Successful aerial survey using thermal camera to detect wild orangutans in a fragmented landscape

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Abstract

Asia's only great ape, the orangutan, builds nests for the night in the upper rainforest canopy. Due to the location in the upper canopy, aerial surveys of orangutans rely primarily on counting nests. This method has come under increasing criticism, because nest decay rates can vary greatly over space and time and is depended on e.g. local climatic conditions, tree species and presence of termites and other animals. Whereas empty nests may not provide a good measure of presence, live orangutans in their nests does. Assuming the orangutan is the only animal species of the size that can be found in the upper rainforest canopy at night, we used thermal camera fitted to a drone to successfully detect and identify orangutan in Kumai Estate, Central Kalimantan, Indonesia. Our results provide an encouraging new census platform for conservationists and park managers.

Abstrak

Satu-satunya kera besar di Asia, orangutan, membuat sarang di malam hari pada kanopi hutan hujan tropis. Karena lokasinya di atas kanopi, survey udara untuk orangutan mengandalkan pada perhitungan sarang. Metode ini mendapat banyak kritikan, karena tingkat pembusukan sarang bisa sangat bervariasi tergantung pada kondisi tempat dan waktu serta tergantung misalkan pada kondisi iklim setempat, jenis pohon, keberadaan rayap atau serangga serta hewan lainya. Sarang orangutan yang kosong tidak memberikan informasi yang cukup jelas tentang keberadaanya, tetapi kalau orangutan ada di atas sarangnya tentu saja bisa. Dengan asumsi orangutan dengan ukuran tubuh yang dimilikinya, adalah satu-satunya jenis dapat ditemukan di atas kanopi hutan tropis pada malam hari, kami menggunakan termal kamera yang dipasang pada drone telah berhasil mendeteksi dan mengidentifikasi orangutan di perkebunan Kumai, Kalimantan Tengah, Indonesia. Hasil kami memberikan platform sensus baru yang menggembirakan bagi para konservasionis dan pengelola kawasan.

Keywords: Orangutan, FLIR, thermal camera, drone, survey, Indonesia

Introduction

Using consumer drones fitted with a thermal camera to detect and estimate mammals in the wild is an opportunity that has emerged only in the past decade. A major challenge in studying mammals in the field is finding them and because ground-based observation of wildlife is often limited by access and topography, aerial surveys are often the only practical way to detect and estimate a target species' numbers. Small air planes have been used for aerial detection and population surveys of a range of wildlife species for years, for example, caribou (Courtois et al., 2003; Neufeld and Vennen, 2015), water birds (Chabot and Bird, 2010), elephants (Vermeulen et al., 2013), dugong (Hodgson et al., 2013) and sea turtles (Bevan et al., 2015). Forward-looking Infrared (FLIR) cameras were tested in aerial surveys in the 1960-70s (Croon et al., 1968; Parker and Driscoll, 1972), but it was only in the 1990s that FLIR had become sufficiently advanced for effective application in aerial wildlife surveys (Boonstra et al., 1994; Haschberger et al., 1996; Wiggers and Beckerman, 1993). The downside was the combined cost of adequate

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FLIR technology and flying time, which made it prohibitively expensive for most users. The past 10 years has seen the emergence of mainstream drone technology (Anderson and Gaston, 2013; Bevan et al., 2015; Gonzalez et al., 2016), which has paved the way for endless new aerial FLIR applications, such as disease detection in wildlife (Dunbar and MacCarthy, 2006; Dunbar et al., 2009), mammal surveys (Dunn et al., 2002; Storm et al., 2011; Vermeulen et al., 2013), detection and location of polar bear dens (Amstrup et al., 2004), survey of other wildlife species (Christiansen et al., 2014; Franke et al., 2012), rhino protection (Mulero-Pazmany et al., 2014) and law enforcement activities (Gonzalez et al., 2016).

