Rapid development of individual identification and presence systems for a critically endangered antelope, the Mountain bongo

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Rapid development of individual identification and presence systems for a critically endangered antelope, the Mountain bongo

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Abstract

Monitoring of species, particularly remnant populations requiring urgent conservation is often hampered by the lack of reliable tools for individual identification (using images or their spoor). Here, we develop rapid monitoring tools for individual animals of the Mountain bongo (*Tragelaphus eurycerus isaaci*), a critically endangered subspecies of the bongo only found in Kenya. We developed and tested an individual identification system using camera trap footage, as well as a quantitative tool to identify bongo spoor in the field, both useable by naïve observers. We implemented an information content approach to assess the importance of different visual elements in 61 individual bongos to optimise our identification system. We tested the reliability of the system with 15 naïve observers. We conclude that an optimal identification system should rely on three main visual features (stripe pattern, facial markings and horns appearance). We show that reliability amongst observers is high ($\kappa = 0.64$). We also developed a field scheme to identify footprint and spoor sign. Measurements of bongo footprints were compared with those of waterbuck (*Kobus ellypsiprimnus*), a syntopic antelope. Confusion occurs between spoor and footprints of both species. We find that differences in the aspect ratio of bongo and waterbuck footprints can identify the two species, 1.22 (±0.08) for bongo and 1.49 (±0.10) for waterbuck. The acquisition of reliable tools ensures monitoring activities are less dependent on individual expertise, which will allow consistent monitoring of bongo remnant populations in the future. The methods we used to develop these monitoring tools can help managers and field workers in the study of this and similar rare species where monitoring is a challenge.

KEYWORDS
antelope, identification system, monitoring, Mountain bongo, one plan approach, tracking, *Tragelaphus eurycerus isaaci*

Abstraite

Le suivi des espèces, en particulier des populations restantes nécessitant une conservation urgente, est souvent entravé par le manque d'outils fiables pour l'identification des individus (à l'aide d'images ou de leurs traces). Nous développons ici des outils de suivi rapide des animaux individuels du bongo des montagnes (*Tragelaphus eurycerus isaaci*), une sous-espèce de bongo en danger critique d'extinction que l'on ne trouve qu'au Kenya. Nous avons développé et testé un système d'identification individuelle à l'aide des images de pièges photographiques, ainsi qu'un outil quantitatif permettant d'identifier la trace du bongo sur le terrain, tous deux utilisables par des observateurs naïfs. Nous avons mis en œuvre une approche du contenu de l'information pour évaluer l'importance des différents éléments visuels chez 61 bongos individuels afin d'optimiser notre système d'identification. Nous avons testé la fiabilité du système avec 15 observateurs naïfs. Nous concluons qu'un système d'identification optimal devrait s'appuyer sur trois principales caractéristiques visuelles (motif des rayures, marques faciales et apparence des cornes). Nous montrons que la fiabilité entre les observateurs est élevée (Kappa = 0,64). Nous avons également développé un schéma de terrain pour identifier les empreintes et les signes de traces. Les mesures des empreintes du bongo ont été comparées à celles du Cobe defassa (*Kobus ellypsiprimnus*), une antilope syntopique. Il y a confusion entre les traces et les empreintes des deux espèces. Nous avons constaté que les différences dans le rapport d'aspect des empreintes du bongo et du Cobe defassa permettent d'identifier les deux espèces, 1,22 (±0,08) pour le bongo et 1,49 (±0,10) pour le Cobe defassa. L'acquisition d'outils fiables garantit que les activités de suivi dépendent moins de l'expertise individuelle, ce qui permettra un suivi cohérent des populations restantes de bongos à l'avenir. Les méthodes que nous avons utilisées pour développer ces outils de suivi peuvent aider les responsables et les travailleurs de terrain dans l'étude de cette espèce et d'autres espèces rares similaires pour lesquelles le suivi est un défi.

1 | INTRODUCTION

The Mountain bongo (*Tragelaphus eurycerus isaaci*, hereafter bongo) is a large forest antelope endemic to the Afromontane forests of central Kenya (East, 1999). The known range is limited to four areas (Elkan & Smith, 2013; Faria et al., 2011) and with less than 50 individuals left in the wild (Sandri et al., in press) its situation is critical, with IUCN considering this subspecies Critically Endangered (IUCN SSC Antelope Specialist Group, 2016). Given the situation of this antelope in the wild, monitoring the remnant populations would positively affect its conservation. However, its scarcity, elusiveness and difficult terrain make it a difficult animal to study (Kingdon, 1982). While wild bongo populations are in a dire situation, ex-situ conservation of bongo has been successful, with a captive breeding program initiated in the late 60s that now comprises a global population of over 700 animals (Bosley, 2016). Captive individuals can prove beneficial to their wild counterparts in allowing access to otherwise difficult-to-study species (Mendelson III et al., 2019). Therefore, issues encountered while studying populations in the wild can be overcome by relying on captive individuals to develop methods and tools to implement in field studies (Hutchins & Conway, 1995), and thus help conservation actions. The development of monitoring tools could, therefore, enhance the chances of persistence of threatened populations in the wild.

