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Commercial drones can provide accurate and effective monitoring of the world's rarest primate

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Abstract

The recently established Hainan Tropical Rainforest National Park has designated the Hainan gibbon (*Nomascus hainanus*) as its flagship species, providing new hope for recovery of the last surviving population of the world's rarest primate. However, current monitoring methods are labour-intensive and only conducted for discrete periods, meaning that detailed information is still lacking on key Hainan gibbon population parameters (such as movement patterns, sleeping site selection and home range size). Alternative monitoring techniques are therefore necessary to supplement traditional methods and provide more accurate estimates of population parameters. Here, we tested whether flying two drones (DJI MAVIC2 Enterprise Advanced), one in the understory and the other above the canopy, could provide new information on Hainan gibbon biology and ecology. During a total of 60 flights, we successfully collected clear RGB and thermal infrared footage of Hainan gibbons. These data provide new baseline information on gibbon movement within the understory and the canopy, their surface body temperatures (23.0–34.7°C), and their movement area during the survey period. The low cost of this equipment could reduce the running costs for Hainan gibbon monitoring. Although drone-based monitoring has some limitations (e.g. monitoring efficiency could be affected by variation in forest structure and gibbon group size), this new method could complement existing monitoring approaches. Drone-based monitoring, using multiple drones and a real-time transmission network, could therefore contribute further towards Hainan Tropical Rainforest National Park's conservation planning for this Critically Endangered primate.

Introduction

Approximately 60% of primate species across the world are now threatened with extinction due to escalating habitat loss, hunting and expanding trade and consumption of global commodities (Estrada et al., 2017). The Critically Endangered Hainan gibbon (*Nomascus hainanus*), the world's rarest primate, is restricted to Bawangling National Nature Reserve (BNNR) in Hainan, China and is at high risk of extinction (Geissmann & Bleisch, 2020). This species has been the focus of long-term conservation management efforts (Chan et al., 2005; Fellowes et al., 2008; Turvey, Traylor-Holzer, et al., 2015), and in 2020 it was designated as the flagship species of the recently established Hainan Tropical Rainforest National Park, which includes BNNR and other nature reserves and forms part of China's new protected area network. Although this has raised the profile of this species, accurate information on key population parameters and dynamics is still needed before the national park can develop evidence-based conservation strategies (Liu et al., 2020).

As a result of historical hunting and habitat loss, only about 36 Hainan gibbons, which comprise five social groups, are estimated to currently survive within BNNR (Chan et al., 2020; Turvey, Traylor-Holzer, et al., 2015). Hainan gibbons can be elusive and cryptic, as they live in the canopy and only call for limited periods (Dufourq et al., 2021). Detection and monitoring of gibbons at BNNR has been conducted using a fixed-point count survey method, where monitoring teams listen opportunistically to calls from elevated listening posts for periods of 5–10 days at a time (Bryant et al., 2017; Chan et al., 2005; Fellowes et al., 2008; Turvey, Traylor-Holzer, et al., 2015). However, this approach is time- and labour-intensive and is only conducted for discrete survey periods. This approach has also been unable to provide detailed information on important gibbon population parameters and dynamics such as movement patterns and sleeping site selection (Liu et al., 2020; Zhang et al., 2020). Alternative monitoring techniques are therefore necessary to supplement such traditional gibbon monitoring methods at BNNR, and to provide further insights into these conservation-relevant factors (Dufourq et al., 2021; Turvey, Traylor-Holzer, et al., 2015; Zhang et al., 2020).

Thermal infrared images, captured by unoccupied aerial vehicles (UAVs) or drones, have recently been shown to constitute a potentially useful tool for detecting and monitoring threatened primates and other arboreal species across a variety of forested landscapes (Burke et al., 2019; He et al., 2020; Kays et al., 2019; Spaan et al., 2019). Thermal infrared images can also be used to derive surface body temperature data, which have been shown to be effective in monitoring populations, determining the behaviours and physiologies of individual animals, and detecting diseases and pregnancies (Collier et al., 2007; Cilulko et al., 2013; Dunbar et al., 2009; Hilsberg-Merz, 2008; Mccafferty, 2007; Thompson et al., 2017; Tattersall & Cadena, 2010). Thermal infrared images captured by drones can be used to survey primate populations, and to monitor their behaviour and health. However, such studies have typically used large drones that lack high-definition RGB sensors (He et al., 2020; Kays et al., 2019; Spaan et al., 2019; Zhang et al., 2020). This presents a challenge for determining whether hotspots detected in thermal images represent the target primates or other similar-sized mammalian species.

