfeasible. We provide recommendations to improve survey design using drones to monitor arboreal mammal populations.

KEYWORDS: drones, conservation technology, detection, primates, aerial surveys, occupancy modelling

DECLARATIONS:

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Conflict of interest/ competing interests

The authors have no conflict of interest to declare.

Availability of data and material

The datasets generated and analyzed during the current study are included as Supplementary Material.

Code availability

Not applicable

Ethics approval

Research complied with protocols approved by the Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT: SGPA/DGVS/03005/19].

Consent to participate

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INTRODUCTION

Timely conservation action depends on accurate and precise information on species' presence (occurrence) and population density (number of individuals per km^2) across a landscape, as well as an understanding of the threats facing these populations (Buckland et al. 2015; Campbell et al. 2016). Although a wide range of methods exist to determine the presence of arboreal mammals in an area, such as recces walks, line-transect and point-transect surveys, and the use of automatic devices (camera traps and passive acoustic monitoring), these methods can be costly, time-consuming, and difficult to implement depending on the terrain, accessibility, and size of the survey area. In addition, passive acoustic monitoring is usually applied to frequently vocalizing species (Horton et al. 2015), and camera traps often need to be deployed for extended periods of time before it is possible to confirm whether a species of interest is in fact present in an area due to the low detection probability (Enari et al. 2019; Crunchant et al. 2020). As forests are rapidly being converted into other landcovers (Hansen et al. 2013), there is a clear need to explore the efficacy of other methods to rapidly survey arboreal mammal populations.

Drones are opening new avenues for the ways that bird and mammal populations can be monitored. Although research estimating population density from drone surveys is emerging (e.g., Beaver et al. 2020), the vast majority of the drone-based studies thus far have focused on determining species' presence (Linchant et al. 2015; Wich and Koh 2018; Wang et al. 2019). Drones can survey areas in a fraction of the time of other existing methods (Jiménez López and Mulero-Pázmány 2019), and observer bias (i.e., differences between observers in their ability to detect the presence of the animal of interest) can be minimized as multiple observers can review images or video footage obtained (Vermeulen et al. 2013; Martin et al. 2015; Scarpa and Piña 2019) and machine learning algorithms can be used to automatically detect species or individuals (Seymour et al. 2017; Corcoran et al. 2019, 2020; Chalmers et al., 2021). In addition, a wide variety of sensors (e.g., multispectral or hyperspectral imaging outside of the typical RBG frequency range, LiDAR, chemical imaging) can be mounted on drones to achieve particular desired research objectives (Wich and Koh 2018; Jiménez López and Mulero-Pázmány 2019).

Increasingly common sensors used for aerial surveying of animal populations are thermal infrared cameras. Thermal imagery captured from drones has been used effectively to detect and count a wide range of bird and mammal species (Chrétien et al. 2016; Kays et al. 2019; Spaan et al. 2019a; Lee et al. 2019). To increase the chance of detection, the drone is ideally flown at a time of day that ensures high contrast between the ambient temperature of the background substrate and the species of interest (Burke et al. 2019a). For arboreal species living in the tropics, this is often at night, as tree canopies heat up quickly after sunrise (Kays et al. 2019). However, national regulations may prohibit or limit flying at night, or require a license (Brunton et al. 2020), potentially reducing the time that effective flights with a thermal camera can be carried out to a few hours around sunset and sunrise (Spaan et al. 2019a). Additionally, although prices have fallen, thermal infrared cameras may still be too costly for conservation organizations operating on small budgets (Semel et al. 2020).

High-resolution visual spectrum (red-green-blue; RGB) cameras are often fitted on commercial off-the-shelf (COTS) multirotor drones. The relative ease of use and low cost of these drones makes them a potentially attractive tool for wildlife surveys (Valle and Scarton 2019; Semel et al. 2020). RGB sensors may enable the detection of large-bodied species or species living in relatively open habitats. For instance, multirotor drones with RGB cameras have been used to detect water birds (Lyons et al. 2019), ungulates (Schroeder et al. 2020), crocodiles (Ezat et al. 2018) and reptilian nests (Scarpa and Piña 2019). Studies aimed at detecting wildlife using multirotor drones with RGB cameras in closed-canopy tropical forests are lacking, but preliminary studies have been performed on large-bodied arboreal mammals (Kays et al. 2019; Semel et al. 2020).