A powerful method for monitoring wild populations is mark-recapture, as it allows insight into vital parameters such as survivorship, recruitment and population growth rate (Lebreton et al., 1993; Pradel, 1996). However, mark-recapture requires individuals either to be physically marked or to be identifiable noninvasively using, for example, unique natural markings (Petit & Valiere, 2006). Whereas the use of camera traps has enhanced chances to study rare and elusive species with limited effort (O'Connel et al., 2011; Rovero et al., 2014). Monitoring of small and fragmented populations thus relies on identifying individuals, even to provide minimum population estimates before any mark-recapture analysis is conducted. However, individual identification often requires reliance on observer expertise, which may be non-repeatable or time-consuming (e.g. see Hiby et al., 2009). Individual identification through camera trap footage has been very successful in some taxa, for example large felids (Alexander et al., 2016; Harmsen et al., 2017; Karanth et al., 2006a, 2006b; Karanth & Nichols, 1998; Soisalo & Cavalcanti, 2006; Weingarth et al., 2012). In these studies, typically one or more observers may identify individuals through direct observation or via footage, and individual animals are assigned an identity on observer agreement or according to an objective scheme (Alexander et al., 2016; Rich et al., 2014). Moreover, reliance on observer expertise not only hampers the immediate replicability of the analysis, but it also affects the likelihood that a monitoring program may continue in time if expertise changes or is lost, an issue encountered in multiple monitoring programs (Legg & Nagy, 2006). Therefore, a system that is repeatable and relies less on, or excludes altogether, observers' expertise is to be preferred.

Individual bongos possess multiple markings on flanks, chest and limbs (Elkan & Smith, 2013), and there is evidence these markings are informative for individual identification (Gibbon et al., 2015). Hence, an identification system for this antelope can be developed without relying on observer expertise or software, by using features that vary amongst individuals by shape, size or other attributes (Pennycuick, 1978). The use of a system that relies on objective features would further alleviate the need for individual expertise and, if repeatable and reliable, could be implemented by different observers on any available footage. The basic requirements for such a system are ease of use and reliability amongst observers with little or no expertise. However, for such a system to be effective for bongo monitoring it needs to be efficient in discerning individuals (i.e. informative) and it should be repeatable amongst different observers (i.e. reliable). Reliance on known individuals in a captive setting can facilitate the development and rigorous assessment of such a system.

An additional problem when studying bongo in its native range is the co-occurrence of the waterbuck (*Kobus ellipsiprymnus*), which is similar in size and difficult to distinguish from bongo based on spoor and footprints. As bongo direct sightings are virtually non-existent, fieldwork relies on spoor to assess its presence in a location. Even experienced trackers can easily confound waterbuck and bongo dung (Faria et al., 2011). Whereas bongo and waterbuck tracks are considered easier to distinguish due to differences in shape, field workers still need to rely on experienced trackers (Estes et al., 2008) due to the lack of quantitative measures to facilitate species identification. While tracks can be reliably used to assess species presence (Stander et al., 2009) the difficulty in encountering bongo in the wild results in a limited amount of information available regarding the characterisation of spoor, hence even experienced trackers may lack this expertise. Bongo monitoring efforts would benefit from the development of a quantitative tool to discern spoor from waterbuck. Hence, both the lack of an ID system to conduct monitoring from camera trap footage, and a reliable tool to identify spoor represents a challenge for in situ conservation of this iconic antelope.

Here, we rely on a captive population of bongo (61 individuals at the time of research) at the Mount Kenya Wildlife Conservancy (MKWC, www.animalorphanagekenya.org, Nanyuki, Kenya) to rapidly develop and test an informative individual identification system that is repeatable and requires little training and a measure to help in differentiating tracks between bongo and waterbuck. Our objectives were (1) to identify visual features that contain the greatest variation amongst individuals, (2) to devise an identification system for these features, (3) to test the repeatability of our identification system amongst multiple naïve observers, and (4) to develop a quantitative way to distinguish bongo and waterbuck spoor. We discuss our results in the context of relying on captive populations to rapidly design effective tools to help field workers in monitoring rare and elusive species, with the aim that our approach may be relevant to other species.

