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RESEARCH ARTICLE

Locating Chimpanzee Nests and Identifying Fruiting Trees With an Unmanned Aerial Vehicle

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Monitoring of animal populations is essential for conservation management. Various techniques are available to assess spatiotemporal patterns of species distribution and abundance. Nest surveys are often used for monitoring great apes. Quickly developing technologies, including unmanned aerial vehicles (UAVs) can be used to complement these ground-based surveys, especially for covering large areas rapidly. Aerial surveys have been used successfully to detect the nests of orang-utans. It is unknown if such an approach is practical for African apes, which usually build their nests at lower heights, where they might be obscured by forest canopy. In this 2-month study, UAV-derived aerial imagery was used for two distinct purposes: testing the detectability of chimpanzee nests and identifying fruiting trees used by chimpanzees in Loango National Park (Gabon). Chimpanzee nest data were collected through two approaches: we located nests on the ground and then tried to detect them in UAV photos and vice versa. Ground surveys were conducted using line transects, reconnaissance trails, and opportunistic sampling during which we detected 116 individual nests in 28 nest groups. In complementary UAV images we detected 48% of the individual nests (68% of nest groups) in open coastal forests and 8% of individual nests (33% of nest groups) in closed canopy inland forests. The key factor for nest detectability in UAV imagery was canopy openness. Data on fruiting trees were collected from five line transects. In 122 UAV images 14 species of trees ($N = 433$) were identified, alongside 37 tree species ($N = 205$) in complementary ground surveys. Relative abundance of common tree species correlated between ground and UAV surveys. We conclude that UAVs have great potential as a rapid assessment tool for detecting chimpanzee presence in forest with open canopy and assessing fruit tree availability. UAVs may have limited applicability for nest detection in closed canopy forest. Am. J. Primatol. 77:1122–1134, 2015.

Key words: chimpanzee; nest; survey; tree; UAV; presence

INTRODUCTION

The number of great apes in the wild is rapidly declining due to habitat loss, hunting, and infectious diseases [Bermejo et al., 2006; Campbell et al., 2008; Funwi-Gabga et al., 2014; Junker et al., 2012; Tranquilli et al., 2012; Walsh et al., 2003; Wich et al., 2008]. All great ape species and subspecies are classified as either endangered or critically endangered [IUCN, 2014]. Therefore, it is important to monitor their habitat and regularly assess population sizes and trends, as such data form the basis of science-based conservation management and policy guidance [Kühl et al. 2008; Nichols & Williams, 2006].

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Different methods are used to determine ape presence, density, community composition, and population size [Kühl et al. 2008]. Depending on the question and resources available, commonly applied data collection techniques are line transect distance sampling [Buckland et al., 2001,2010], reconnaissance trail surveys [Walsh and White, 1999], dung sampling for genetic analysis [Arandjelovic et al., 2010, 2011] and remote camera trapping [Head et al., 2013; Nakashima et al., 2013].

Line transect or reconnaissance trail nest count distance sampling is currently widely used for surveying large areas. This approach requires little equipment and has been applied to bonobos, chimpanzees, gorillas, and orang-utans [Junker et al., 2012; Murai et al., 2013; Plumptre 2000; Stokes et al., 2010; Serckx et al., 2014; Wich et al., 2011]. However, these surveys can be time consuming and therefore are not repeated frequently. This limits immediate detection of population changes, which is crucial for effective conservation management [Campbell et al., 2008].

The advantage of aerial nest surveys compared to other ground methods is that they can determine the distribution of apes (absence/presence) more rapidly and efficiently. Counts of orang-utan nests using helicopters in Malaysia required only 72 man-days compared to 1,100 man-days for a similar ground survey [Ancrenaz et al., 2005]. Orang-utan nests are more likely to be seen from the air as they build their nests between about 5 and 10 meters higher than chimpanzees [Hicks, 2010; Prasetyo et al., 2009]. A survey in the DR Congo by Hicks [2010] indicated that 79% of chimpanzee nests were covered by canopy, suggesting that 21% of nests could possibly be detected by an aerial survey.

As helicopters are costly and not always available, the innovation in the field of unmanned aerial vehicles (UAVs) (also referred to as drones) has inspired researchers to test them for surveying the habitat and distribution of orang-utans [Koh & Wich, 2012], as well as elephants [Vermeulen et al., 2013]. Small UAVs can fly pre-programmed GPS tracks at a low altitude (80–250 m), while taking videos or photographs at predefined intervals. Objects of interest, like ape nests, can then be manually detected in photos or by using object recognition algorithms [Kühl & Burghardt, 2013; van Gemert et al., 2014].

Additionally, UAVs can provide information on the state of the habitat surveyed, providing a better understanding of the factors determining distribution and density of the apes [Bracebridge et al., 2012; McLennan & Plumptre, 2012]. Broad habitat categories or obvious threats can be identified from satellite imagery, but details such as the presence of certain individual tree species is not straightforward [Nagendra et al. 2013].

In this study, we evaluate if UAV-derived aerial imagery can be used to: i) detect chimpanzee nests, and which conditions increase the detection rate; ii) locate and identify fruit tree species to characterize chimpanzee habitat. We systematically compare detection rates of chimpanzee nests and trees obtained from both ground surveys and aerial UAV surveys.

