UAV-assisted counts of group size facilitate accurate population surveys of the Critically Endangered cao vit gibbon *Nomascus nasutus*

OLIVER R. WEARN, HOANG TRINH-DINH, QUYET KHAC LE and THO DUC NGUYEN

Abstract Gibbons are often difficult to observe in dense forest habitats using traditional ground-based methods. This makes it challenging to estimate group sizes and, in turn, population sizes. This has proven to be a key constraint on accurate monitoring of the last remaining population of the Critically Endangered cao vit gibbon *Nomascus nasutus*. However, new technologies are beginning to circumvent the problems associated with traditional methods. We hypothesized that, by using an unoccupied aerial vehicle (UAV) equipped with thermal and standard (RGB) cameras, we could obtain more accurate group size counts than by using ground-based observations, as fewer gibbons would be missed. We tested this during a population survey of the cao vit gibbon, finding that the thermal video footage revealed additional individuals that were not counted by ground-based surveyors. Statistically, there was strong evidence (93% probability) that UAV-derived counts were higher (by 41%) than concurrent ground-based counts. We recorded six primate groups of three species (cao vit gibbon, rhesus macaque *Macaca mulatta* and Assamese macaque *Macaca assamensis*), including 24 gibbons across four groups (c. 20% of the global population). The RGB video footage also revealed seven female gibbons, two of which were carrying infants, providing vital group composition data. These data have contributed directly to a more accurate population survey of the species than would have been possible using direct observation only. We anticipate more widespread use of UAVs in the study of gibbons and other threatened species, leading to a more robust evidence base for their conservation.

Tóm tắt Với các phương pháp điều tra truyền thống, điều tra viên di chuyển trên mặt đất thường khó quan sát được vượn trong rừng rậm. Khó khăn này là thách thức đối với việc ước tính số cá thể trong đàn và trong quần thể. Trên thực tế, việc khó quan sát là trở ngại chính trong theo dõi, giám sát chính xác quần thể cuối cùng của loài Vượn cao vít *Nomascus nasutus,* đây là loài đang rất nguy cấp. Tuy nhiên, công nghệ mới đã bắt đầu giải quyết các vấn đề liên quan tới các phương pháp truyền thống. Chúng tôi giả thuyết là sử dụng tàu bay không người lái (UAV) có máy ảnh tầm nhiệt và máy ảnh quang học có thể thu được dữ liệu về số cá thể trong đàn chính xác hơn so với quan sát bởi điều tra viên di chuyển trên mặt đất vì ít cá thể bị bỏ sót hơn. Chúng tôi thử nghiệm phương pháp này trong một đợt điều tra quần thể Vượn cao vít, thực tế ghi nhận từ video hồng ngoại đã bổ sung thêm các cá thể không được ghi nhận bởi các điều tra viên dưới mặt đất. Về mặt thống kê, có bằng chứng vững chắc (xác suất 93%) rằng số lượng đếm được từ tàu bay không người lái cao hơn (41%) so với số lượng đếm bởi các điều tra viên dưới mặt đất trong cùng thời gian. Chúng tôi ghi nhận sáu đàn linh trưởng thuộc ba loài (Vượn cao vít, Khỉ vàng *Macaca mulatta* và Khỉ mốc *Macaca assamensis*), trong đó có bốn đàn vượn với 24 cá thể (khoảng 20% số lượng của loài). Các video quang học cũng ghi nhận bảy vượn cái, trong đó hai vượn cái có con non, bổ sung thông tin quan trọng về cấu trúc đàn. Những dữ liệu từ tàu bay không người lái đã đóng góp trực tiếp vào cuộc điều tra quần thể Vượn cao vít, làm cho kết quả chính xác hơn so với chỉ sử dụng dữ liệu quan sát thông thường. Chúng tôi dự đoán phương pháp dùng tàu bay không người lái (UAV) sẽ được sử dụng rộng trong nghiên cứu vượn và các loài đang bị đe dọa khác, cung cấp những cơ sở vững chắc hơn cho bảo tồn các loài này.