Aerial population surveys of great apes are rare, because all species live in rainforest habitat, where a thick canopy shades them from visual detection. Furthermore, aerial surveys are expensive and good high-resolution satellite images are limited and often costly too. Tests in Tanzania and Gabon involving the detection of chimpanzee nests and fruiting trees were undertaken recently using a camera fitted to a drone were successful although with a high-degree of misidentification (Bonnin et al., 2018; van Andel et al., 2015). Asia's only great ape, the orangutan (*Pongo spp.*) was surveyed in 1986 (Payne, 1987), using helicopter to count nests as they are easily detected from the air and, subsequently, aerial nest counting became common practice, using a similar technique or combining it with ground counts (Ancrenaz et al., 2010; Ancrenaz et al., 2005; Ancrenaz et al., 2004a; Felton et al., 2003; Johnson et al., 2005; Meijaard et al., 2010; Russon et al., 2001). The cost of aerial surveys remained prohibitive until a preliminary survey using drones to assess the distribution and density of Sumatran orangutan was successful (Wich et la., 2015) and allowed for possible future cost-reduction. While surveys using fixed-winged drones fitted with daylight cameras can cover large tracts of land, challenges persist with regards to detection reliability, speed and altitude. In addition, the counting ape nests is associated with a number of variables that are difficult to predict and estimate, for example, nest decay rates vary greatly over space and time and is dependent on a range of variables such as local climatic conditions, tree species, presence of termites and other animals and degree of nest re-use (Cheyne et al., 2013; Felton et al., 2003; Husson et al., 2009; Wich and Boyko, 2011). Recent studies have recommended abolishing the use of single-number decay time estimates for the estimation of orangutan populations (Marshall and Meijaard, 2009; Mathewson et al., 2008; Spehar et al., 2015; Wich and Boyko, 2011). Whereas direct nest counts can be difficult and success is dependent on picture resolution, flying altitude and speed, counting orangutan in nests at night, using FLIR fitted to a drone, will provide a new and complimentary method to increase the accuracy of population estimates, perhaps with a potential for near absolute population counts.

To our knowledge, this is the first of its kind that uses FLIR fitted onto consumer-range drones for detecting and/or estimating orangutan populations in the wild.

Methods

Assumptions

Orangutans, males and females, build nests in the upper canopy. In our population estimate, we assume that all individuals that sleep in the canopy are detectable with a FLIR thermal sensor. Assuming that a majority of orangutans sleep in a nest in the canopy, this approach to orangutan survey can add significant additional accuracy to population counts in those two forests blocks and other orangutan habitats.

Drone platform

We used two DJI drones as aerial survey platforms (hereafter "drones"). The first was DJI Phantom 4Pro (P4P) with a 24mm, f2.8 on board RGB camera. The 1" sensor supports 4K video and 20 megapixel still pictures. The P4P has a limit of approx. 25-30 minute flying time and we tested the video transmission range from drone to controller

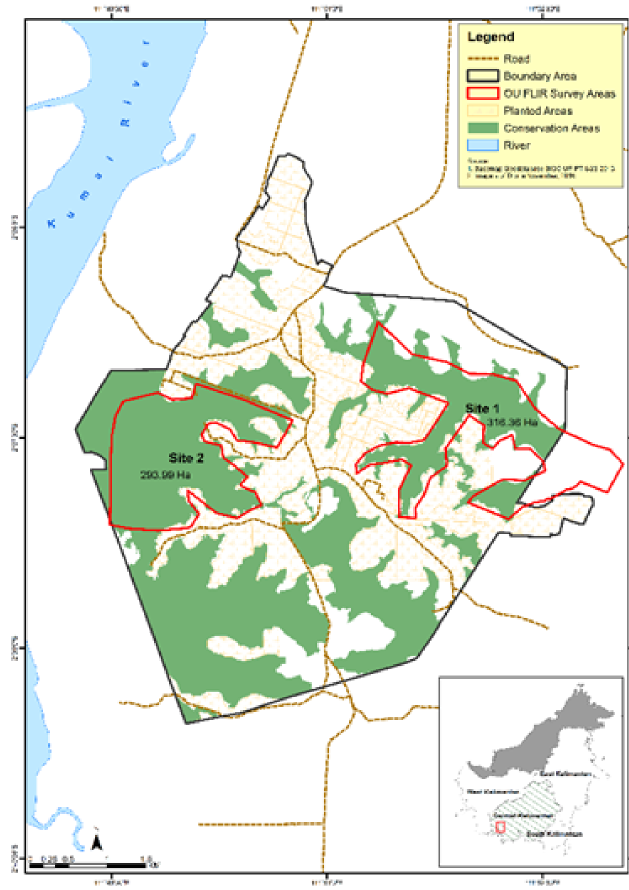

Figure 1. Our study sites in a fragmented forest landscape with known presence of orangutan.