In 2020, a DJI drone (DJI M600 Pro) with a thermal infrared sensor was shown to be able to detect individuals and nocturnal behaviour for the largest Hainan gibbon social group (group C), which currently contains eight individuals: three subadults (one 3-year-old, one 5-year-old and one 6-year-old) and five adults (9–16 years old) (Zhang et al., 2020). However, this equipment is very expensive ($150 000), which is a considerable limitation for its application in studying many arboreal mammals. The DJI M600 Pro is also large and difficult to integrate simultaneously with both clear RBG and thermal sensors. Its heavy mass (16 kg) and specific requirement of large flat open areas for launching and landing limits its usage, as it can only be flown from sites situated far from gibbon groups, and can only record images from above the canopy rather than within the understory. Application of this drone for studying Hainan gibbons is thus further limited by the incomplete available information on the species' ecological and behavioural characteristics, such as how gibbon groups exploit different levels of the canopy. In addition, to avoid disturbance to primates, researchers usually conduct drone surveys from long distances away from target animals (typically 50 m above the canopy) (He et al., 2020; Kays et al., 2019). Such approaches have limited ability to establish the species identity of detected animals, with potential for confusion between Hainan gibbons and rhesus macaques (*Macaca mulatta*), which also occur within BNNR. Detections by this drone therefore typically require manual confirmation of thermal infrared sensor data to establish the identity of gibbons.

More detailed and cost-effective monitoring data might instead be obtained by using different types of drones, and by simultaneously flying multiple drones both in the understory and above the canopy. A new drone (DJI MAVIC2 Enterprise Advanced), produced by DJI Innovations, is relatively inexpensive (only $6900), is much lighter (0.9 kg) and includes both an RGB camera and a thermal infrared camera (Figure S1). These factors allow it to fly directly from the hand and the ground, and to record RGB and thermal infrared footage in both the canopy and the understory. Flying multiple drones directly from locations where gibbons are observed may therefore be able to provide new baselines on gibbon movement ecology and surface body temperature.

To investigate the potential of this new technology, we used two DJI MAVIC2 Enterprise Advanced drones to monitor Hainan gibbon group C. Specifically, we aimed to determine whether these drones can: (1) record clear RGB and/or thermal infrared footage of all eight gibbon individuals in this group; (2) monitor their movement in both the understory and the canopy; and (3) provide estimates of gibbon movement patterns, movement area (i.e. the maximum spatial area across which gibbons moved during the period of our survey) and surface body temperate.

Materials and Methods

Study site

The study was conducted from 3 to 30 July 2021 at the northeastern margin of BNNR (109°14′47.35″E, 19°5′45.17″N; Fig. 1). This area is covered by tropical evergreen rainforest, with trees reaching a maximum of 30 m in height (Zhang et al., 2020), surrounded by crop plantations around the edge of the reserve (see Video S1). The terrain is relatively mountainous, with a vertical elevation difference of about 500 m. BNNR is located at the northern edge of the tropics and has a tropical monsoon climate, with a mean annual temperature of 22.5–26.0°C, mean annual rainfall of 1759 mm and a distinct wet season in May–October when c. 80% of total rainfall occurs (Hainan Meteorological Information Network: http://www.hainanqx.cn; Du et al., 2020). Fieldwork was approved by Hainan Tropical Rainforest National Park, with a drone permit issued for 25 days in the field.

Drone flight protocols

In our previous study (Zhang et al., 2020), we used a DJI M600 Pro drone to record thermal infrared hotspots that might represent Hainan gibbons during nocturnal flights. However, it was impossible to observe these animals directly at night, and therefore we could not confirm that they definitely represented gibbons. We therefore performed diurnal flights with DJI MAVIC2 Enterprise Advanced drones to obtain both RGB and thermal infrared images of individuals that could be confirmed as gibbons. Additional efforts to obtain RGB and thermal infrared images and videos during several nocturnal drone flights proved unsuccessful.

Drone surveys must avoid any possible disturbance to the target species (Mulero-Pázmány et al., 2017). In particular, low-altitude drones, when flown close to animals, may elicit avoidance behaviours where animals move away from the drone (Penny et al., 2019). We therefore first determined threshold flight distances for both above-canopy and within-understory drone flights that would not cause any disturbance to gibbons while still being able to collect clear footage. Drones were flown as close to the gibbons as possible until they displayed notable avoidance behaviour, that is, they started to move away from the drone. We selected 30 m above the canopy (50 m above the ground; hereafter ‘long distance’ above the ground) as an appropriate flight distance for surveying the canopy; gibbons did not respond to the presence of the drone at this distance (see Video S5), but moved away when we flew the drone closer to the canopy, preventing us from obtaining images or videos. Similarly, we selected 20 m as an appropriate general flight distance in the understory. This threshold was suitable for taking clear photos and videos, but not for taking clear thermal infrared images to estimate gibbon body surface temperature (Figure S2 and Video S2). However, whereas most gibbons in group C moved away when the drone was flown at closer distances in the understory, the youngest gibbon in the group did not move away when the drone was ≥10 m away, so we used this threshold as an appropriate flight distance for this individual, allowing us to take clear RGB and thermal infrared footage (see Fig. 2 and Figure S3 and Video S3 and S4).