There are several limitations for the application of commercial multirotor drones to wildlife surveys. One current limitation is the relatively short flight time associated with certain drone models (e.g., for the Mavic 2 Pro a popular and relatively low-cost COTS multirotor drone, the maximum flight time is ~31 minutes under optimal conditions). In addition, although drones with RGB cameras can be flown throughout the day to survey wildlife, glare from the sun may affect the image quality and hence limit the effectiveness of midday flights (Brunton et al. 2020). Depending on the species of interest, however, this may not be a significant limitation as many diurnal mammals, including primates, are mostly active in the early morning and late afternoon and rest around midday (Fleagle 2013). Even if flying is limited to the early morning and late afternoon, survey time may be increased compared to flying with a thermal camera in areas where regulations prevent nighttime flights, thus the use of high-resolution RGB cameras could provide a cheaper alternative for surveying large-bodied arboreal diurnal primates.

We therefore aimed to evaluate the viability of using a COTS multirotor drone with a high-resolution RGB camera to detect Geoffroy’s spider monkeys (*Ateles geoffroyi*), a species that has successfully been detected using thermal infrared cameras mounted to drones (Kays et al. 2019; Spaan et al. 2019a). We did so using a 3-component approach: 1) flying the drone directly over sites where spider monkeys had been spotted from the ground to test aerial detection effectiveness, 2) performing trial drone surveys in areas of known high and low spider monkey relative abundance, and 3) comparing the ability of different coders to detect monkeys in drone-collected RGB videos.

METHODS

Study areas and subjects

This study was carried out between April 2019 and February 2020 in four areas in the Yucatan Peninsula, Mexico (Fig. 1): la Ruta de los Cenotes (RC), the Botanical Garden “Dr. Alfredo Barrera Marín” (BG), Otoch Ma’ax yetel Kooh (OMYK), and Los Arboles Tulum (LAT).

RC consists of several sites along a road between the coastal town of Puerto Morelos (20° 51' N, 86° 53' W) and the inland village of Leona Vicario (20° 59' N, 87° 12' W), in the state of Quintana Roo. The majority of these sites are characterized by small patches of old growth medium semi-deciduous forest surrounded by large swathes of regenerating forest in differing stages of succession. The 8,800 hectares covered by these sites (AH, unpublished data) were identified as a high priority conservation area (Tobon et al., 2012), but they are not protected and mostly consist of private properties where tourist operators provide popular recreational activities. The road connects most of the tourist attractions, and two small villages are located along the road (Central Vallarta, 20° 51' N, 87° 2' W and Delirios, 20° 50'

N, 87° 11' W). Spider monkeys are either not or are only moderately habituated to human presence (personal observation, AH).

BG is the botanical garden of Puerto Morelos, Quintana Roo (20° 51' N, 86° 53' W). The majority of the 65-hectare area consists of medium semi-deciduous forest and mangrove (Scherbaum and Estrada 2013). Spider monkeys are habituated to human presence as BG receives visitors on a daily basis, and several research projects have been carried out on them (e.g., Scherbaum and Estrada 2013).

OMYK is a Fauna and Flora Protected Area located in the state of Yucatan (20°38' N, 87°38' W). Around 300 Yucatec Mayan people live in villages or small land-holdings in or around the reserve (García-Frapolli et al. 2007). The 5,367-hectare protected area consists of old growth medium semi-deciduous forest and regenerating forest in differing stages of succession due to the historical practice of slash-and-burn agriculture (García-Frapolli et al., 2007). Spider monkeys have been studied in the protected area for the past 20 years and are habituated to human presence (Ramos-Fernández et al. 2018).

LAT is a sustainable residential development located about 14 km from the city of Tulum, Quintana Roo (20° 17' N, 87° 30' W). Most of the 400-hectare area remains forested as sustainably built houses within the development area are only allowed to occupy 5% of each 2-hectare plot leaving the rest of the forest untouched, and fewer than 30 of the 221 plots in the development have completed residential homes (Spaan et al. 2019a). The area consists of medium semi-deciduous forest. Two groups of spider monkeys inhabit LAT and have been studied since November 2016. The monkeys are habituated to human presence (DS, unpublished data).

Data collection and analysis

We used a Mavic 2 Pro COTS drone (SZ DJI Technology Co.) fitted with a Hasselblad L1D-20c RGB camera. The camera has a 3-axis gimbal with a 1” CMOS (20M effective pixels) sensor, and the lens has a 28 mm focal length with an image size of 5472 x 3648 pixels. At canopy height, this led to a 0.17 cm ground sampling distance. The drone was controlled using an iPad mini model 4.0.