Keywords Cao vit gibbon, drone, group size count, *Nomascus nasutus*, population survey, thermal camera, unoccupied aerial vehicle, Vietnam

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The Critically Endangered cao vit gibbon *Nomascus nasutus* is one of the rarest apes, with an estimated global population of c. 120 individuals, all in a single forest block (Ma et al., 2020; Wearn et al., 2021). Current methods to survey the species involve two components: (1) an exhaustive count of the number of family groups that are heard or seen from mountain-top survey posts throughout the range of the species, and (2) opportunistic counts of family group size for any gibbons that are observed (Ma et al., 2020). Total population size ($\hat{N}$) is then estimated by multiplying the number of groups (g) by the average group size ($\hat{s}$) of observed groups (i.e. $\hat{N} = g \times \hat{s}$).

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TABLE 1 Primate group size counts made by direct observation and derived from UAV video footage in the Cao Vit Gibbon Species and Habitat Conservation Area, Vietnam.

		Direct observation			UAV observation		
Species	Date, time	Duration (min)[1]	Count	Composition[2]	Duration (min)[1]	Count	Composition[2]
Cao vit gibbon *Nomascus nasutus*	27 Oct. 2021, 10.00	182	5	2 female, 3 black	5	5	1 female, 3 black, 1 unknown
Cao vit gibbon	28 Oct. 2021, 9.32	28	2	1 female, 1 black	14	5	2 female, 3 black
Rhesus macaque *Macaca mulatta*	4 Nov. 2021, 13.05	8	4	Unknown	10	22	Unknown
Assamese macaque *Macaca assamensis*	6 Nov. 2011, 8.46	3	3	Unknown	8	13	Unknown
Cao vit gibbon	9 Nov. 2021, 9.22	50	5	2 females, 2 black, 1 small infant	6	7	2 females, 4 black, 1 small infant
Cao vit gibbon	10 Nov. 2021, 6.24	65	5	2 females, 3 black	17	7	2 females, 2 black, 2 unknown, 1 infant
Total		336	24		60	59	

[1]Total duration of each observation.

[2]Black individuals are either males, subadults or juveniles; these age classes cannot be distinguished easily in the field.

Despite the importance of the average group size parameter, obtaining an accurate estimate has proved difficult in practice (Trinh Dinh et al., 2018; Ma et al., 2020). Group size counts are made typically at distances of 30–500 m, with individual gibbons often passing in and out of view as they move through the dense vegetation. Observers must attempt to track multiple individuals as they move or they must wait for all gibbons to enter a feeding tree with a relatively open canopy (which happens infrequently). As a result, gibbon group counts are often incomplete and average group sizes are underestimated.

New technologies are beginning to overcome some of the difficulties associated with surveying gibbons and other cryptic primates, including the use of camera traps and acoustic recorders (Piel et al., 2021). In this study, we propose a new method for counting gibbon group size using unoccupied aerial vehicles (UAVs) and report on their use during a population survey of the cao vit gibbon. Our hypothesis was that group size counts using UAVs would miss fewer individuals, and would therefore be higher than those from traditional ground-based observations.

During 26 October–10 November 2021, we surveyed the cao vit gibbon population from 30 mountain-top survey posts across the range of the species in Vietnam (Cao Vit Gibbon Species and Habitat Conservation Area) and China (Bangliang National Nature Reserve), with methods closely following those of previous surveys (e.g. Ma et al., 2020). Each post was monitored by an observation team of 2–3 people for several (range 1–9) consecutive mornings (4.00–12.00). Independent from the observation teams, we also had a roving drone team, comprising a pilot and assistant, with a portable UAV (DJI Mavic 2 Enterprise Advanced, Shenzhen, China) and five batteries (each providing a maximum of 31 min of flight time). The UAV was equipped with a 640 × 512 pixel thermal camera and a 48 megapixel standard (RGB) camera. For each survey day, the drone team chose a survey post that was thought to have a high chance of detecting gibbons that were close by and/or observable (based on gibbon records from previous days and long-term monitoring data). If the observation teams sighted or heard gibbons, the drone team flew the UAV manually to the approximate location and attempted to obtain video footage. Flight heights were 30–120 m above the ground surface, camera angles were not standardized and line of sight with the UAV was maintained. We did not fly speculative missions to search for gibbon groups, to reduce any potential disturbance from the UAV during the population survey.