Survey methods

Since Hainan gibbons are detected by their early morning calls (Chan et al., 2005; Dufourq et al., 2021), we slept within the core area of the known distribution of group C to determine the location of the group's first-calling position. Because the approval to fly drones in the forest was limited to only 25 days, we devoted the first 10 days of fieldwork (3–13 July 2021) to determining the location of the group's first-calling position. During this period, group C always called from 06:00 to 08:00 at the similar location, so we selected a site (109°14′46.3″E, 19°05′38.9″N; Fig. 1b) from which we flew our drones in a diameter of 50 m around that location.

We designed a drone flight line transect to cover the current known home range of group C (BNNR management office, unpublished survey data), and conducted survey flights for the following 15 consecutive days (15–30 July 2021). One drone was always flown 30 m above the canopy for 1 h, once every 2 h from 06:00 to 18:00, to search for gibbons and obtain topographic information. The total survey route was of 2 km^2 and

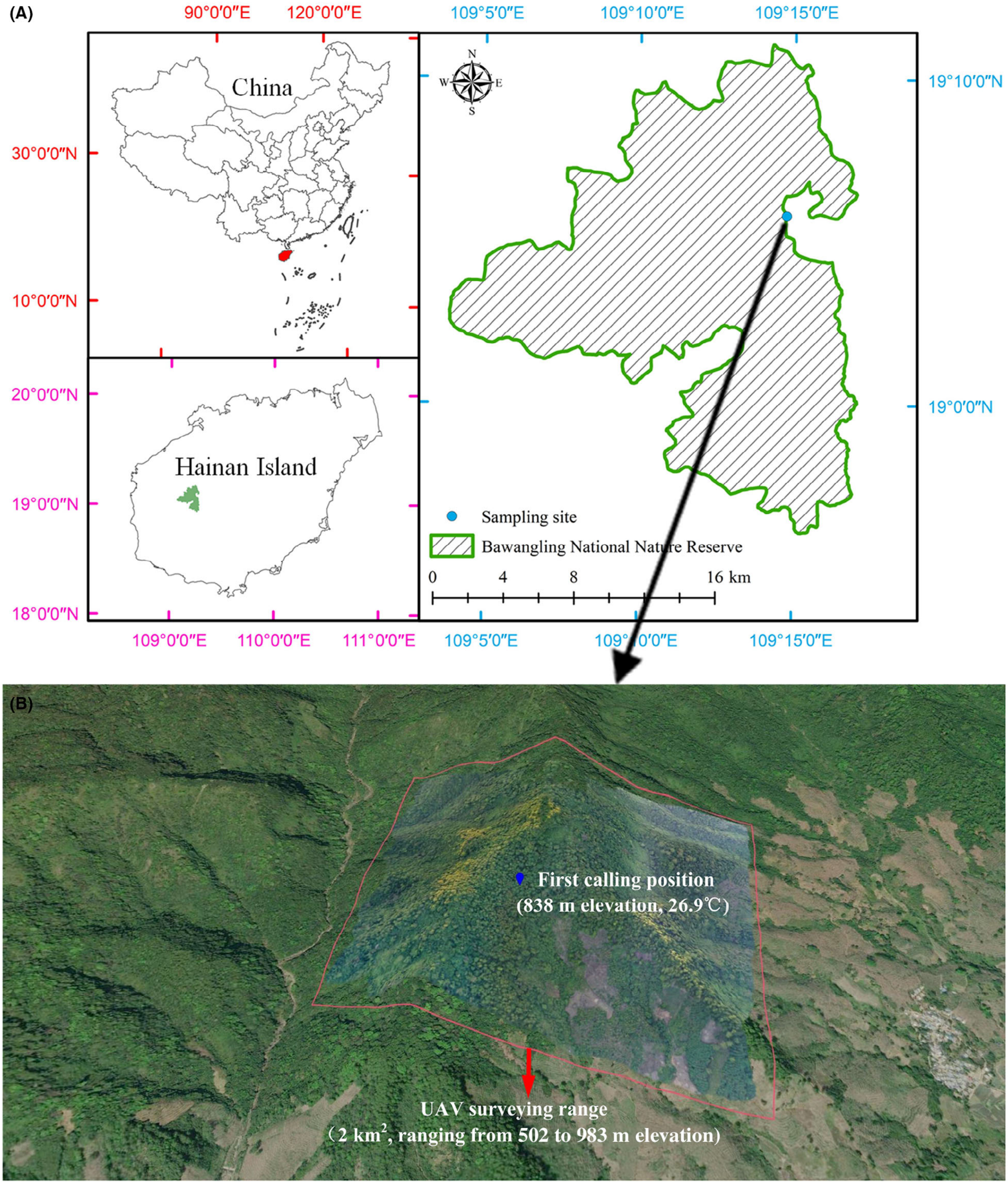

Figure 1. Map and landscape of survey site at Bawangling National Nature Reserve, Hainan, China, showing the process of flying a drone (DJIMAVIC2) (A). The fixed first-calling position of group C (the largest Hainan gibbon social group) and the UVA route range are also shown (B).