2 | METHODS

2.1 | Identification system

The bongo is characterised by 9–15 vertical lateral stripes and variable white markings on cheeks, chest and limbs (Elkan & Smith, 2013). Gibbon et al. (2015) confirmed that these features can be used for individual bongo identification thus opening the potential for developing a repeatable tool for this purpose. For this study, we obtained photographs of 61 captive individual of both sexes (aged between 2 months and 16 years) held at MKWC in August 2016. Because the coat pattern in bongos is bilaterally asymmetrical, it is, therefore, necessary to develop a unique identification system for each flank (i.e. there are two unique flanks per individual). Therefore, each individual flank ($N = 122$) was photographed to create a reference identification library.

We focused on three distinct visual features found in every individual: (1) the shape and number of all facial markings, (2) the count and shape of pale vertical stripes on the flank, and (3) horn condition (e.g. normal, broken or bent). The stripe pattern was coded as a combination of letters and numbers: letters indicate convergent *stripes* on the flank ('V', two stripes converge ventrally, or '*y*' one stripe bifurcates medially Roman numerals are used to indicate *narrow stripes*, stripes that appear relatively close together compared to others on the flank do but do not converge (e.g. *II* indicates two narrow stripes). Arabic numerals identify the number of *typical stripes* interposed between convergent and narrow stripes, if present, or simply identify the number of typical stripes on a flank in the case of no convergent or narrow stripes being present (see Figure 1). Individual codes include the portrayed flank side, *L* for left and *R* for right and the sex of the portrayed individual, *F* for female and *M* for male. We can assign a sex to individual flanks as like in other *Tragelaphus* species mature males are larger and darker in colour whereas horns, although present in both sexes, appear narrower in females (Elkan & Smith, 2013).

Markings are generally visible in camera trap footage and can be reliably identified with both daylight and infrared light at night. We adapted elements of a code system used for zebra (*Equus quagga*) based on stripe characteristics as a template for our system (Petersen, 1972). To determine the minimum set of characters of

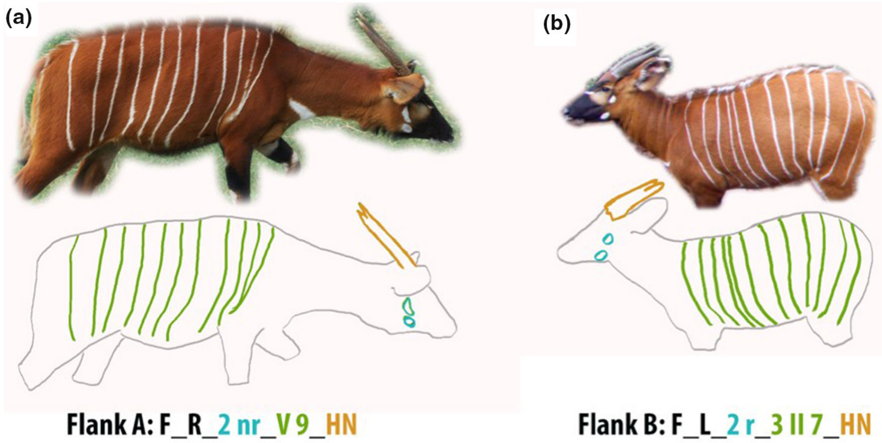

FIGURE 1 Example of our newly developed ID system for bongo flanks: Flank a is coded as *F* (female), *R* (right flank), 2*nr* (two facial spots, upper spot is not round), V (two stripes converge), 9 (nine stripes with no peculiar feature), HN (horns appear normal). Flank b is coded as *F* (female), *L* (left flank) 2*r* (two facial spots, upper is round), 3 (three stripes with no peculiar feature), *II* (two stripes appear narrower than the others on the portrayed flank), 7 (seven stripes with no peculiar feature), HN (horns appear normal).

each feature required to identify each flank (e.g. do we need all characters of facial markings), we followed an iterative process. In this, we implemented multiple rounds of feature coding where a single character of a feature was arbitrarily excluded and flanks recoded accordingly. If the new code could not uniquely identify the flanks, it was discarded, and a different version was tested.