METHODS

Study Site

This study was conducted during 2 months from November 2012 to January 2013 at the Loango Ape Project study site (2°04' S, 9°3' E) in Loango National Park, Gabon (Fig. 1). The study area is 160 km^2 and situated on a peninsula [Head et al., 2011, 2013]. Mean annual rainfall is about 2,200 mm, and mean temperature is between 22.9°C and 27.2°C [Head et al., 2011]. The area selected for this study was approximately 25 km^2. Two main habitat categories were distinguished based on previous forest classification [Head et al., 2011]. Coastal forest covers an approximate 500-m strip between the savannah and the beach. It is characterized by unique floral composition, with mature trees with a height of approximately 20 m and several tree species with an open crown structure. The larger forest strip between the savannah and the lagoon of approximately 7 km is referred to as inland forest in this study. A large part of the inland forest contains heterogeneous mature, secondary and inundated tropical rainforest, exhibiting both open and closed understory [Head et al., 2012]. Depending on the species, mature trees have a height between 30 and 55 meters, and often a dense crown structure. These different types of inland forest were combined for this study, as specific tree species (see section "Ground truth tree surveys") and not habitat types were identified from the air.

UAV Model

The fixed-wing UAV model "Maja" was used [Bormatec, 2012], which costs about US$5,000 when fully equipped with a camera, sufficient batteries, spare parts and tools. The UAV was deployed with a wingspan of 180 or 220 cm and Lipo batteries of 5,000 or 8,000 mAh. An ArduPilot Mega (APM) was used as the autopilot system [3D Robotics, 2012; Koh & Wich, 2012]. The APM system has a computer processor, geographic positioning system (GPS), data logger, pressure and temperature sensor, airspeed sensor, triple-axis gyro, and accelerometer. The APM missions (height, waypoints, speed) were programmed using the APM-planner open-source software [Ardupilot, 2012]. Photos were taken by a Canon Powershot SX230 HS with GPS, which was programmed by a Canon Hack Development Kit to

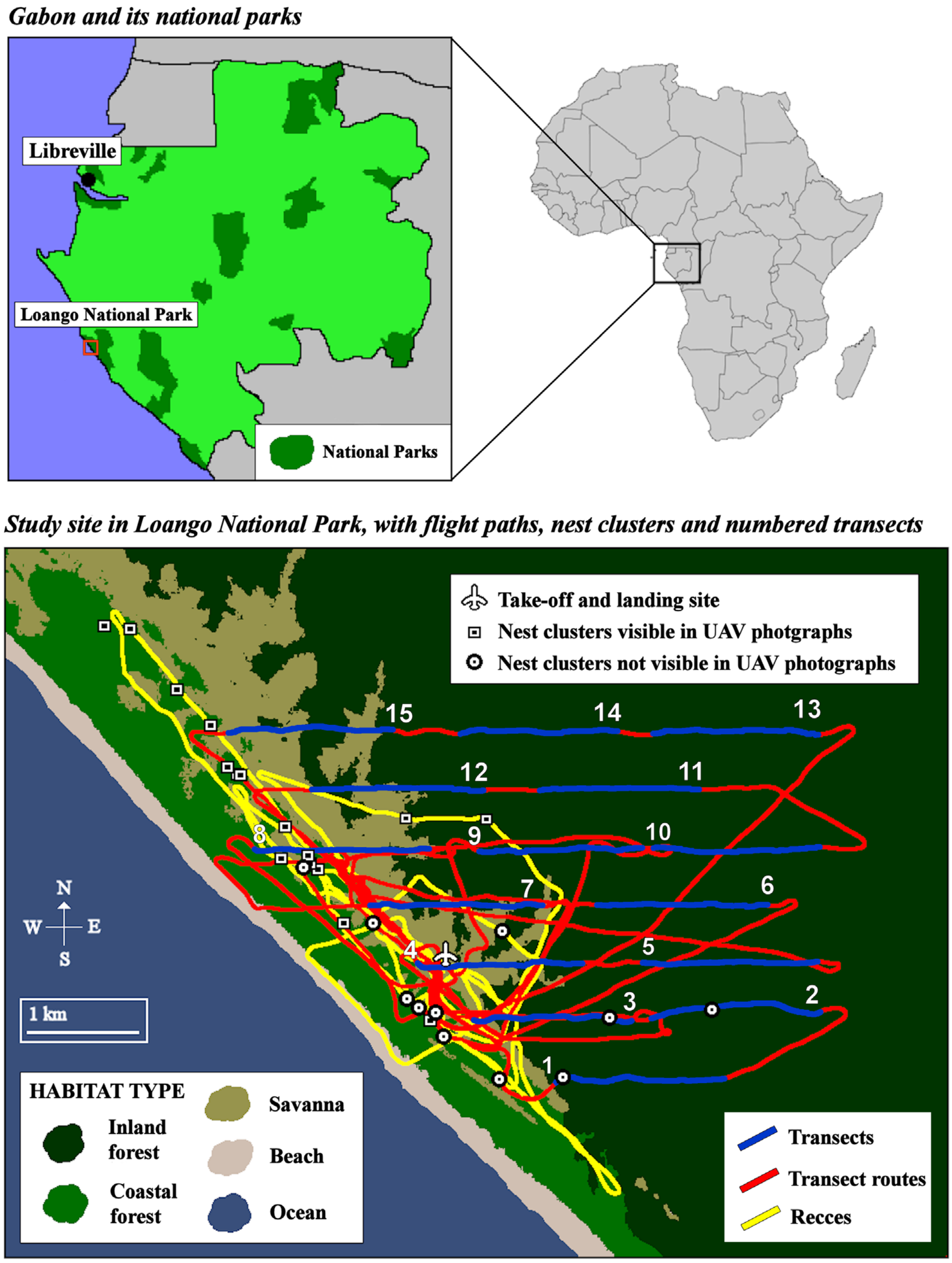

Fig. 1. Map of study area in Loango National Park in coastal Gabon, Africa. Study area with flights (red = 9transect flights, yellow = 7 reconnaissance trails flights) and nest sites (squares = Nest clusters were visible in UAV photographs, circles = nest clusters were not visible in UAV photographs).

automatically taking a picture every three seconds [CHDK, 2012].