At each of the four study areas, we flew the drone at multiple survey locations. First, we selected the take-off and landing place for each location. We then carried out manual preliminary flights at each location using the set-up return to home (RTH) to estimate canopy height, to evaluate the signal transmission quality (GNSS, remote control, and video signal), and to assess the presence of anthropogenic barriers which could endanger the drone during flights (e.g., buildings, power lines; Duffy et al. 2018). To estimate canopy height, we flew the drone with the camera positioned horizontally (0°) and directed toward the survey location. We then flew the drone, gradually raising it to determine the height at which no vegetation was visible. Additionally, we estimated the height of the 3 - 5 tallest trees at each location, using the drone altimeter and its obstacle sensors. To evaluate signal transmission quality, we flew the drone in straight lines to the four cardinal points at 50 meters above ground level (a.g.l) until signal transmission was low or lost. To detect anthropogenic barriers, we flew the drone toward the centre of each location at 50 meters a.g.l. and rotated the drone 360 degrees clockwise at a speed of 1 km/h. All preliminary flights were performed in manual mode using the *DJI GO 4.0* drone application (Version 4.3.32).

To detect spider monkeys using the drone, we conducted pre-programmed grid flights in a lawnmower pattern. None of the locations contained busy roads, buildings or power lines. We drew a square outline polygon measuring 100m x 100m (1 ha) for each location using *ArcMap 10.4* and imported each 1-ha polygon into *Mission Planner V1.3.64* (ArduPilot). We created the lawnmower flight paths using the Automatic Waypoint-Survey feature. The number of flight lines in the lawnmower pattern were between four or five (depending on canopy height) of the same overall length. Overlap and sidelap were kept constant at 20% at ground level, which was equivalent to 0% overlap at the canopy level. Under these conditions we covered around 45% of the 1-ha polygon per flight at canopy level. We set up grid flights in *Litchi Mission Hub* (VC Technology Ltd) with the following settings: flight speed of 3.0 km/hour, camera inclination of -90° and 4k video recording (3840 x 2160 Full FOV). We flew the drone 10 meters above the maximum canopy height at each location to optimize the chance of detecting monkeys in the videos as they are easily visible from this height. The Mavic 2 Pro has low-noise rotors and is less noisy than prior models of its kind. Grid flight duration ranged between 8.6 and 16.0 minutes (mean ± SD: 11.8 ± 1 minute) depending on flight height. Grid flights were loaded to *Litchi for DJI Drones* (VC Technology Ltd) and performed using the waypoint mode. Take-off and landing were performed manually, and fly mode was automatic. All flights were performed from 07:00 to 10:00 and from 14:00 to sunset.

We also carried out line-transect surveys at all study areas using a well-established methodology (Spaan et al. 2017) to determine whether a study area had a high or low relative abundance (i.e., encounter rate: number of individual monkeys per kilometre of surveyed transect) of spider monkeys (see Online Resource 1 for further details). Based on the encounter rates presented in Table 1, we considered the LAT, BG, and OMYK study areas to have a high relative abundance of spider monkeys and the RC study area to have a low relative abundance. Although no spider monkey was sighted during line-transect surveys at RC, the presence of spider monkeys at the study area was confirmed by data collected using passive acoustic monitoring (AH, unpublished data; Online Resource 1).

To evaluate whether a COTS multirotor drone with a high resolution RGB camera could be used to detect Geoffroy's spider monkeys, we used a 3-component approach.

Component 1 – detection test flights

We flew the drone directly above monkeys that were visible from the ground in the BG and at one site in the RC. In preparation for these flights, we marked a waypoint with a GPS (Garmin ETrex 10) at each location where monkeys were frequently observed on prior occasions to prepare different potential 1-ha survey grids and to select the most suitable take-off and landing place for each location. Upon sighting monkeys, the drone pilot loaded the 1-ha polygon that best covered the area where monkeys were detected from the ground while an assistant checked for movements of the monkeys to ensure their continued presence in the area covered by the survey grid. The assistant also noted the behaviour of the monkeys during flights and the emission of any vocalizations. If the monkeys moved out of the survey grid, the flight was aborted. We were able to complete 20 detection test flights.

Component 2 – trial flights

We flew the drone at RC, where prior work suggested spider monkey relative abundance is low (Table 1). We flew the drone at 13 locations where spider monkey presence was confirmed using passive acoustic monitoring or via direct observations (AH, unpublished data). The mean distance between neighbouring locations was 2,006 m (range: 593 - 5,253 m). We performed three trial flights at each location, for a total of 39 trial flights. Flights at each location were separated by at least one month.