to be well above 2.5km, while flying at 150m above local canopy height. The range of the live video transmission varies based primarily on the flying altitude. Flying lower generally reduces the range. Actual range depends on local conditions such as canopy density, location of the receiver, and electromagnetic interference. The second drone was a DJI Inspire 1 V2.0 with DJI TB48 battery, which has a flight time of 13-15 minutes. The standard Zenmuse X3 camera and gimbal is interchangeable with a Zenmuse XT 640 Pro thermal camera (FLIR) with built-in gimbal. The range of video transmission was in excess of 2.5km at 100m above the local canopy height in this location. We used an Apple 9.7" iPad (128GB, Wi-Fi + 4G LTE) as our live-feed screen for both systems.

FLIR setup

We custom fitted a FLIR™ 640 Pro 9 Hz camera with 13mm lens to the P4P behind the on-board camera. To prevent the on-board camera from shielding the FLIR camera, the FLIR camera was mounted on a separate 2-axis gimbal with tilt/roll that extended below the on-board camera. The gimbal is necessary to reduce vibrations in the video and still pictures and to keep the image frame horizontally stable. This imaging system was setup independently of the P4P electric system to prevent unnecessary drainage of the main flying battery. The system was powered by a self-contained 9V rechargeable battery providing approx. 15-20min of gimbal power. The addition of the FLIR camera and gimbal required a 7cm extension of the drone's landing gear to prevent the FLIR camera from touching the ground during landing and when stationary. We used an additional 900MHz transmitter with a 5" screen in order to see live FLIR video feeds using this system (separate from the iPad). The live video stream range of the FLIR system was approx. 750m at 150m above local ground level. The FLIR 640 Pro camera records 8-bit digital video in MJPEG or H.264 formats and 14-bit still imagery to a removable micro-SD. The camera is controlled over Pulse Width Modulation commands, enabling the operator to select colour palettes, start and stop recording, or trigger the camera in-flight using the radio controller. The thermal image could be adjusted between "white hot", "black hot" and "colour". The "white hot" setting provided the best visual detection of heat signatures in the rainforest canopy and was used for both video and still images.

The second drone was a DJI Inspire 1 fitted with a Zenmuse XT 640x512 9Hz thermal camera with a 9mm lens that is fully integrated on a 3-axis gimbal. The thermal sensor used for the Zenmuse XT is the same as the FLIR VUE 640 Pro used with the P4P but it is integrated for use with DJI drones. Thus, both the drone and camera controls are operated using the DJI GO application on an iPad. Images and video are recorded to an on-board micro SD card and live video feed is transmitted using the DJI Lightbridge software and displayed on the iPad. This system provides a single interface for

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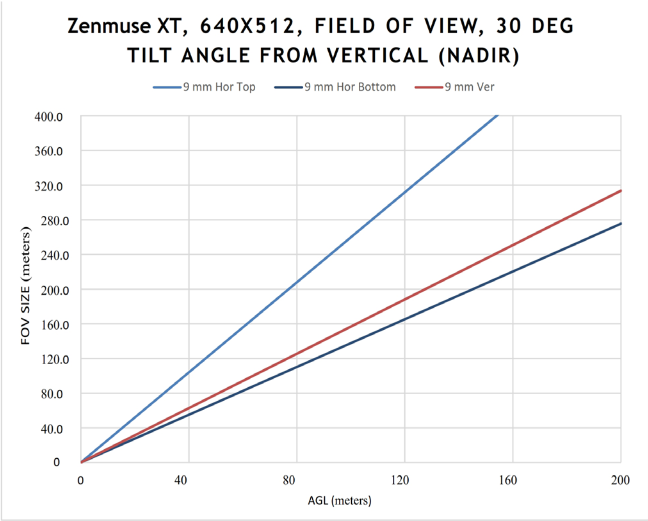

Figure 2. Maximising the field-of-view. We maximised the field-of-view (FOV) by recording video and stills at a 30-degree angle.

control of the drone and the camera with additional features for changing palette colour options in-flight and integrated GPS position stored in EXIF.