Field Data Collection

UAV and camera calibration

For calibrating the UAV and camera settings, 15 flights over 9 days were conducted over a 5-week period. Flights were made to confirm if the UAV would navigate correctly over the marked GPS points, and to ascertain which UAV and camera settings would provide the best visibility. For this, two chimpanzee nests without canopy cover were first located from the ground and a bright yellow buoy was placed in each nest. These flight showed that the optimal altitude to locate an object on top of the canopy was between 80 and 110 m, while flying at a groundspeed of about 13 m/s, and that the optimum shutter speed was 1/1,000 s.

Aerial nest and tree surveys

Sixteen UAV flights in 8 days were made over a 3-week period. Flight preparations, UAV repairs, and grounds surveys were also conducted during this time. In total, 134 km were flown, with an average flight distance of 8.4 km (SD 3.0), and a total flight time of approximately 3 hr averaging 10 min per flight. The longest flight was 13.6 km using a 220 cm wing, and an 8,000 mAh battery that had 41% of its power left at the end of the flight. This 13.6 km took approximately 20 min which is roughly 1–2% of the time needed for a ground survey along the same distance.

Of the 16 data collection flights, nine were made to detect chimpanzee nests and tree species composition along 15 transects (each 1.5 km long) and seven flights were made to specific locations at which nests were first confirmed from the ground, either by reconnaissance trails or by opportunistic sampling (Fig. 1).

Of the 15 transects surveyed, five were validated on the ground (see section "Ground truth tree surveys"). Associated with these 15 transects were travel routes (reconnaissance routes) from the spot where the UAV was launched to the transect start, and from the transect end to either the next transect start or back to the landing place. Transects were placed using the "Systematic Segmented Trackline Sampling" option in the software "DISTANCE," and spaced 500 m apart [Thomas et al., 2010] (Fig. 1).

Ground truth nest surveys

Chimpanzee nest data were collected on the ground using two approaches within 8 days. In "approach 1" nest data were collected first via ground surveys and later confirmed in UAV photos. Data on nests with and without canopy cover were collected along reconnaissance trails [Walsh & White, 1999]. Additional locations of nests without canopy cover were collected opportunistically, by field teams habituating apes in the same area. Information on nest locations and tree species was then used to locate them in UAV imagery of flights. Nests covered by the canopy were not expected to be visible in a UAV photo, but this was later verified (see section "Image analysis"). In "approach 2," chimpanzee nests were first detected in UAV photos taken along five of the fifteen 1.5 km transects and associated reconnaissance trails, and then after located on the ground. For every nest, the following data were collected on the ground: GPS location; "nest height" (using a Ranging TLR75 Optical Range Finder); estimated "nest age" since construction (young; middle; old) [Tutin & Fernandez, 1984]; "habitat" type (inland forest or coastal forest); the level of "canopy openness" (open/closed); the tree species in which the nest was built; and the nest group to which it belonged.

The nest age classes were based on Tutin and Fernandez [1984] and considered young when leaves were still "*green and not wilted*," middle when leaves were "*dry and changing color*" and old when leaves were "*dead but nest* still *intact*." The habitat type was based on type of vegetation found and the location west (coastal) or east (inland) from the savannah. For the predictor on nest detectability "canopy openness", it was considered open when from the ground it appeared that no leaves or branches covered the nest and closed when either leaves or branches did cover the nest. A nest group is a cluster of nests built during a single night in one or several adjacent trees. It is possible that some but not all individual nests of a nest group were detected by the UAV. A picture was taken of each nest from the ground whenever possible. The nest-building species, that is, chimpanzees or gorillas, were distinguished based on nest height, nest type and understory closure [Sanz et al., 2007].

Ground truth tree surveys

Data were collected on tree species that are known to be used by chimpanzees for their fruits, leaves, or other purposes [Head et al., 2011]. Additional data were collected for some common species that were expected to be easily identified in aerial photographs. The first five 1.5 km transects selected for nest detection with approach 2 were also selected for the tree study. These five transects were sampled on the ground in 5 days, no later than 4 days after the equivalent flight, by following the flight path of the UAV as closely as possible by using a GPS. We recorded each species only once every 100 m and discarded all further observations of that species. We only recorded trees up to a maximum distance of 20 m perpendicular to the transect line. The trees were identified by an experienced local guide. The following factors were recorded for each tree: GPS location; height, distance to transect line, DBH, habitat type, and when possible, a photograph of the crown.

Analytical Methods

Image analysis

The image analysis for both nests and trees were initially done using the expertise of local field assistants and botanical literature [Prota4u, 2013]. The main information used to detect nests in the images was the color differences and type of structure that distinguished parts of a tree from the surrounding branches. Tree detection and identification was based on the structure, color of the crown and sometimes leaf shape. The nests that were first found on the ground were subsequently identified in complementary UAV photos, based on GPS location, the combination of tree species, nest height, and/or canopy openness estimated from the ground. The nests that were first found in a UAV photo were then located during complementary ground surveys based on the GPS location, tree species, and by assessing the surrounding trees and habitat.