We also flew the drone at BG, OMYK, and LAT, where prior work suggested that spider monkey relative abundance is higher (Table 1) and where the monkeys are well habituated to human presence. We flew the drone at seven locations in OMYK within the known home range of one group of spider monkeys that has been studied for over 20 years (Ramos-Fernández et al. 2013) and at two and nine locations in BG and LAT, respectively, that were frequently used by spider monkeys (unpublished data). The distance between the two locations in BG was 537 m, and the mean distance between a location and its closest neighbouring location was 505 m (range: 354-876 m) and 460 m (range: 342-634 m) in OMYK and LAT, respectively. We performed one trial flight at each location across these three areas, for a total of 18 flights.

All drone-collected RGB videos for both Components 1 and 2 were reviewed by CERR (hereafter the main coder) and coded for the presence or absence of spider monkeys based on sighting at least one individual. Videos were played using VLC Media Player 3.0.8 at normal speed. When the main coder detected a possible monkey based on canopy movement or features resembling the spider monkey appearance, she used the *Speed slower* and *Interactive Zoom Tools* to confirm monkey presence. Video segments with confirmed monkey presence were extracted and stored in separate files along with the location and flight details.

We calculated the proportion of replicates where at least one spider monkey was detected as the number of flights in which at least one spider monkey was detected divided by the total number of flights. To place our results into context, we compared this proportion with the equivalent proportions calculated using data from three other survey methods employed to determine spider monkey presence: line transects, point transects, and passive acoustic monitoring (see Online Resource 1 for details on the methods).

Component 3 – intercoder agreement

A subset of the drone-collected RGB videos (n = 20, including 12 monkey-absent videos and 8 monkey-present videos, according to scoring by the main coder) were independently reviewed for monkey presence or absence by four additional blind coders who all had experience studying spider monkeys in their natural habitat. Videos were 1.5 to 5 minutes in length. Sixteen of the 20 videos were 5 minutes long, corresponding to the first and second drone survey video segments, but as our grid flight times typically lasted <15 minutes, the last video recorded during any given flight was less than 5 minutes in length. Thus, 2 additional monkey-present and 2 additional monkey-absent videos used for assessing intercoder agreement were shorter than 5 minutes. Overall, the mean length for monkey-present and monkey-absent videos were 4.2 minutes and 4.4 minutes, respectively.

After the coding, we recorded the number of videos for which each blind coder determined the presence or absence of spider monkeys and compared the results with those obtained by the main coder using Cohen's Kappa (McHugh 2012). Agreement between pairs of coders was categorized as "absent" (0.00 – 0.20), "minimal" (0.21 - 0.39), "weak" (0.40 – 0.59), "moderate" (0.60 – 0.79), "strong" (0.80 – 0.90), or "almost perfect" (> 0.90; McHugh 2012). We also compared the agreement between all observers using Fleiss' Kappa (Nichols et al., 2010), where agreement was scored as "poor" (<0.00), "slight" (0.00 – 0.20), "fair" (0.21 - 0.40), "moderate" (0.41 – 0.60), "substantial" (0.61 – 0.80), or "almost perfect" (> 0.81; Landis and Koch 1977). Cohen's Kappa and Fleiss' Kappa were calculated using the *kappa2* and *kappam.fleiss* functions, respectively, with the *irr* package (Gamer et al. 2012) in R (R Core Team 2020).

RESULTS

Component 1

The coding of the drone-collected RGB videos resulted in the detection of at least one spider monkey in a total of 17 detection test flights (Fig. 2). Thus, we were able to confirm monkey presence in 85% of the 20 flights when we flew the drone directly above monkeys that had just been detected by observers on the ground (i.e., false absence in 15% of flights). Spider monkeys were easily detectable in the drone-RGB videos as they cause the tree branches to move in a characteristic manner, which can be distinguished from the movement caused by wind (except when wind speeds are high). Once such branch movements were detected, monkey presence was confirmed using *Speed slower* and *Interactive Zoom Tools*. Spider monkeys reacted to the presence of the drone in 41% of flights (n = 7) where monkeys were detected. In all cases the reaction consisted in vocalizations: whinnies (n = 4), alarm calling (n = 1) and other calls (n = 2).