The Inspire 1/Zenmuse XT 640 combination has several important advantages over the P4P setup. Although both systems use the same FLIR thermal sensor with a resolution of 640x512 pixels, the Zenmuse XT camera is able to record video and take still pictures at the same time. It also records GPS location in the thermal image EXIF file, which reduce the amount of post processing necessary. This system also permits the operator to use real-time digital zoom at 2x, 4x, or 8x. Image signal transmission from the thermal camera to the remote pilot's live feed screen on the iPad is significantly better with the Inspire 1 using DJI Lightbridge technology compared with the 900Mhz transmitter used with the P4P. "White hot" was also used for the image and video recording using this system but the same palette of colours is available to the operator.

Basic photogrammetry techniques were used to determine the approximate size of the hot spots given the flying height of the FLIR thermal sensor and the height of the canopy. For example, if the sensor height was 60m and the canopy height was 20m, the relative distance from the sensor to the hot spot would be approximately 40m. At this distance, the thermal sensor horizontal field of view (FOV) would be 55m at the canopy (using a 9mm lens) and the vertical FOV would be 42.5m. Thus, at 40m each pixel has ground sample distance of 8.6cm (horizontal) by 8.3cm (vertical). A cluster of ten pixels then has ground spot distance for measurement (target subtends 10 pixels) of just under 1m. There are very few arboreal mammals in Southeast Asia with a heat signature of approximately 36 degrees C that would even come close to emitting a $1m^2$ thermal signature. A large male proboscis monkeys, *Nasalis larvatus*, could emit close to $1m^2$, but with a long tail and mostly quadrupedal they are easily discriminated from orangutans. The survey team was comprised of an experienced wildlife biologist and a drone pilot experienced in aerial survey, thermal imaging and photogrammetry. The wildlife biologist acted as visual observer and they both monitored the live feed while the pilot was flying. If there was any doubt whether the thermal image was of an orangutan based on size and body motion, the drone was repositioned for a closer look to confirm.

Study sites

Drone flights were performed in United Plantations' "Kumai Estate", Central Kalimantan, Indonesia (Lat: -2.627644, Lon: 111.831075) (Fig. 1) in an area where the presence of orangutans is known over the course of 4 days. Two fragmented forests sites, Site 1 (316.36 Ha) and Site 2 (293.99 Ha) (Fig. 1), were surveyed thermal imaging.

Day 1) At Site 1, three planned flights at 1.5-2.5km, 200m and 100m above ground level (AGL) were performed as well as three opportunistically after 20:00 and at 22:00 local time, using the P4P system and video setting to record each flight while monitoring the live feed. The primary objective of these flights was to scout for possible orangutans in their nests and to verify that the settings used would provide good discrimination between orangutans and the forest canopy. While the 200m flying altitude provided excellent signal transmission and coverage of a large area per flight, the 100m flying altitude provided the optimal balance between transmission range, video/image resolution and the area covered per flight.

Day 2) Five flights were performed in Site 2 between 20:30-22:30 local time at 60m AGL using the P4P system. If the FLIR signal returned a white-hot-signal in the canopy, we made a low-pass fly-over at approx. 30m AGL to identify the source of the signal and recorded video sequences as well as still-pictures of the object. Videos and still pictures were reviewed in the field on a laptop. Post-processing of the imagery was required in order to determine the lat/long coordinates of the orangutan nests.

Day 3) Eight flights were performed between 20:00 and 01:00 local time using the Inspire 1 system flying at 60m AGL. Flights were carried out over two fragmented forest blocks in pre-planned flight transects with >20% average side overlap in the sensor field of view to ensure 100% coverage of the study areas. When a "white-hot-signal" was detected, still images and video were taken with the GPS position embedded in the image EXIF. Oblique video and still images were recorded at an angle 30 degrees up from vertical (slightly forward looking) allowed the pilot and visual observer to see into the secondary forest and below the canopy, minimizing the chance of false positives or "hot spots" concealed by vegetation. The distance at which "hot spots" could be detected depends on the environmental conditions, including canopy density, temperature of the forest and location of the orangutans in the canopy. This approach also enabled the survey team to view farther in front of the platform with increasing field of view, optimizing the resolution at the horizontal bottom of the image and enhancing the field of view at the top of the scene (Fig. 2). Parallel opposing flight paths were spaced 80m apart, resulting in a minimum overlap of 20m between the transects at the average field of view (FOV). Flying transects with opposing flight lines minimizes the chance of an orangutan being concealed by vegetation. Viewing live video allowed the survey team to see movement and positively identify several of the "hot spots" as orangutan by characteristic motion and outstretched limbs. The orangutans did not display any aversion to the drone flying between 30-40m overhead. Movements were observed to be casual and none of the orangutans attempted to leave their nest or conceal themselves. As the onboard GPS records the image location in the EXIF data of each photo with this system, verification of the location and flying subsequent

Figure 3. First thermal image of a wild female orangutan. A female orangutan embracing her infant in their nest approx. 25m above ground level.