ranged from 502 to 983 m in elevation. Hainan gibbons are restricted to closed-canopy forests (Bryant et al., 2017; Chan et al., 2005), so we avoided areas of crop plantation or other open habitats at the edge of the reserve in our survey route (Fig. 1b). The route was set in the DJI pilot software; overlap and side-lap were both set at 80%,

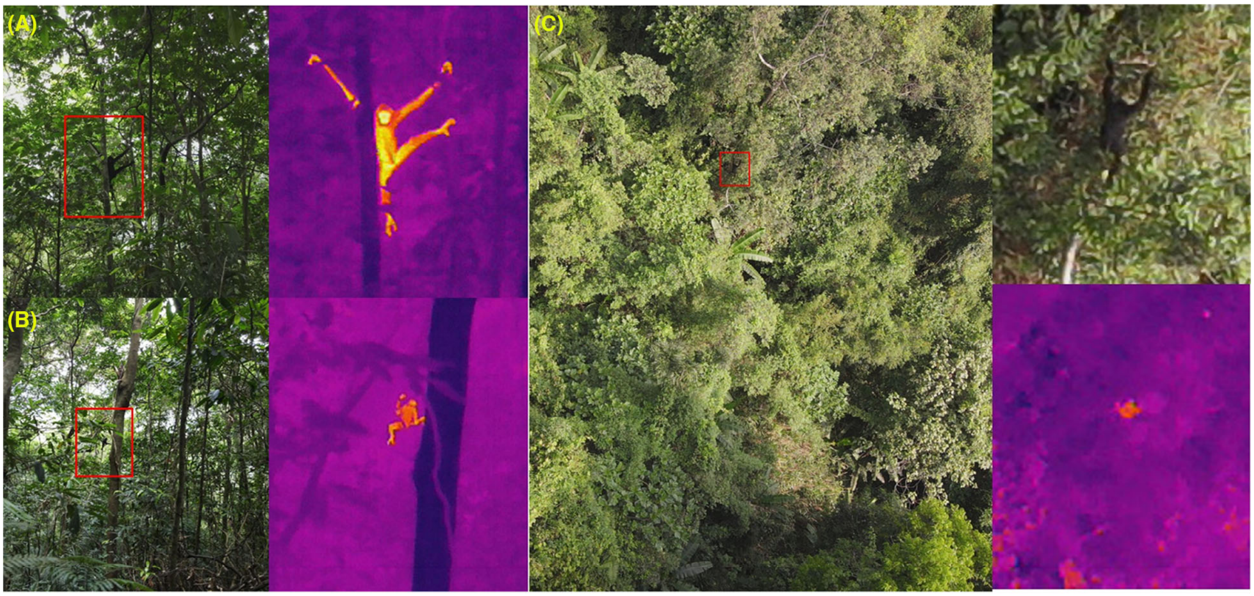

Figure 2. Recorded RGB and thermal infrared images of Hainan gibbon taken from (A) short (5–10 m above the ground), (B) medium (15–20 m above the ground) and (C) long (30 m above the canopy) distances.

speed was set at 5 m/s, and camera angle was set at 90°. The other drone was flown directly from the hand for short (5–10 m) and medium (15–20 m) distances above the ground whenever gibbons were observed in the understory (from 06:00 to 18:00, with camera angle set at 30° to keep a safe distance from gibbons to avoid disturbance). When we observed gibbons either above the canopy or in the understory, they were followed by the drone and photographed until they could no longer be observed.

The locations of individual gibbons and the movement area of group C during our field survey were determined from RGB and thermal infrared videos. Gibbon surface body temperatures (face/head, torso and limbs) were determined from thermal infrared images using the Thermal Analysis Tool in DJI. The elevation of group C's first-calling point and the drone survey route were derived from a digital elevation model formulated by Photoscan software. Each gibbon photograph had a recorded GPS location, so the location data from multiple photographs of moving gibbons were used to reconstruct their movement paths and group C's overall movement area (Table 1).

Results

Hainan gibbon individual identification

In a flight of 1 h, we were able to record RGB and thermal infrared footage for nearly 50 min, in both

Table 1. Drone model and parameters.

Model	Parameter	Description
Mavic 2 enterprise advanced 	Takeoff weight (without accessories)	909 g
	Dimensions (L × W × H)	Folded: 214 × 91 × 84 mm
		Unfolded+RTK Module: 322 × 242 × 125 mm
	Maximum flight time	28 min (RTK module attached)
	Hovering accuracy range	Vertical: ±0.1 m (with RTK)
		Horizontal: ±0.1 m (with RTK)
	Thermal camera	Focal length: approx. 9 mm
		Sensor resolution: 640 × 512 @30 Hz
		Accuracy of thermal temperature: ±2%
		Scene range: −40 to 150°C (high gain), −40 to 550°C (low gain)
	RGB camera	Sensor:1/2″ CMOS, effective pixels: 48 M
		Max image size: 8000 × 6000 pix

Table 2. Descriptions of recorded RGB and thermal infrared videos of Hainan gibbons during the 15 consecutive-day survey period.