Component 2

In the 39 drone-collected RGB videos recorded during trial flights at 13 RC locations in the low relative abundance RC site, we did not detect any monkeys. Thus, despite the fact that we know monkeys were present in this area based on the use of passive acoustic recorders, our drone-based surveys (like line transect surveys conducted at the same site) were inadequate for documenting their presence. We were able to detect monkeys in the drone-RGB videos recorded during trial flights in one of the three areas where prior work demonstrated that spider monkey relative abundance is high. Although we did not detect any monkeys in the set of 9 videos recorded at the study locations in the BG and OMYK areas (2 locations at BG and 7 at OMYK), we detected at least one monkey in 3 of the 9 videos recorded at the LAT locations (Fig. 3). Thus, we detected monkey presence in 17% of the 18 trial flights in the high relative abundance sites. Spider monkeys observed in the drone-RGB videos obtained from LAT were foraging on leaves, resting, scratching, or moving. The proportion of replicates where at least one spider monkey was detected using drone-collected RGB videos was lower than that using two of three other survey methods: line-transect surveys and passive acoustic monitoring (Table 2). However, no methods determined presence in more than 10% of survey replicates (Table 2).

Component 3

Agreement between coders regarding the presence or absence of spider monkeys in drone-RGB videos was “substantial” (Fleiss’ Kappa = 0.751). Agreement between the main coder and each additional coder varied from "moderate" to "strong" (Table 3).

Discussion

We demonstrate that COTS multirotor drones fitted with RGB cameras can be used to detect large-bodied arboreal primates during the day in closed-canopy forests and may therefore be a useful tool to assess species occupancy and distribution. Several factors may have led to the 85% detectability of spider monkeys in the drone-RGB video footage obtained when the drone flew directly over areas where monkeys had been detected on the ground (Component 1). First, flying the drone relatively low over the canopy (10 meters above the maximum canopy height) ensured high resolution of the top layers of the forest canopy. Second, the large amount of time that spider monkeys spend in the tree canopy (McLean et al. 2016) and the distinct movement of tree crowns caused by their semi-brachiation form of locomotion meant that spider monkeys were easily observed when located at the top of the canopy or alerted the observers to their presence in the video footage, which could then be confirmed using the *Interactive Zoom Tools* of the VHL video player.

For component 1, false-absences occurred in 15% of the drone-RGB video footage. It is possible that when spider monkeys were not detected in drone-RGB video footage even when they were determined to be present by ground observers (n = 3 flights), the monkeys were either present in areas outside of the drone´s field of view, did not cause observable movement of the tree foliage, or remained below the canopy stratum of the vegetation. Given that 55% of the 1-ha polygon was outside of the drone camera’s field of view, this is a likely explanation for our false-absence rate. Assuming this to be the case, spider monkey detectability in drone-RGB video footage obtained flying 10 m above the canopy is likely to increase if 100% of the survey polygon is surveyed. High detectability and low probability of occurrence (i.e., the likelihood of finding a monkey at a random survey location) are strong pre-requisites for efficient occupancy sampling (Guillera-Arroita et al., 2010). Performing surveys using drone-RGB video footage may therefore have promising applications for modelling spider monkey occupancy, especially if the sidelap values are increased to cover a larger survey area within a single flight.

Spider monkeys did not show any avoidance behaviours in response to the drone, although they emitted some contact calls and alarm calls in 41% of the flights where monkeys were detected in Component 1. The emission of vocalizations in response to the drone is similar to the response of unhabituated spider monkeys to human observers during line-transect surveys (DS, personal observation). However, due to the frequent use of line-transect sampling for primate surveys, such behavioural responses are rarely reported. Previous studies have shown that drones can disturb wildlife (Mulero-Pázmány et al. 2017; Rebolo-Ifrán et al. 2019) which may not be expressed behaviourally (Ditmer et al. 2015). It is therefore important that future studies not only focus on detailed behavioural observations in response to drones but potentially also incorporate measures of physiological stress.

To evaluate whether COTS multirotor drones with RGB cameras can be used to effectively survey spider monkey populations and gain information on their presence in different areas, we flew the drone in areas of known relative abundances in a standardized survey grid for a total of 57 trial flights. When considering all 57 flights, the proportion of replicates where at least one spider monkey was detected from the drone-collected RGB video footage was lower than that using two of the other methods: line-transect surveys and passive acoustic monitoring (Table 2). The higher probability of detecting spider monkey presence using passive acoustic monitoring and line-transect surveys compared to drones in our study areas may be due to the overall higher survey effort for passive acoustic monitoring (18 hours vs. 12 minutes for a drone flight) and the greater area covered per replicate for line transects (2 hectares vs. 0.45 hectares for a drone flight) at each location. COTS multirotor drones are more expensive than the other three methods. Although prices are likely to continue to fall, they are not nearly as accessible as new PAM recorders that may come in as low as $100. Line- and point-transect methods require little equipment cost and minimal training, but personnel cost can be considerable if large areas are to be surveyed. Although line- and point-transects may be applicable to studies of species distribution, they do not provide reliable estimates of spider monkey population density (Spaan et al., 2019b) which questions the value of such high personnel costs. Future surveys will likely need to employ a mixture of methods to determine accurate and precise estimates of spider monkey presence and abundance.