Statistical analysis

A logistic regression was performed to evaluate which of the predictors (nest height, nest age, canopy openness, and surrounding habitat) influenced the detectability of chimpanzee nests in UAV photos using the software R. Possible combinations of predictors in models were examined and models then ranked by Akaike Information Criterion (AIC). Due to issues of model stability and validity, the nesting tree species could not be included; that is, the total nest sample size was too small relative to the number of tree species in which nests were built and for which parameters would have to be estimated (number of nests: 116; number of nesting tree species: 16). A Spearman correlation was used to test for a correlation between the relative abundance of tree species found in the ground and the aerial UAV survey.

Inter-observer reliability test in tree species identification

An inter-observer reliability test was conducted in order to compare the reliability of detection between different observers. "Anki" software [ankisrs.net] was used as a learning tool for tree species identification. Two observers were trained to review and mark trees. For the five selected transects, images taken along two and a half transects were screened by the first observer, who indicated a level of confidence for identified tree species (positive, unsure) followed by the second observer (positive, unsure, negative). The observers switched the roles for the remaining two and a half transects. All recognized trees were marked on the images, except for the species *Onthostema aubryanum* (Euphorbiaceae). This species was marked only once per image, as it was very common. Both tree and nest datasets of the two observers were then tested using the Kappa test function of the "fmsb" package in R [Pearson Education Japan, 2007], as this test calculates the agreement for qualitative categorical variables.

The authors complied with the protocol approved by the Gabonese National Park Authority (ANPN) for field research on wild chimpanzees. ANPN provided all necessary permits to fly a UAV in Loango National Park. All research reported in this manuscript adhered to the legal requirements of Gabon and to the principles of the American Society of Primatologists (ASP) for the ethical treatment of non-human primates.

RESULTS

Aerial Surveys

A total of 1,773 photographs were taken during the 16 data collection flights in January 2013. 22.5 km of transects and approximately 111 km of associated reconnaissance route flights were conducted. Of those photographs, 1,251 were considered suitable for detecting chimpanzee nests based on visual assessment of image quality. The quality images comprised of 787 photographs with inland forest and 464 with coastal forest. The other 693 photos were not included, mainly because photos were taken during take-off or landing, or because the quality of the photos was not sufficient to recognize nests. The low quality was often due to vibration or poor light conditions. The 693 excluded photos included 153 with savanna and 12 with beach where chimpanzee do not construct nests.

Chimpanzee Nest Detection

During the ground surveys, $N = 116$ chimpanzee nests belonging to $N = 28$ nest groups were detected along the five selected 1.5 km long transects, and while walking 17.5 km of reconnaissance routes. The 28 nest group nests were located in 27 UAV photos as one photo showed two nest groups (Fig. 2 shows examples). Using approach 1 (nest detection on ground followed by locating nests found in images) 26 of the 87 nests and 10 of the 21 nest groups found on the ground were also detected in aerial imagery (30% nest detection and 48% nest group detection rate) (Table I). With approach 2 (nest detection in aerial imagery followed by locating nests on the ground) 20 of the 29 nests and 7 of the 7 nest groups were detected in aerial imagery (69% nest detection rate).

The average height of all 116 nests located on the ground was $16.4 \pm$ SD 5.58 m. The average height of nests seen in the UAV photos was $20.0 \pm$ SD 5.04 m and $14.1 \pm$ SD 4.29 m for nests that were not seen from the air. No nests below a height of 10 m were seen in a UAV photo (Table I and II). 33% of young nests, 76% of middle age nests, and 7% of old nests were identified in UAV photos. Of the 92 chimpanzee nests found in the coastal forest, 48% were visible in a UAV photo, belonging to 68% of all nest groups. In the inland forest, only 8% of the 24 nests seen from the ground were visible in UAV photos, belonging to 33% of the nest groups (Table I). The average number of nests in a group was $4.5 \pm$ SD 2.61 nests. Nest groups visible in the UAV photos had an average of $5.5 \pm$ SD 2.85 nests, while the non-visible nest groups had an average of $3.2 \pm$ SD 1.40 nests.

Tree species might also influence nest detectability in UAV photos but trees were not included as a factor in the logistic regression as the sample size of nest (116) was too low for the amount of tree species (16) (Table II). More than 50% of nests built in *Pachypodanthium staudtii* (Annonaceae), *Dialium dinklagei* and *Guibourtia tessmannii* (both Caesalpinaceae) were found in both the ground and aerial surveys. These tree species are mainly found in the