Drone survey distances	Recorded RGB videos	Recorded thermal infrared videos
Short (5–10 m above ground)	5–10 videos of youngest gibbon per day	5–10 videos of youngest gibbon per day
Medium (15–20 m above ground)	5–10 videos of youngest gibbon per day	5–10 videos of youngest gibbon per day
Long (50 m above ground)	One video of 5–6 gibbon individuals per day	One video of 5–6 gibbon individuals per day

understory and above-canopy surveys (Table 2, Figs. 2 and 3; Video S2, S3, S4, S5). Gibbon heads, faces, torsos and limbs could be clearly identified from RGB and thermal infrared images at short distance (Fig. 2a). Faces could no longer be distinguished at medium and long distances (Fig. 2b and c). Heads, torsos and limbs could still be seen in images taken at medium distance, although they were less clear (Fig. 2b). Torso and arm outlines could still be distinguished in images taken at long distance, but heads and torsos were difficult to differentiate clearly (Fig. 2c).

Gibbon surface body temperature

Surface body temperature estimates derived from thermal infrared images taken at short distance ranged from 23.0 to 34.7°C. The mean detected gibbon temperature was 28.9°C (range across 15 different images for the youngest gibbon individual). The lowest mean temperature was 23.0°C on the legs, and the highest temperature was 34.7°C on the face (Fig. 3a). From images taken at medium distance, mean temperature was 25.9°C (range across 15 different images for the youngest gibbon individual), with lowest mean temperature of 23°C on the legs, and highest mean temperature of 28.1°C on the head (Fig. 3b). From images taken at long distance, mean temperature was 26.9°C (range across 30 different images for 5 to 6 individuals), with lowest mean temperature of 25.6°C on the arms, and highest mean temperature of 28.1°C on the head (Fig. 3c). Thermal infrared images taken at all distances thus demonstrated that temperatures across different parts of the gibbon body were: face or head > torso > limbs (Fig. 3).

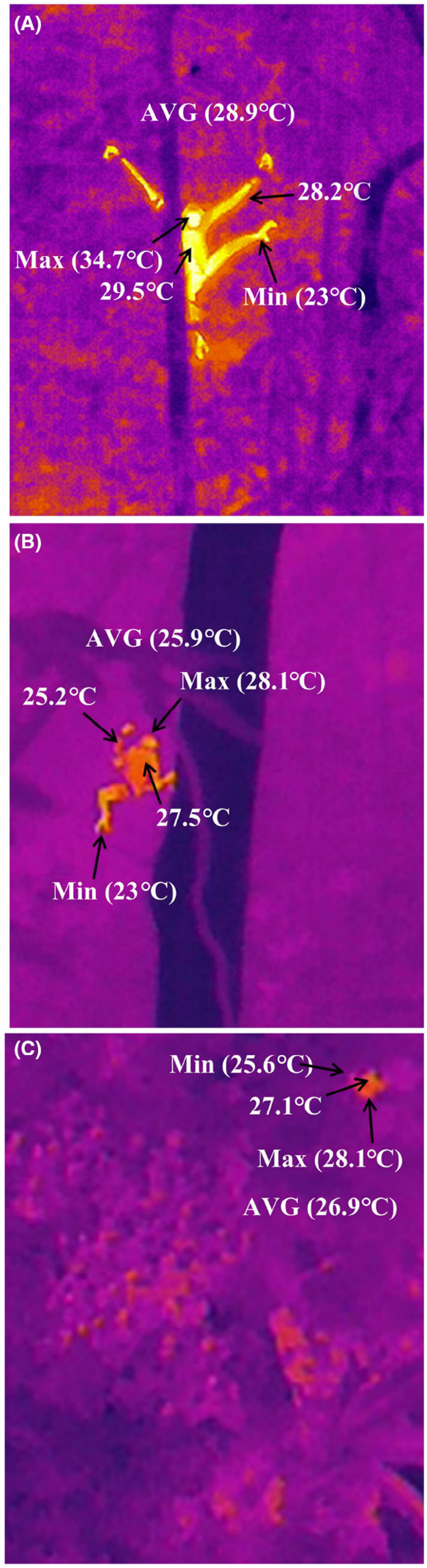

Figure 3. Surface body temperature of different parts of a Hainan gibbon, derived from thermal infrared images taken from (A) short, (B) medium and (C) long distances.

Individual gibbons and movement patterns

All eight known members of group C were captured in one video recorded on 17 July 2021 (see Video S6). We were only able to record the group using the visual video at short distance (see Video S6). During 15 consecutive days, group C moved around an area of c. 0.3 km^2, and across an elevational range of 670–963 m along a ridge near the border of the reserve (Fig. 4).