The design of the drone surveys may also have affected the number of spider monkey detection events, as only a relatively small area (0.45 hectares) was covered during each survey. Our survey design was chosen to standardize the survey area at each location while maximizing battery efficiency by flying at a standard height over the forest canopy. The clarity with which spider monkeys could be seen in the drone-collected RGB video footage, especially when observed with the VHL Video Players's *Interactive Zoom Tools*, suggests that future flights could take place at a higher altitude, which would increase the overall survey area that could be covered in a single flight.

As spider monkeys can have home ranges in the Yucatan Peninsula that reach up to 166 ha (Ramos-Fernández et al. 2003), we suspect that surveys may need to cover a much larger area than 0.45 hectares in order to detect presence when monkey relative abundance is low. It is also possible that drone surveys with RGB cameras might prove more efficient in forest fragments where less area needs to be covered and where spider monkey home ranges are smaller (Chaves et al. 2012). Furthermore, the association patterns of spider monkeys may enhance their chance of being detected even in small-area surveys. Spider monkeys exhibit a high degree of fission-fusion dynamics, living in large groups in which group members are rarely all together at one point in time; instead, they form small subgroups that change in size and composition over the course of the day (Aureli et al. 2008). As a consequence, group members are often divided across different subgroups that use different areas of the group’s home range at any one point in time (Pinacho-Guendulain and Ramos-Fernández 2017). This pattern potentially increases the likelihood of determining spider monkey presence in a survey area even if only a portion of the entire home range is surveyed compared to the likelihood of determining the presence of other group-living animals with lower degrees of fission-fusion dynamics.

Spider monkeys in the BG, OMYK, and LAT areas are all highly habituated to the presence of humans due to frequent exposure to tourists and researchers (Scherbaum and Estrada 2013), potentially minimizing their behavioural reaction to the drone. It is plausible that the design of the Mavic 2 Pro causes less disturbance to spider monkeys than larger or noisier drone models. Despite flying at higher altitudes above the canopy, earlier surveys performed using a larger and noisier multirotor drone over spider monkey sleeping sites in LAT elicited both vocal and behavioural responses, including monkeys moving a few meters down or moving away from the sleeping site when multiple flights were performed in succession (Spaan et al. 2019, but see Bennitt et al. 2019). Although habituation to repeated drone flights has been demonstrated in bears (*Ursus americanus*; Ditmer et al. 2019), we cannot be sure that the same individuals were exposed to both sets of drone flights in LAT, and it is therefore not clear whether habituation could have explained the overall lack of overt behavioural response to the Mavic 2 Pro. Studies on dolphins found that group size and environmental factors (e.g., cloud cover) can affect the frequency of behaviour change during drone flights, with larger groups changing behaviors in response to the drone more frequently (Giles et al. 2020). Future studies on large-bodied arboreal mammals, including spider monkeys, should investigate the factors that may affect behavioral reactions to drones. Such factors can then be incorporated as observer-level covariates into occupancy models to account for their effect on detection probability (Mackenzie et al. 2002). Incorporating survey date as a covariate could help control for potential effects of habituation to the drone, as one might expect higher habituation to be associated with lower detection (i.e., a negative effect of survey date on detection).

In this study, we performed only one to three trial flights at each individual survey location, and one might argue that had we performed additional flights at each location we may have increased the number of locations where monkeys were detected. However, it bears noting that for occupancy modeling, when detection probability is high (e.g., 85% as in our case), a low number of replicate surveys is sufficient to obtain reliable occupancy estimates (Guillera-Arroita et al. 2010). For instance, with a low relative abundance and a high detectability, such as possibly in our case, two to three replicates are recommended (Guillera-Arroita et al. 2010). Performing flights covering different seasons, is particularly relevant for spider monkey surveys as home range size and use changes by season (larger in the dry season compared to the rainy season; Smith-Aguilar et al. 2016). Absence during one flight may thus be due to the monkeys not using that area during a particular season. The use of dynamic (also called multi-season) occupancy models can reveal detailed spatio-temporal patterns of occurrence for species that change ranging patterns between seasons (MacKenzie et al. 2003).