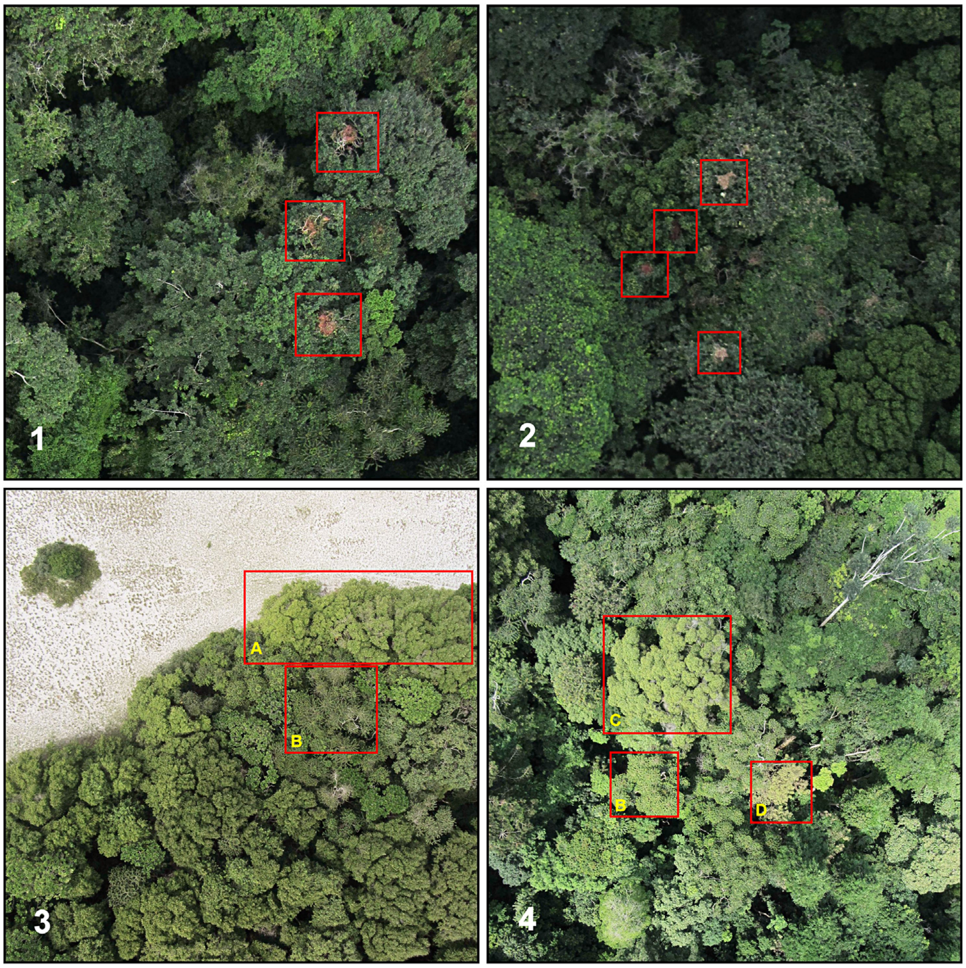

Fig. 2. Examples of UAV photos of chimpanzee nests (1 and 2) and of marked tree species (3 and 4). The tree species that were marked in photo 3 and 4 are Saccoglottis gabonensis, Humeriaceae (A), Onthostemaaubryanum, Euphorbiacea (B), Klainaedoxa gabonensis, Irvingiaceae (C), Vitex doniana, Lamiaceae (D).

coastal forest although they can also be found further inland (Head unpublished). No nests were detected in UAV photos in other tree species that are more common in inland forest such as *Irvinga gabonensis* (Irvingiaceae) and *Monodora myristicaceae* (Annonaceae).

Factors Influencing Chimpanzee Nest Detectability

In the logistic regression the four nest predictors were tested: "nest height" (classes: <10m, 10–<20m, 20–<30m), "nest age" (classes: young, middle old), "canopy openness" (classes: closed, open), and surrounding "habitat" (classes: inland, coastal). When ranking all possible models by AIC, there was a strong increase in AIC when the predictor "canopy openness" was not included in the model (Table III). Overall, the full model was significant as compared to the null model (likelihood ratio test: $X2 = 104.6$, $df = 5$, $P < 0.001$). From the predictors only canopy openness turned out to have a significant influence on nest detectability in UAV photos (LR $Z = 5.34$, $P < 0.001$) (Table IV).

Tree Species Identification and Inter-Observer Reliability Test

Along the five selected 1.5 km transects with UAV and corresponding ground surveys, 122 useable images taken. In these images, 433 individual trees were identified, comprising 14 different species. The complementary ground surveys along these five transects revealed 205 trees from 37 species. Out of the 14 tree species detected in the images, there were only 10 that we found three times or more in both the air and the ground surveys. From eight of these ten species, it is known that chimpanzees eat their fruits, for two species this is not known [Head et al., 2011]. A comparison of the relative abundance of these ten

TABLE I. Detectability of Nests and Nest Groups in UAV Photographs

	Nest height			Nest age			Habitat		
	<10 m	10 to <20 m	20 to <30 m	young	middle	old	Coastal forest	Inland forest	Total
Approach 1 Nests[a]									
Open canopy (UAV detected)[c]	1 (0)	8 (7)	17 (16)	9 (8)	16 (14)	1 (1)	25 (22)	1 (1)	26 (23)
Closed canopy (UAV detected)	11 (0)	39 (2)	11 (1)	23 (2)	4 (0)	34 (1)	38 (2)	23 (1)	61 (3)
Approach 2 Nests[b]									
Open canopy (UAV detected)	0 (0)	10 (10)	9 (9)	1 (1)	17 (17)	1 (1)	19 (19)	0 (0)	19 (19)
Closed canopy (UAV detected)	0 (0)	7 (1)	3 (0)	0 (0)	5 (1)	5 (0)	10 (1)	0 (0)	10 (1)
Ratio of all nest detected by UAV	0%	31%	65%	33%	76%	7%	48%	8%	
Approach 1 Nest groups (UAV detected)	3 (0)[d]	13 (5)	5 (5)	7 (5)	4 (3)	10 (2)	15 (8)	6 (2)	21 (10)
Approach 2 Nest groups (UAV detected)	0 (0)	5 (5)	2 (2)	1 (1)	5 (5)	1 (1)	7 (7)	0 (0)	7 (7)
Ratio of all nest groups detected by UAV	0%	55%	100%	75%	88%	27%	68%	33%	

[a]Approach 1 nests: ground survey followed by UAV survey.
[b]Approach 2 nests: UAV survey followed by ground survey.
[c]Numbers outside brackets are the total number of nest or groups in a certain category, numbers between brackets are nests or groups detected in UAV photographs.
[d]Nest height of nest group is based on the average height of all nests in a group.

species showed that the UAV survey gave a fairly comparable result to the ground survey (Spearmann correlation $r_s = 0.81$, $N = 10$, $P < 0.01$) (Table V) (Fig. 2 shows examples). There was significant inter-observer agreement in the detection and identification of trees in aerial imagery, with 297 out of 433 trees being assigned to the same species by both observers (Kappa test, $\kappa = 0.66$ (0.6–0.73), $P < 0.001$).