Discussion

In this study, we tested the efficacy of using two DJI MAVIC2 Enterprise Advanced drones to provide biological and ecological information on the Hainan gibbon, the world's rarest primate species. During our 2-week survey period, we were able to obtain clear thermal infrared footage of Hainan gibbons, and could detect and film all eight known members of group C and study their movement in the forest understory and canopy. We also collected data on the surface body temperature of this species. Identifying new monitoring methods has been a priority for conservation of Hainan gibbons and other threatened primate species (Piel et al., 2022; Semel et al., 2020; Turvey, Traylor-Holzer, et al., 2015). Drones may therefore represent a useful, cost-effective and labour-saving new component of the Hainan gibbon monitoring toolkit, as they complement existing methods and strengthen the conservation monitoring baseline at BNNR.

Human disturbance has been identified as a possible factor that restricts the local-scale distribution of Hainan gibbons, and may also have driven gibbons to alter their home ranges within BNNR (Bryant et al., 2016; Turvey, Traylor-Holzer, et al., 2015). Drone surveys must therefore avoid any possible disturbance to Hainan gibbons (Mulero-Pázmány et al., 2017). Two species of eagles present at BNNR, the mountain hawk-eagle (*Nisaetus nipalensis*) and black eagle (*Ictinaetus malaiensis*), represent potential gibbon predators and have been observed trying to predate young gibbons (Chan et al., 2005); as such, it is important to recognize that drones might present a threatening visual cue to gibbons at BNNR. The use of drones for monitoring primates also creates noise and causes changes in air turbulence. All of these factors might have an impact on an animal's psychology, physiology and behaviour (Ditmer et al., 2015; Mesquita et al., 2021; Vas et al., 2015). Indeed, we observed that

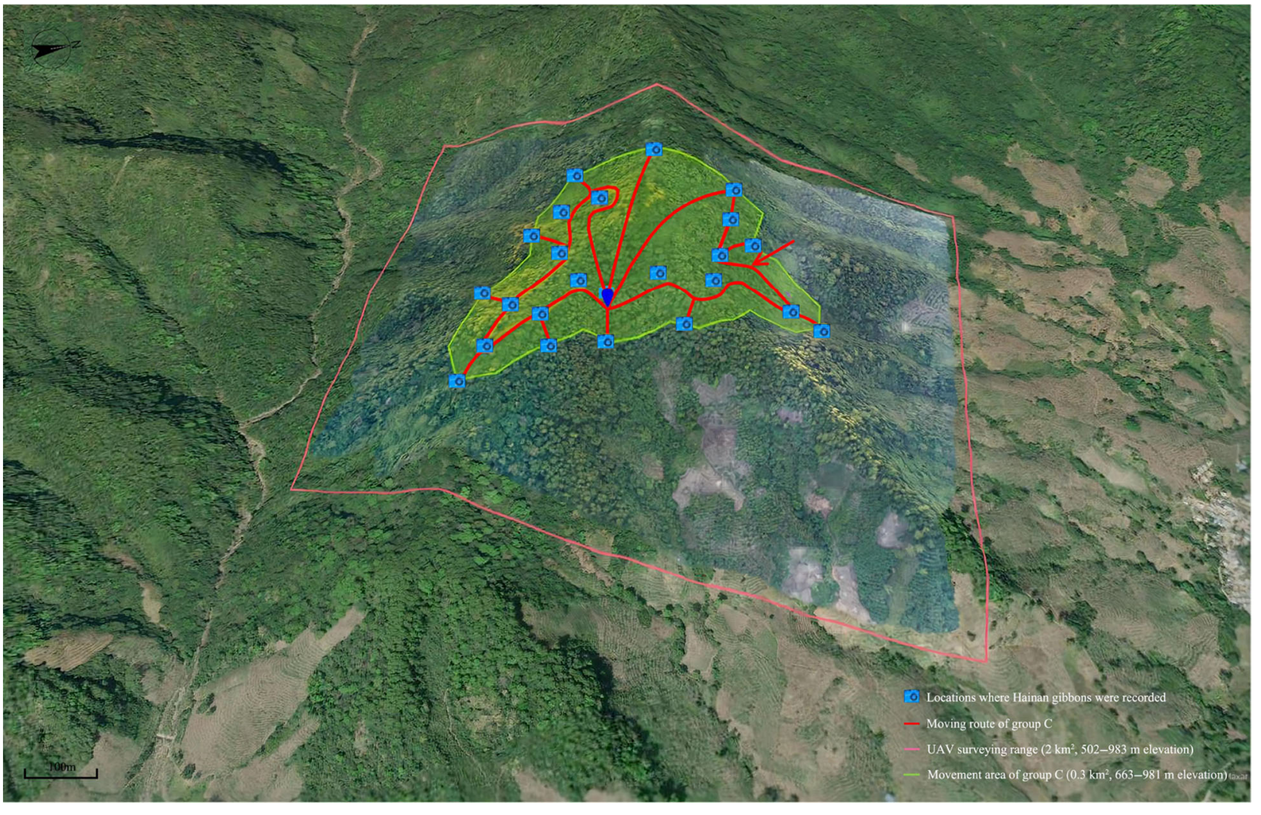

Figure 4. Movement route and area covered by group C during the survey period.