Agreement between all video-coders was "substantial", and agreement between the main coder and each of the four additional coders ranged from "moderate" to "strong". Although the additional coders had considerable experience studying wild populations of spider monkeys in the Yucatan Peninsula, they were not provided with training in observing spider monkeys in drone-collected RGB videos. Linchant et al. (2018) found detection rates of common hippopotamus (*Hippopotamus amphibius)* from drone-collected RGB photographs was higher for observers with prior experience in looking. This result suggests that with training coder agreement would likely improve, making it possible for several coders to independently analyse drone-RGB videos for the presence of spider monkeys. The use of multiple observers is recommended to reduce potential observer bias when animal presence or counts are determined manually (Vermeulen et al. 2013; Brack et al. 2018). However, despite the potential of being able to use multiple coders to screen drone-RGB videos for spider monkey presence, manual processing and analysis of these videos remains time-consuming, making the application of this methodology to large-scale spider monkey surveys unfeasible without the use of computer algorithms to automate the detection (Lamba et al. 2019).

Our results highlight the need to critically evaluate the efficacy of different drone-based methods in pilot work before adopting their widespread use. Recent studies demonstrate that drones fitted with thermal cameras can successfully detect spider monkeys (Kays et al. 2019; Spaan et al. 2019a) and other arboreal primates (*Pongo pygmaeus*: Burke et al. 2019b; *Alouatta palliata*: Kays et al. 2019; *Rhinopithecus roxellana*: He et al. 2020; *Nomascus hainanus*: Zhang et al. 2020) within short time frames. New drone models, such as the Mavic 2 Enterprise Advanced, that carry dual thermal and RGB cameras provide a promising avenue to survey spider monkeys in the future as both nocturnal and diurnal flights can be performed. We were able to detect spider monkeys from video footage obtained from COTS multirotor drone surveys with an RGB camera with a 15% false absence rate in areas where spider monkeys were detected at the same time from the ground. An improved survey design that increases coverage of the survey area will likely increase detection. We suggest that survey design should, minimally, include multiple locations within the same area in order to cover a larger survey area overall. In addition, we recommend the number of survey replicates to be adjusted to the expected relative abundance as recommended in Guillera-Arroita et al. (2010). For species with low relative abundance, such as spider monkeys, it is recommended to increase the number of sampling sites rather than the number of survey repetitions per site (Mackenzie and Royle 2005). Such changes in survey design would likely provide reliable data to estimate spider monkey occupancy and update information on their current distribution. Still, given seasonal shifts in home range use patterns, such surveys for spider monkeys would need to take place over several months and would therefore require substantial funds. Although COTS multirotor drones with RGB cameras can be used to survey large arboreal mammals like spider monkeys in closed-canopy tropical forests, the lower proportion of detections compared to other methods implies that the survey method is likely not sufficiently developed to replace other survey methods as of yet. The method is currently not suitable as a rapid-assessment tool in areas where information on species' distributions are needed promptly for conservation decision-making, such as in regions where forests are rapidly being converted into other landcovers. Only when newer drone models appear on the market with in-flight zoom options, built-in thermal cameras, and longer flight durations at affordable prices, rapid-assessments may become more realistic.