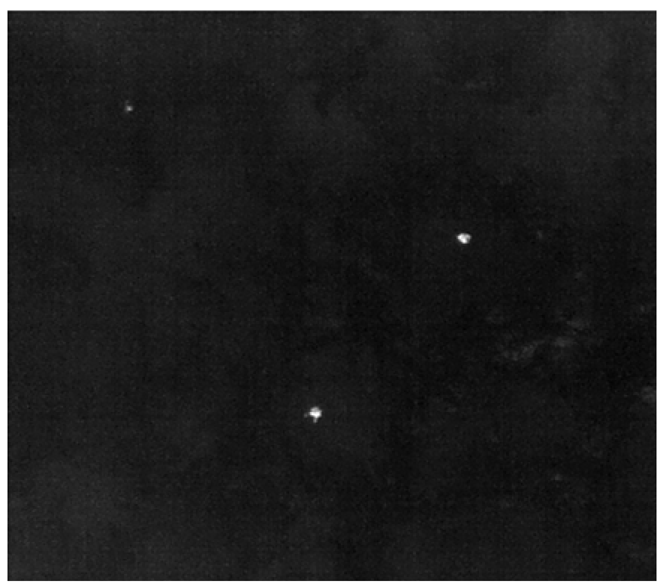

Figure 4. A thermal image of three orangutan hot spots. that were verified by measurement of body size and true colour images of nests in the same location the following morning.

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sorties using either thermal or RGB camera to the actual location of the orangutan sighting did not require post-processing of the imagery. The camera was tilted to vertical while hovering overhead each suspected or known orangutan and an image was captured for measurement of pixel sizes.

Day 4) Before sunrise the next day (05:30 local time), we revisited the same locations at where "white-hot-signal" were recorded in an attempt to verify the presence of orangutans and/or nests before they left the nests. We prepared the Inspire 1 drone for flight while it was still dark and attempted to fly over the nests where orangutans had been observed at night while taking true colour images of the area of interest as soon as there was enough light to take pictures. The true colour images were acquired using >60% overlap between adjacent images so they could be used to create a digital surface model of tree canopy structure and measure tree and nest height. Due to low clouds over the canopy, we did not observe any orangutans still in the nests with the true colour images/video that morning. When the clouds dissipated at 07:45 we were able to record images of the nests, where they were located the night before using the GPS referenced thermal camera images. However, by this time, the orangutan had already left their nests.

Results

Orangutan identification

The test flights confirmed the usefulness of FLIR to identify orangutans in nests at night. This was successful using both the P4P and the Inspire 1 drones. The test flights recorded several heat-signals that could easily be identified as orangutans based on body size, body heat, location and, in many cases, movements within the tree canopy. When operating the P4P, we used the two nearest points from the access road for low-pass flying and recorded both video and still pictures of a nest with a female with her infant and a nest with a single individual (Fig. 3). The closest distance between a drone and an orangutan was approximately 20m. None of the orangutans observed during these surveys appeared to be disturbed by the sound of the drones. While multiple techniques were used to confirm the presence and location of the orangutans in the survey areas, visual cues were the primary indicators. All of the orangutans, which were identified using the Inspire 1 system were initially detected in the thermal live view video on the iPad when the distance between the drone and the orangutan was in excess of 150m. In several cases, when the orangutans were located high in the canopy and the background forest temperature was significantly cooler (late at night), the initial sighting of a large "hot spot" (potential orangutan) occurred when the drone was in excess of 400m from the "hot spot". In these situations, the "hot spots" were approximately 10-12 degrees Celsius warmer than the forest and they appeared very bright and easily visible from a distance. When these "hot spots" were seen, the drone could easily be repositioned to confirm if it was an orangutan, with thermal video and still images.