DISCUSSION

Our study shows that UAVs can be used to locate chimpanzee nesting sites that are not covered by canopy. In turn, this depends on how high nests are built or the density of the habitat. Nest detection probability was higher in the lower and more open coastal forest than the inland forest. There is also great potential for using UAVs to identify fruit tree species that are part of the chimpanzee diet. In this study, we were able to reliably identify ten common species from the air. However, the crowns of many more unidentified tree species were clearly distinct from neighboring trees. It is, therefore, likely that they are also distinguishable in UAV imagery with comprehensive botanical knowledge. The identification of trees can help conservationists and park managers determine the tree composition in an area, which can help to verify habitat quality and food availability for animals.

In its current usage, UAV surveys may have potential as a rapid assessment technique for determining chimpanzee presence and distribution, in particular for habitats that are more open and do not have very tall trees. Such an approach would also be useful for areas that are more difficult to access, such as mountainous or swampy habitat as these areas are often important for gorillas chimpanzees and bonobos, although only if these habitats have an open and fairly low canopy [Mulavwa et al., 2010; Poulsen & Clark, 2004; Rainey et al., 2010; Terada et al., 2015]. For gorillas, UAVs might be useful in areas were gorillas are known to nest in canopy gaps [Rothman et al., 2006].

Limitations of Study and Approach

As our analyses have shown, nest detectability depends on whether a nest is covered by branches or leaves. Therefore, the comparability of UAV-derived encounter rates between different areas needs to be treated with caution. Variation in nest encounter rate can simply be a result of ape nesting behavior, seasonal influences, or habitat structure and detectability by the UAV, rather than true variation in ape density. Even though UAV-nest surveys are currently unlikely to provide more than a confirmation of chimpanzee presence, the results from this study can be used to develop more advanced UAV surveys in the future. To get a measure on nest visibility in a certain habitat UAV surveys first require complementary baseline ground survey to calibrate aerial nest detection rates and thus quantify observed variation. There is also a need for good terrain maps in mountainous terrain, and for suitable weather conditions (Mulero-Pázmány et al. 2014; Paneque-

TABLE II. Tree Species in Which Chimpanzee Nests Have Been Detected or Not Detected in a UAV Photo

	Coastal forest		Inland forest							
Tree species	Not UAV detected	UAV detected	Not UAV detected	UAV detected	Total	% seen on ground and by UAV	Family	Chimpanzee use 1) Head unpublished, 2) Head et al. [2011]	Fruiting season by Head unpublished	Most common habitat by Head unpublished
Pachypodathium staudtii	2	9			11	82	Annonaceae	Fruit[1]	December to February	Coastal forest
Dialium dinklagei	5	15			20	75	Caesalpina-ceae	Fruit[1]	January to April	Coastal forest
Manilkara lacera	1	2			3	67	Sapotaceae	Fruit[1]	January to February	Coastal forest and edge beach
Guibortia pellegriniana	3	4			7	57	Caesalpina-ceae	Seed[1]	August to October	Coastal forest
Baphia sp.	1	1			2	50	Papiliona-ceae	None[2]	Unknown	Coastal forest
Saccoglottis gabonensis	8	6	4		18	33	Humeria-ceae	Fruit[2]	March to November	Edge savannah and inland forest
Chitranthus sp.	3	1			4	25	Sapindaceae	Fruit[2]	Unknown	Coastal forest
Diospyros dendo			4	1	5	20	Diospyros dendo	Fruit[2]	Febraury to April[1]	Throughout but mostly coastal forest
Scytopetalum sp.	12	1	4	1	18	11	Scytopetala-ceae	Fruit[2]	June to November	Throughout but mostly swamps
Burceraceae sp.	11	1			12	8	Burceraceae	Unknown	Unknown	Coastal Forest
Irvingia gabonensis			4		4	0	Irvingiaceae	Fruit[2]	January to March	Inland forest
Cola sp.			3		3	0	Sterculicae-ceae	Leaves/Other[2]	November to February	Throughout mostly inland
Monodora myristicaceae	1		1		2	0	Annonaceae	Fruit[2]	January and July	Inland closed forest
Onthostema aubrianum			1		1	0	Euphorbia-cea	Fruit[2]	Unknown	Inland forest
Chrysobalanus sp.	1				1	0	Chrysobala-naceae	Fruit[1]	November to March	Savannah, and on beach
Coula edulis			1		1	0	Olaceae	None[2]	December to April	Inland forest

TABLE III. Result of for All Models Ranked by the Akaike Information Criterion (AIC)

Model	AIC
1+canopy_openness[a]	56.83
1+nest_height_m_1[b]+canopy_openness	58.17
1+canopy_openness+habitat[c]	58.76
1+nest_age+canopy_openness	59.69
1+ nest_height_m_1+canopy_openness+habitat	60.06
1+nest_age[d]+nest_height_m_1+canopy_openness	61.24
1+nest_age+canopy_openness+habitat	61.68
1+nest_age+nest_height_m_1+canopy_openness+habitat	63.23
1+nest_age+nest_height_m_1+habitat	111.42
1+nest_age+nest_height_m_1	111.85
1+nest_age	115.58
1+nest_age+habitat	116.17
1+nest_height_m_1+habitat	130.38
1+nest_height_m_1	143.40
1+habitat	145.13
1	157.81

Once "canopy openness" is removed from the model there is a steep increase in AIC from 63 to 111. Models below or equal to AIC 63.23 have an intercept above −2 and a *P*-value below 0.05.
Considered nest predictors were as follows:
[a]Canopy openness (classes: closed, open).
[b]Nest height (classes: low (<10 m), medium [10 to <20 m], high [20 to <30 m]).
[c]Habitat (classes: inland, coastal).
[d]Nest age (classes: young, middle, old).