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FIGURES

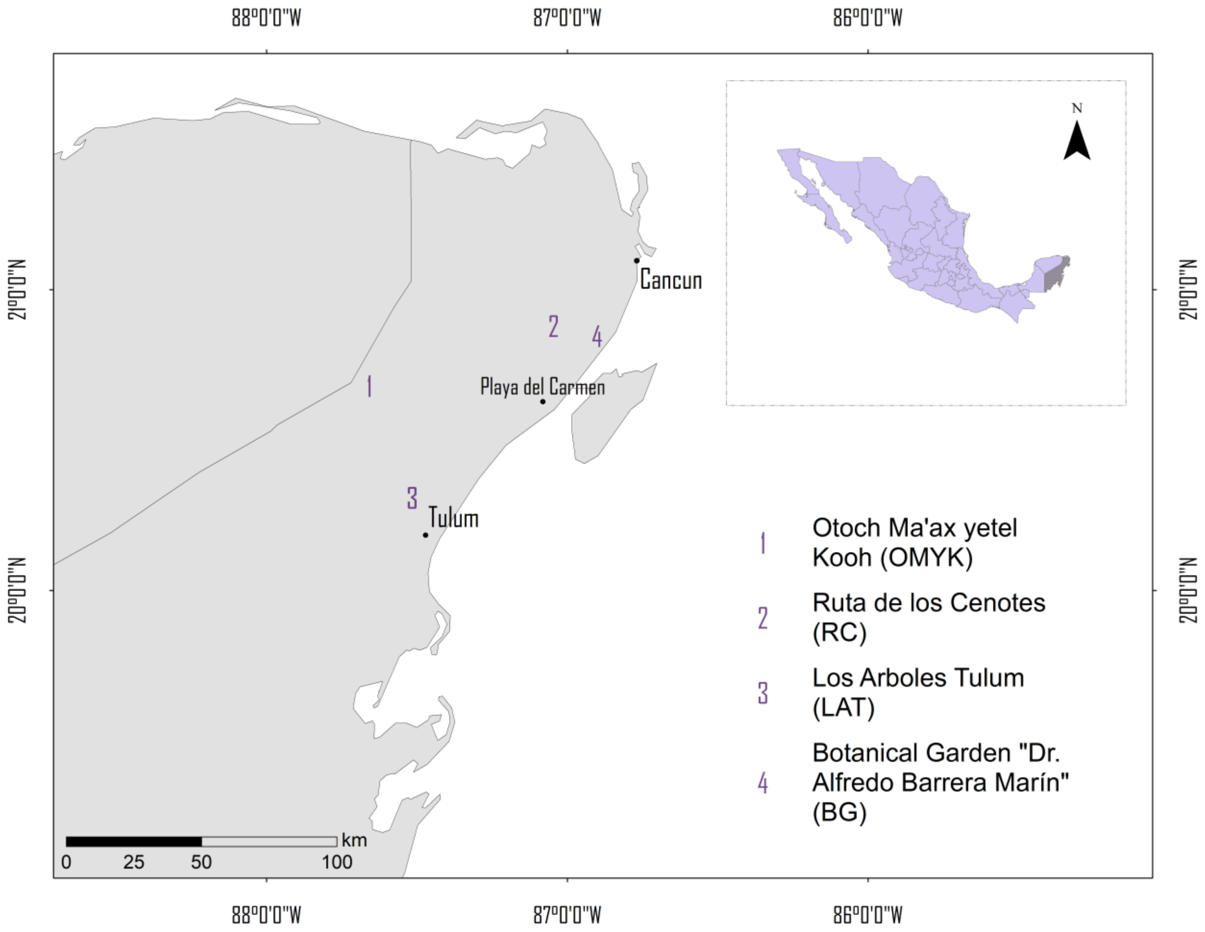

Fig. 1 The four study areas in the Yucatan Peninsula, Mexico

Fig. 2 Example of a spider monkey detected during the coding of drone-RGB videos using the *Interactive Zoom Tools* in *VLC Media Player*

Fig. 3 Example of a spider monkey detected at one of the locations in LAT

TABLES

Table 1: Data collected from line-transect surveys in the four study areas.

Study area	Number of surveys (500 m)	Total survey effort (km)	Number of surveys in which spider monkeys were detected	Proportion of detections*	Total number of individuals detected	Encounter rate
LAT	102	51	11	0.11	45	0.88
BG	58	29	10	0.17	79	2.72
RC	64	32	0	0.00	0	0.00
OMYK	36	18	4	0.11	20	1.11

*Proportion of detections = number of surveys in which spider monkeys were detected / total number of surveys; Encounter rate = number of individuals detected per km surveyed.

Table 2: Comparison of performance and characteristics among four survey methods.

	RGB drone	Line transect	Point transect	Passive acoustic monitoring
Proportion of detections*	0.053	0.1	0.054	0.166
Data collection time**	12 min	20 min	20 min	18 hours
Post-processing time**	30-60 min	none	none	20 min***

Automatic detection	Possible			Possible
Cost of equipment****	US$ 3600	US$ 950	US$ 950	US$ 1750

* Proportion of detections = number of survey replicates in which at least one spider monkey was detected / total number of survey replicates.

** For one replicate.

*** This is based on using a semi-automated analysis approach using the Cluster Analysis tool of Kaleidoscope Pro (Wildlife Acoustics).

**** Cost is calculated for conducting one replicate. The cost of the RGB drone is based on one Mavic 2 Pro (US$ 1700), one iPad mini model 4.0 (US$ 400), a laptop with good processing power (US$ 1500). The cost of the line-transect and point-transect survey is based on two binoculars (US$ 150 each), one GPS device (US$150) and a laptop with average processing power (US$ 500). The cost of passive acoustic monitoring is based on one Wildlife Acoustics SM4 recorder at time of purchase (US$ 850), a laptop with average processing power (US$ 500) and the cost of a one-year license of the Kaleidoscope Pro software (US$ 400); there are cheaper devices on the market which would reduce the cost.

Table 3: Agreement between the main coder and each of four additional coders on the presence or absence of spider monkeys in drone-collected RGB videos measured using Cohen’s Kappa.

Additional Coder	Cohen's Kappa	Agreement
1	0.894	Strong
2	0.667	Moderate
3	0.667	Moderate
4	0.792	Moderate