when a drone approached the Hainan gibbon group, they became alert and looked around upon hearing the drone's sound, and moved away or hid in the canopy when they saw the drone. UAVs might therefore have visual and acoustic impacts on gibbons, and monitoring frequency could also have an impact. In this study we established suitable survey parameters for using drones to survey group C, which do not cause any disturbance but also allow us to obtain clear RGB and thermal infrared footage of individual gibbons. However, as these survey parameters might be specific to this particular group and a specified part of the BNNR landscape, investigation of other groups in the future would warrant the reevaluation of these parameters; different Hainan gibbon groups occur across different forested areas of BNNR, and are known to vary in their level of habituation and proximity to human settlements and disturbance (Chan et al., 2020; Dufourq et al., 2021; Turvey, Traylor-Holzer, et al., 2015). Specific flight parameters would also need to be determined for drone surveys of other species of gibbons or arboreal mammals that occur in other landscapes.

Due to a lack of consistent methods for assessing existing monitoring data, and varying availability of monitoring data for different gibbon groups, the estimated Hainan gibbon home range area has been debated (Bryant et al., 2017). The use of DJI drones with well-established non-invasive survey parameters for longer survey periods could therefore represent a useful method to determine Hainan gibbon group home ranges. This approach could build upon our data on group C's movement area reported here. Given that we could collect gibbon spatial movement data over only a 2-week period, it is likely that this movement area is a subset of group C's true home range. Consistent with Spaan et al. (2019), we also demonstrate that DJI drones can allow remote monitoring of relative differences and patterns in surface body temperature across different parts of gibbon bodies. This approach could therefore additionally be used to monitor signs of disease, pregnancy, thermoregulation and associated conservation-relevant behaviours within the Hainan gibbon population in the future (*cf.* Cilulko et al., 2013; Collier et al., 2007; Dunbar et al., 2009; Dunbar & MacCarthy, 2006; Hilsberg-Merz, 2008; McCafferty, 2007; Tattersall & Cadena, 2010; Zhang et al., 2020).

Primate species in southeast Asia will become increasingly vulnerable to the impacts of future climate change (Graham et al., 2016), so developing approaches to evaluate potential climate change impacts on the Hainan gibbon population at BNNR is a high research priority (Liu et al., 2020). The last Hainan gibbon population is restricted to montane forests at the likely upper edge of the species' elevational range, suggesting that it might be particularly vulnerable to the effects of ongoing and future climate change (Turvey, Crees, & Di Fonzo, 2015). Thermoregulation represents a crucial factor that determines how primates can adapt at an individual level to climate change (Buck et al., 2018; Thompson et al., 2017). The use of DIJ drones to measure daily surface body temperature variation in Hainan gibbons can therefore provide potentially important insights for evaluating whether and how they could adjust and respond to physiological stresses associated with future change.

In addition to relative temperature patterns obtained from our drone data, absolute surface body temperature data could also provide important baselines for conservation management of Hainan gibbons. For example, such data could help in the future to understand how primates choose sleeping sites, as some species prefer sites that are close to their own temperature to reduce thermoregulatory costs (Cui et al., 2006; Fei et al., 2012; Xiang et al., 2010). However, comparison of Hainan gibbon temperature data obtained from thermal infrared images at short, medium and long distances in this study demonstrate that temperature estimates are influenced by filming distance: estimates derived at short distances are higher than those at medium or long distances.

Previous studies have shown that shooting distance (the distance between object and camera) can influence estimation of temperature values from TIR images, with similar variation previously documented for other species (Cilulko et al., 2013; Faye et al., 2016; Nienaber et al., 2010). Although gibbon surface body temperature estimates based upon close-range photographs are likely to be close to individuals' true body temperature, we recognize that the relationship between shooting distance and changes in estimation of surface body temperature by drones is complex, and understanding this relationship needs further examination beyond the scope of the current study.

However, different temperature data obtained from the same survey distance could still provide important comparative insights. For example, group C sleeps close to the canopy (Zhang et al., 2020), so temperature data obtained at long distances could be used to quantify whether this group selects sleeping sites that are comparable to their own temperature. During our survey period, group C always made its first call from the same location every morning, indicating that this location represented its sleeping site during this period. The average temperature of the thermal infrared image taken from 30 m above the canopy at this location is 26.9°C, which is the same value as the estimated mean gibbon surface body temperature at the same distance. Based on these initial observations, we hypothesize that Hainan gibbons might select sleeping sites on trees with similar temperatures. If this hypothesis is correct, it would also explain why gibbons made their first calls at the same location throughout the duration of the survey. Although we presently lack extensive comparative data on canopy temperatures across the BNNR landscape, these observations may open a new window of future investigation regarding the possible influence of tree temperature on sleeping site selection by gibbons.