Population estimates

There were no orangutan heat signals identified in study Site 1 but a total of 7 orangutans were observed in study Site 2 during one night of aerial thermal surveying (Fig. 4). Orangutans were detected using both drone systems, however, with the P4P being used for the low passes and the Inspire 1 for higher altitude flying. The P4P is significantly cheaper than the Inspire 1 and, consequently, we chose to use this for "riskier" test flights, whereas the Inspire 1, with its better range and higher resolution live-video transmission, was used for higher altitude flights.

In situations where we did not positively identify orangutans visually using the thermal camera, we recorded the GPS location of the hot spot, measured it based on the pixel size to verify that it was orangutan size and then flew to the same location the following morning, using a true colour camera to either observe that there was a fresh nest in the same location as the recorded "hot spot".

In every incident, there was a fresh nest in every location where a likely orangutan heat signal were recorded.

Discussion

This study successfully demonstrated that using thermal camera fitted to a consumer range DJI-drone can detect and identify orangutans in their nests, thereby also providing useful additional tools to estimating orangutan population in relatively small forest areas. We did not encounter difficulties in identifying orangutans from detected heat signal, most likely because of its large size. We experienced better detection probability after midnight until before sunrise, because the difference between the ambient temperature and a warm-blooded animal is highest, creating a clearer heat signal. At early evenings, 3-4 hours after sunset, many trees remained sufficiently warm to emit heat signals and create "false" detections. However, such false "detections" were usually easy to identify, due to their narrow linear features.

The primary weakness associated with using thermal camera fitted to a drone for orangutan population estimates is that we assume that all orangutans sleep in nests in the canopy. At this point in time, we are not aware of how big a proportion of orangutans in a population sleeps in nests and how many that do not sleep in nests. If "canopy nest sleepers" approximate all individuals in a given population, the survey technique can potentially provide accurate population estimates on its own. The accuracy, however, declines with a lower proportion of the population that are "canopy nest sleepers", although it will still provide a very important compliment to nest-counts from the ground.

Expanding on this study, we will use thermal cameras to compliment "traditional" nest counts and cross reference these with daily overflights over a period of time to better understand if some orangutans are permanently "ground sleepers" and others permanently "canopy nest sleepers" and, if so, the ratio between nest-sleepers and ground sleepers. In addition, orangutans staying on the ground or building nests at the lower part of canopy can still be detected, although the heat-signal may be so small that the risk of misidentifying it as a different or smaller animal species increases. If there are any identification uncertainties, closer inspection in real-time by repositioning the drone (e.g. we saw a few bearded pigs on the forest floor but were easily able to identify them by body shape and movement) or by follow up censuses using true colour aerial imagery or ground based surveys can eliminate this bias. It requires, however, that the observers continue to watch the detected object until sunrise. In the immediate future, we plan to carry out additional surveys with two teams to test the efficiency and complementarity of using the methods described in this study i.e. one team will use standard nest counts while the other uses drone based thermal imaging.

When using the Inspire 1 system, we were able to extend the distance in which we could maintain live feed of the video and record the locations of multiple orangutans due to the better video transmission of the DJI Lightbridge system. This approach can be applied to larger area surveys, such as Usun Apau National Park in Sarawak, Malaysia, (Arnold, 1957; Dow et al., 2015) using video and images recorded beyond the range of the live video feed on pre-loaded autonomous flight plans. Orangutan "hot spots" can be recorded over large areas during a single night of aerial surveying and then confirmed with follow-up true colour aerial imagery or ground based surveys. Using drones with better battery life can extend the survey range and cover 1000's of hectares in a one night survey. Orthorectified imagery and digital surface models can provide accurate location and nest height above ground and in the tree canopy (+/- 2 meters).

We also detected groups of other animals in the canopy but did not descend sufficiently close to identify the species, because our focus was on orangutan. Although we were able to clearly identify them as small primates by body size and patterns of movement in the video, species identification becomes increasingly difficult with decreasing body size as also reported in other

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studies (Goodenough et al., 2018; Kays et al., 2018). Once mainstream FLIR technology allows for higher resolution images as well as optical zoom capabilities, identifying small species will undoubtedly become easier.