Gálvez et al., 2014). Fixed-wing UAVs can be lost due to unexpected weather conditions, technical failures, or a miscalculation in flight planning. Multirotor UAVs such as quadcopters have the advantage of being more stable than fixed wing UAVs, though their range is generally smaller.

UAV Application at Other Sites

When planning a UAV survey of apes or other species, several issues need to be considered. Working with a UAV requires thorough preparation and training, in particular when going to remote field sites with limited opportunity for further communication with UAV engineers. This includes both thorough UAV flight and maintenance training, as landing and take-off can damage the UAV. In this study, one UAV crashed in the initial phase and with the second UAV approximately one third of the time was spent on flight preparation and repair. Furthermore, it is important that the study site has certain facilities, including a power supply, a place to safely store spare parts, and a suitable place to make repairs and adjustments. Crucially, a large enough air strip (approximately 100 by 300 m) is needed for take-off and landing the UAV by a non-professional UAV pilot, although there are parachute techniques that require smaller open areas for landing. From a single appropriate landing strip and a UAV safe range of 30 km (total distance covered with a single battery charge) approximately 700 km^2 could be surveyed. Weather conditions will play a role in the

TABLE IV. Results of Logistic Regression for Evaluating the Influence of Predictors on Nest Detection Probability by UAV

	Estimate	Std. error	*z* value	*P*-value
Intercept	−2.08	0.97	−2.14	**0.032**
Nest age[a] (class middle)	0.28	0.98	0.28	0.778
Nest age[a] (class old)	−0.77	1.07	−0.72	0.473
Nest height[b] (class medium)	−0.57	0.84	−0.68	0.496
Canopy openess[c] (class open)	4.86	0.91	5.34	**9.55E-08**
Habitat[d] (class inland)	−0.07	1.19	−0.06	0.951

Considered nest predictors were as follows:
[a]Nest age (classes: young, middle, old).
[b]Nest height (classes: low (<10 m), medium [10 to <20 m], high [20 to <30 m]).
[c]Canopy openness (classes: closed, open).
[d]Habitat (classes: inland, coastal).

TABLE V. Comparison of Tree Species Counted in the Five Ground Transect and Corresponding UAV Images of Those Five Transects. Abundances comparable (Spearman correlation $r_s = 0.81$, $N = 10$ $P < 0.01$).

Species	Ground count	Ground %	Ground rank	UAV count	UAV %	UAV rank	Difference in %	Different rank	Family	Chimpanzee use 1) Head unpublished, 2) Head et al. [2011]
Irvingia gabonensis	16	16.0%	1	48	14.9%	3	−1.1%	−2	Irvingiaceae	Fruit[2]
Sacoglottis gabonensis	15	15.0%	2	93	28.9%	1	13.9%	1	Humeriaceae	Fruit[2]
Klainedoxa gabonensis	14	14.0%	3	39	12.1%	4	−1.9%	−1	Irvingiaceae	Fruit (not in Loango)[2]
Onthostema aubryanum	13	13.0%	4	54	16.8%	2	3.8%	2	Euphorbiacea	Fruit[2]
Vitex doniana	12	12.0%	5	22	6.8%	6	−5.2%	−1	Lamiaceae	Fruit[2]
Calypocalyx sp.	8	8.0%	6	11	3.4%	8	−4.6%	−2	Caesalpinaceae	Fruit[2]
Pycnanthus angolensis	6	6.0%	7	25	7.8%	5	1.8%	2	Myristicaceae	Fruit[2]
Chrysobalanus sp.	4	4.0%	8	2	0.6%	10	−3.4%	−2	Chrysobalanaceae	Fruit[1]
Aucoumea klaineana	3	3.0%	9	9	2.8%	9	−0.2%	0	Burseraceae	Unknown
Symphonia globulifera	2	2.0%	10	12	3.7%	7	1.7%	3	Clusiaceae	Unknown
Total	93			315						

success of a UAV survey including wind speed and rain. However, the same could also be said for ground-based surveys.

When extrapolating from our study, it is suggestive that UAV nest surveys would most likely be successful in the woodland savannahs of West Africa and at the ape range limits in Central and East Africa (Fig. 3). Surveys might also be successful in degraded rainforest, where canopy cover has been reduced. Due to the low detection rate in closed canopy rainforest, it is still questionable if a UAV survey can provide useful information about ape populations in these habitats.