While our new monitoring approach is able to address several data-gaps, some challenges still remain for monitoring Hainan gibbons using drones. The drone's launch, return and landing can be difficult through forest canopy gaps, especially for small gap sizes. The drone might also be obscured from the operator by the canopy and become hard to locate. This situation can be particularly challenging when a drone is running on low batteries. The drone signal can also be lost in montane landscapes such as that of BNNR. Under such circumstances, our survey method might become more complicated than when conducting an automatic blind drone survey, as it demands greater engagement of the drone operator. Inclement weather conditions often prevalent in tropical rain forests (e.g. rain, high wind, fog, mist) might also severely restrict the detection of gibbons by drones.

With the help of low-frequency UAV monitoring, we were able to determine the activity path of Hainan gibbon group C during the period of our study. Accordingly, thermal infrared cameras could be positioned near the ground in this area to improve the efficiency of passive monitoring. We believe that a combination of all-weather ground-based passive observation combined with low-frequency (e.g. 2 days/month) aerial UAV-based active surveying could therefore provide a suitable low-impact approach for monitoring Hainan gibbons. Ongoing progress in development of small and micro-UAVs and their sensors, as well as development of silent propellers, will hopefully further assist in reducing any possible disturbance to gibbons associated with the use of drones. For example, the Massachusetts Institute of Technology (MIT, USA) has recently developed a ring propeller that can reduce the noise of drone blades by nearly 50% (https://www.ll.mit.edu/news/six-lincoln-laboratory-inventions-win-rd-100-awards). Once this silent drone technology is more readily and cheaply available for conservation management, it will further support drone-based monitoring of Hainan gibbons and other species.

Conclusion

Our study offers important practical implications for future monitoring of Hainan gibbons at BNNR. Current standard monitoring procedures typically require at least five well-trained forest rangers for monitoring one group of Hainan gibbons. This approach has often resulted in insufficient availability of monitoring teams for consistent observation of all five gibbon groups. Conversely, two forest rangers using two DJI drones would be able to monitor one gibbon group: one drone could be flown at short distance to capture detailed RGB and thermal infrared footage, and the other could be flown at long distance to monitor the group's home range and movement patterns. This combined approach would allow cost-effective collection of clear RGB footage of all gibbon groups within BNNR, together with information on their daily movement patterns and area, and their home range and sleeping site selection characteristics. The use of drones would also establish baselines on Hainan gibbon surface body temperatures across different seasons, pregnancy stages and age classes. Together this information could be used to monitor changes in Hainan gibbon population growth and distribution within BNNR, evaluate whether current habitat is suitable for each group, and detect physiological signs of disease and reproduction. Therefore we suggest that the Hainan Tropical Rainforest National Park could use DJI drones for ongoing gibbon monitoring, where two drones may be deployed for each of the five gibbon groups. These could be integrated into a real-time transmission network alongside the existing gibbon monitoring team. Drone usage has the potential to increase the coverage and continuity of long-term monitoring of Hainan gibbons, and could complement existing conservation monitoring for this Critically Endangered species.

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Author Contributions

Hui Zhang and Zhongyu Sun designed the research; Hui Zhang, Xiqiang Song, Nan Wang and Zhongyu Sun performed the research and analysed the data; Hui Zhang, Samuel T. Turvey, Shree P. Pandey, Xiqiang Song, Nan Wang and Zhongyu Sun wrote the paper.

Conflict of Interest Statement

The authors declare that they have no competing interests.

Data Availability Availability

All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. The images of previous drone (DJI M600 pro) and new drone (DJIMAVIC 2) which is used for surveying Hainan gibbon in current study.

Figure S2. The unclear thermal infrared image of Hainan gibbon, which is taken when flying drone 20 m away from it and it cannot be used to deduce body temperature of Hainan gibbon.

Figure S3. The clear visible images of the youngest Hainan gibbon in group C which are taken when flying drone 10 m away from it.

Video S1. The video of the habitat landscape for group C which is attained by the drone.

Video S2. The recorded RGB and thermal infrared footage of group C, when flying drone at > 20 m distance in the understory.

Video S3. The recorded clear RGB and thermal infrared footage and surface temperature of the youngest gibbon, when flying drone in the understory.

Video S4. The recorded interesting video of Hainan gibbon's eating behavior.

Video S5. The recorded clear RGB and thermal infrared footage and surface temperature of the youngest gibbon, when flying drone in the canopy.

Video S6. The recorded video of the whole eight gibbon individuals for group C, when flying drone in the understory.