Author ORW later reviewed the video footage from the UAV to determine group sizes. We then compared these group sizes statistically to those made independently by the observation teams, using Bayesian paired sample *t* tests (Kruschke & Meredith, 2021).

Across 10 survey days, 6 had suitable weather for flying. We obtained video footage (simultaneous thermal and RGB) of four gibbon groups and could make group size counts in each case (Table 1), with individual gibbons evident as bright spots in the videos (Plate 1; Supplementary Video 1). We found it difficult to identify thermal bright spots conclusively as gibbons if individuals were stationary, but their identification became clear once they moved because of their unique locomotory style and relatively long forelimb length. We found the RGB footage to be more useful than the thermal footage for determining group composition, particularly for identifying the number of females

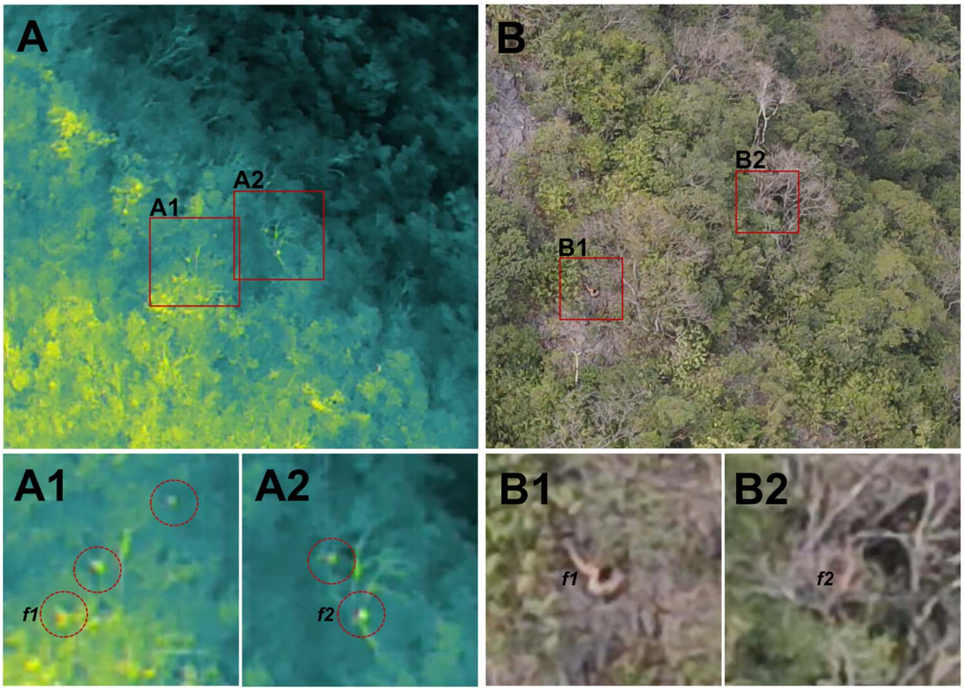

PLATE 1 Freeze-frame examples from the concurrent thermal and RGB UAV footage used in this study. (A) All five individuals in this group are discernible in the thermal video (three in A1 and two in A2). (B) At the same instance in the RGB video it is difficult to see the individuals with black fur, but one female can be seen clearly (B1) and another female is partially visible (B2).

from their characteristic yellow-blonde pelage (in contrast to the black fur of males, subadults and juveniles). We did not notice any obvious disturbances resulting from the presence of the UAV except during our first trial of the method. In this case, we believe that we approached the gibbons too closely (c. 40 m horizontal distance) and this seemed to cause the group to flee.

The UAV approach detected some individuals that were missed by the ground-based surveyors. The mean group size from the ground-based counts was 4.25 ± SD 1.50 compared to 6.00 ± SD 1.15 from the UAV footage, a 41% increase. This is despite the fact that UAV observations were shorter in duration (on average 11 vs 81 min for direct observations). We estimated the difference in the group counts to be 1.79 (95% highest-density interval −1.46 to 4.83; Fig. 1), with an estimated 93% probability that this difference was greater than zero. This provides strong support for our hypothesis that the UAV-derived counts would miss fewer individuals and would therefore be higher.