Comparison With Other Survey Techniques

Assuming that the above mentioned limitations are solved, aerial surveys are among the least time-consuming methods compared to other great ape survey techniques, such as line transects, reconnaissance trails, camera traps, and genetic (Table VI) [Ancrenaz et al., 2005; Arandjelovic et al., 2011; Head

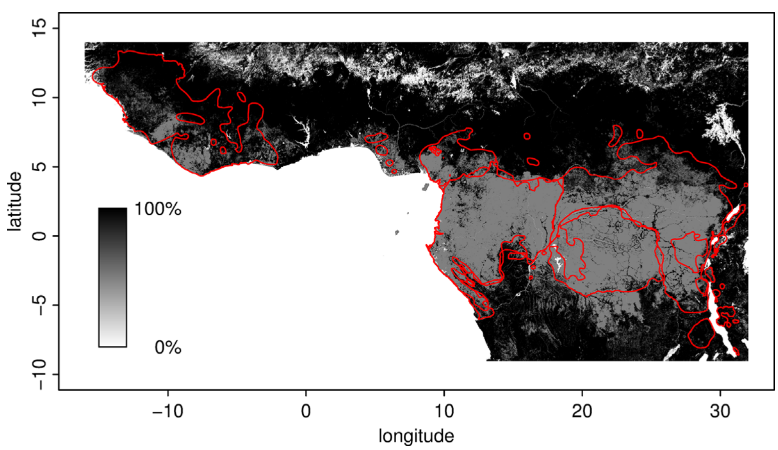

Fig. 3. Map of tropical Africa indicating suitability for UAV nest surveys. UAV suitability classification is based on GlobCover 2005 [European Space Agency, 2008] (high suitability (black): woodland savannah and open agricultural areas; medium suitability (gray): closed canopy rainforest; low suitability (white): remaining areas). Ape geographic ranges are shown as red line.

TABLE VI. Comparing Great Ape Survey Methods with Regard to Time, Costs Equipment, Training Needed, Population Parameters, and Accuracy

	Time used in cited studies	Est. Costs Equipment (in US$) of cited studies[h]	Level of training needed a) basic data collection b) applying the full survey method[h]	Population parameter (method in development)[i]	Level of accuracy for population survey[j]	Method enables to also easily collect data for[k]	a) Main advantage b) Main disadvantage
Line transects[a,b]	2–4 months	<2,500	a) Low: nest identification and recording data b) High: research design and analysis in distance	P, D	Medium: auxiliary variables (nest construction rate, nest decay rate) can be difficult to estimate.	H, O	a) Widely used and thus comparable b) Need for many man hours
Camera traps (SECR)[b,c]	2–13 months	5,000 to <10.000	a) Low: SD card collection & installation camera trap b) High: research design and individual recognition, analysis	P, D, I	High: with recognition of individuals and behavior	O, B	a) Recordings of several species b) Density method not common
Genetic sampling[d]	42 months	5,000 to <10.000	a) Low: recognition and collection of dung b) Very high: genetic analysis	P, D, I	Very high: DNA gives gender, family relations	H	a) Field collection fairly simple b) Hi-tech lab and sample transport
UAVs[e,f]	1–2 months	2,500 to <5,000	a) Medium: basic UAV flying, repair & programming b) High: research design, full UAV flying, repair and programming	P, (D)	Low: an indication that ape nests are present	A, H, O, F	a) Rapid survey over large areas b) No rapid data analysis so far
Helicopter aerial survey[g]	4 months (72 man days)	5,000 to <10.000	a) Low/medium: nest identification recording data and research design b) Very high: a professional flying the helicopter	P, D	Low: an indication that ape nests are present.	A, H, O, F	a) Can survey largest area b) Helicopter not readily available

[a]Hicks et al. 2010 (only considered line transect part of study).
[b]Nakashima et al. 2013.
[c]Head et al., 2013 (SECR, spatially explicit capture–recapture).
[d]Arandjelovic et al. 2011.
[e]Koh and Wich et al. 2012.
[f]This study.
[g]Ancrenaz et al., 2005.
[h]Based on estimates and experience by authors.
[i]P, Presence; D, Density; I, Individuals.
[j]Kühl et al. 2008.
[k]A, Anti-poaching; H, Habitat Disturbance signs; O, Other species; B, Behavior; F, Forest composition.

et al., 2013; Hicks et al., 2010; Koh & Wich, 2012; Kühl et al., 2008; Nakashima et al., 2013]. Compared to helicopter surveys, UAVs are unable to cover such large areas in such a small time, but are cheaper and more readily available. A trained UAV team can fly 100 km per day, given the right weather conditions. Despite an initial high investment of US$2,500–5,000 (including UAV maintenance), this reduces survey cost considerably. The level of training needed for basic data collection is comparable to other methods—as programming flights, changing batteries, and take-off and landing can be learned within a few days.

Conclusion and Outlook

With our study we tested a methodology to rapidly confirm chimpanzee presence in an area. Currently, such an approach may not seem advantageous when applied in relatively small areas compared to other techniques, such as reconnaissance trails or transect sampling, camera trapping, and acoustic monitoring. We see the benefits of UAV ape nest surveys as a rapid assessment tool for monitoring larger areas at a higher temporal resolution than is currently possible with other existing techniques. Regularly UAV monitored areas (e.g. yearly) may not only provide estimates for ape nest occurrence, but also information about the occurrence of other species or a change in land-use due to agriculture, mining or infrastructural developments.

Although the proportion of chimpanzee nests built high in the canopy is less than that of orangutans, their nests can still be detected in UAV images, as long as they are not covered by canopy. The current drawback of the approach is that nest detection through manual image processing of a large number of UAVs images is a challenge. However, it is likely that automated nest detection algorithms will improve this method considerably. UAV technology is improving rapidly with increases in an improved quality of data. In combination with pattern recognition technology, it is likely that such methods will find more and more applications for conservation management in the future [van Gemert et al., 2014]. Further research with regard to nest detection probability, visibility during different nest decay stages, seasonal nesting patterns, and automatic nest detection software are needed to reliably establish chimpanzee population density estimates over large areas with UAV monitoring.

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