Surveying arboreal mammals remains a difficult challenge, because evidence of presence is often confined to canopies. While arboreal surveys using camera traps have been found to be more effective in detecting arboreal mammals and birds, it remains time consuming and difficult (Bowler et al., 2017; Di Cerbo and Biancardi, 2013; Gregory et al., 2014; Olson et al., 2012). Therefore, surveying orangutans has relied primarily on ground based and aerial nest counts that can be affected by a range of uncontrollable variables and often perceived unreliable (Cheyne et al., 2013; Felton et al., 2003; Husson et al., 2009; Marshall and Meijaard, 2009; Mathewson et al., 2008; Spehar et al., 2015; Wich and Boyko, 2011). Using drones to detect chimpanzee and orangutan nests have recently been tested successfully, however, only 17% of known orangutan (*Pongo abelii*) and 8% of known chimpanzee nests (*Pan troglodytes*) were found (Bonnin et al., 2018; van Andel et al., 2015; Wich et al., 2016). There remain significant challenges with regards to selecting the optimal combination of flight speed, flying altitude and area size. Fixed winged drones can travel further distances and cover larger areas than a quadcopter drone with the same battery size. The downside is that a fixed wing must travel faster to create enough lift to stay airborne. This results in reduced nest detection rate at low altitude forcing surveyors to fly at higher altitude and then risk reducing detectability due to distance. Quadcopters can hover and descend closer to a detection to verify either a nest or an animal. However, they consume far more energy and their relative operating range is shorter than a fixed winged drone.

An important goal of our study was to develop and test a FLIR drone system platform that was cost-effective, easy to use, and within the financial means of the average conservation biologist and park manager (the price range for the two systems are between $7,500-$12,000 USD each, depending on where they are purchased). We paid $7,596.00 for all the equipment used with the P4P system and a total of $12,258.00 for the Inspire 1 system (Table 1). The system we developed and described in this study has the potential to be applied to orangutan populations across its distribution range. While we did not experience any problems with it, we recommend caution when flying model P4P, because the location and additional weight of the FLIR Pro and gimbal adds significant weight as well as slight tilt to the Phantom 4P. This puts additional strain on the four motors carrying the camera system, because its computer-controlled navigator will keep the drone pitch in a horizontal position during hovering. Whereas the P4P operates close to its maximum flying weight capacity, the DJI Inspire 1 and Zenmuse XT camera provided many advantages, especially the better range of the live feed image transmission and active recording of the GPS position into the image EXIF data. Based on our surveys, the advantages of the Inspire 1 system far outweighed the additional cost of this system. Drone and thermal imaging technology is changing very quickly these days and there will likely be better systems available for comparable prices.

We hope that our results will encourage researchers and conservationists to utilize and further develop thermal imaging systems and techniques and thereby improve the accuracy of population estimates of Asia’s only great ape as well as other species of great apes known to sleep in the canopy. This will assist in current as well as future conservation intervention and management of the species.

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Table 1. Comparison of the two thermal systems used in this study.

Detail	DJI Inspire 1 Thermal System	DJI Phantom 4 Pro Thermal System
Platform Type	Quadcopter	Quadcopter
Total weight of equipment/case	8.8 kg	7.8 kg
Carrying case dimensions	57 x 55 x 27 cm	60 x 55 x 22 cm
Standard RGB Camera	Z3 with gimbal. 1/2.3" CMOS 12.4MP	Fixed with gimbal 1" CMOS 20MP
Thermal camera sensor/lens	FLIR Zenmuse XT 640x512 9Hz	FLIR Vue Pro 640x512 9Hz
Thermal Imager	Uncooled VOx Microbolometer	Uncooled VOx Microbolometer
Sensor temperature range (high gain)	-13° to 275°F	-13° to 275°F
Digital zoom	yes (2x, 4x, 8x)	no
Gimbal	Integrated with Zenmuse XT Camera (3 axis)	Feiyu 3 axis with tilt and pan control
Controller	DJI Controller and DJI Go Software/iPad	DJI Controller and DJI Go Software/iPad
Live video	On iPad intgrated with drone control	On seperate 5" display with 900Mhz
System Requirements	iOS: 7.1 (or later)	iOS: 7.1 (or later)
Range of thermal camera live video (distance between drone and operator)	1.5-2.0 km Varies with flying altitude and local conditions (line of sight)	250-500m Varies with flying altitude and local conditions (line of sight)
Average flight time as equipped	15-17 minutes	18-21 minutes
GPS coordinates in Exif	yes	no
Simultaneous video and still images	yes	no
Approximate Cost	USD $12,500.00	USD $7,500.00

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