We also encountered two macaque groups during the fieldwork (rhesus macaque *Macaca mulatta* and Assamese macaque *Macaca assamensis*) and collected video footage opportunistically. Counts of the macaque groups using the UAV were substantially larger than those made by direct observation (Table 1). We also used RGB footage to confirm species identity, which can prove difficult for field teams given the similarities between macaque species.

We found evidence that a UAV-based method of counting primate group size was more effective than traditional methods, producing higher counts and in a shorter amount of observation time. Critical to these counts was the use of a thermal camera, in which individuals of a group could be seen as hotspots against the cooler background of the surrounding forest. The UAV-derived count data have been incorporated into the 2021 population survey of the cao vit gibbon, leading to a more accurate estimate of the global population size than would have been possible using only the direct observation data. The UAV footage also helped to provide group composition data for the gibbons, which are also critical for models of population viability for the species (e.g. Wearn et al., 2021). Here, we used a UAV to support

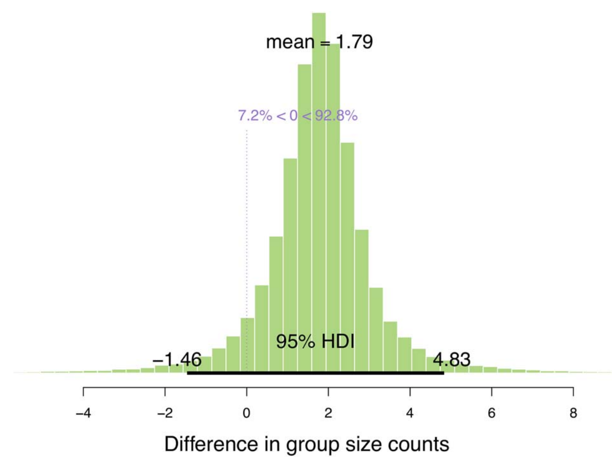

FIG. 1 Posterior probability distribution of the difference in group size counts using a UAV-based approach vs direct observation. Positive differences mean that the UAV method counted more individuals. There was a 7.2% probability that the difference was less than zero and a 92.8% probability that it was greater than zero. The highest-density interval (HDI) is indicated by the horizontal black bar.

traditional observations made by survey teams but we anticipate they could be used on their own to survey gibbons (e.g. using line or point transects), assuming that imperfect detection could be accounted for.

There are both advantages and disadvantages to UAV-assisted monitoring of the cao vit gibbon and other primate species. We found that the advantages include the fact that observations (e.g. of group size and composition) were less biased because of the greater detection capabilities of thermal cameras compared to the human eye. In general, this is likely to be the case when species are cryptic and/or partially obscured by vegetation. Remote observations using the UAV could also be made of groups that would have otherwise been too far away for human observers to reach, providing more data. However, the initial equipment costs are considerable (e.g. in our case a total of USD 6,700 for one UAV, one controller and five batteries), pilots had to be trained to operate the UAV safely and effectively, and technological limitations constrained data collection (in particular the short battery life and requirement for suitable environmental conditions for both flying and effective use of the thermal camera). In common with other studies (Kays et al., 2019; Zhang et al., 2020), we noticed that the effectiveness of the thermal camera was dependent on a sufficient temperature contrast between the target animals and their surroundings. We collected our data during a relatively cool period of the year (with ambient daytime temperatures typically 15–24 °C) and we expect that the thermal camera would be less useful during hotter periods of the year.

Our study adds to a growing, albeit nascent, literature demonstrating the effectiveness of drones for monitoring and studying primates and other threatened taxa (e.g. Hu et al., 2020; Oliveira-da-Costa et al., 2020; Piel et al., 2021). With further technological improvements, especially in battery life and thermal sensor resolution, we foresee an increasing role for UAV-based data collection in the monitoring and study of not just cao vit gibbons but a wide range of other cryptic and difficult-to-study species.

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Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. Flights were operated in accordance with regulations in Vietnam, under license from the Ministry of Defence.

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