2.2 | Information content

We used information theory to assess the effectiveness of our system by quantifying the risk of finding an individual with the same characteristics in our test population (Pennycuick & Rudnai, 1970). The risk of finding a duplicate is related to the information contained in an individual identification score, which we measured using an information-theoretic framework (see Pennycuick, 1978). Implementing this approach, we could assess the efficacy of each individual feature chosen for the system in unequivocally identifying individuals. While no census of bongo populations has ever been conducted, it has been estimated that none of the remnant four populations exceeds 50 individuals (IUCN SSC Antelope Specialist Group, 2016; Sandri et al., in press). Therefore, we developed an identification system (i.e. containing the fewest features possible) for use in the wild to avoid finding duplicates in a population of 50. We assumed that individual variation in the captive population at MKWC is comparable to that found in the wild populations. Moreover, the genetic diversity in the wild populations and in captivity are known to be comparable (Faria et al., 2011; O'Donoghue et al., 2017; Svengren et al., 2017), hence we expect phenotypic variation to be similar between these populations. We evaluated the information content of each code given to individuals by evaluating the information contained in each variant of a character of a feature (e.g. two facial spots; 11 stripes; broken left horn) in the identification system using Equation (1) from Pennycuick (1978):

TABLE 1 Frequency and information of the variants of two features included in the ID system for the 61 Left Flanks.

Feature	Variant	*N* flanks	Frequency	Information
Facial marking	*3r*	2	0.03	4.94
	2r	25	0.41	1.29
	2nr	31	0.51	0.98
	1nr	1	0.02	5.94
	2nr.t	2	0.03	4.94
Number of stripes	9	2	0.03	4.94
	10	12	3.24	2.35
	11	23	0.37	1.41
	12	17	0.27	1.85
	13	3	0.05	4.35
	14	2	0.03	4.94
	15	2	0.03	4.94

Note: For the facial markings, *r* stands for rounded, *nr* for not rounded and the addition of *t* means the markings are in contact. Number of stripes is then included as a component of the stripe pattern in Table 2.

$$\log_2\left(\frac{1}{F_i}\right) = I_i \quad (1)$$

where I_i is the information content of variant i of a feature, and F_i is the frequency of variant i amongst assessed individuals (see Table 1 for an example).

Hence, the less frequent a feature variant is, the more informative it becomes in identifying individuals as the higher the information content the lower the risk of encountering an individual with the same identification code. We excluded sex from the calculation on information content of the system, as the frequency of males and females held at MKWC likely differs to that found in the wild. As we wanted to develop a system that would avoid duplicates in a population of 50, we needed the information content (*I* in Equation 1) to be at least 10, as this is the amount of information needed to avoid a duplicate odd of 1:1000 (Pennycuick, 1978).

2.3 | System reliability

Identification of features by human observers is prone to error. To test the repeatability of the identification system amongst different users we assessed inter-rater reliability (IRR), the quantification of the degree of agreement between two or more observers ('raters') who make independent ratings about the characteristics of a set of subjects (Hallgren, 2012). In our case, the subjects were bongo individual flanks, and the characteristics were the features of the identification system. IRR can be evaluated using an index of concordance such as Cohen's kappa (Cohen, 1960). Here we used Light's kappa (hereafter kappa), a variation of Cohen's kappa allowing the evaluation of concordance amongst multiple observers (Hallgren, 2012; Light, 1971).

To assess IRR for our feature set, a sample of 10 pictures of bongo flanks (from camera traps and captivity) were presented to 15 naïve observers along with simple identification code instructions. In addition, four bongo flank photographs with assigned codes (codes for these were assigned by TS) were provided as examples. Observers were asked to assign a code to each of the 10 test flanks. Observers had no prior experience in using the identification system nor were they experienced with bongo. We evaluated IRR for each feature of the identification system (i.e. concordance in coding facial markings, stripe pattern and horn state) on each of the 10 individual bongo flanks. The resulting kappa is the overall agreement of observers on coding a flank according to the features of the ID system. This results in 10 kappa estimates corresponding to each bongo flank in the test. These values were then used to estimate the overall reliability of the system in coding different individuals amongst the various observers. Landis and Koch (1977) provide an arbitrary scale to evaluate IRR: κ 0.0–0.2 indicates slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; 0.81–1.0, almost perfect to perfect agreement. All analyses were conducted in R (R Core Team, 2019) using the R package {irr} (Gamer et al., 2019).

2.4 | Spoor identification

Bongo tracks were located within enclosures at MKWC where bongo is the only ungulate present. Maximum length and width were measured by a single observer using a pair of callipers accurate to 0.01 cm, to avoid between observers' differences in measurements taken even when using precision callipers (Bowkett et al., 2013). To account for differences in shape, the aspect ratio (max length/max width) of a footprint was calculated.

Waterbuck spoor was collected in open areas at MKWC that are inaccessible to captive bongo herds. Waterbucks in MKWC are free-roaming, therefore, these antelopes were tracked with the help of a guide to search for tracks. These tracks were measured only following direct sightings of a waterbuck so that their origin was certain. Tracks of both species were in multiple terrain types: forest areas, sand, open grassland and mud. Thus, our sample accounts for differences in terrain texture. A total of 152 tracks were measured: 100 of bongo and 52 of waterbuck, an example of the tracks recorded is shown in Figure 2.

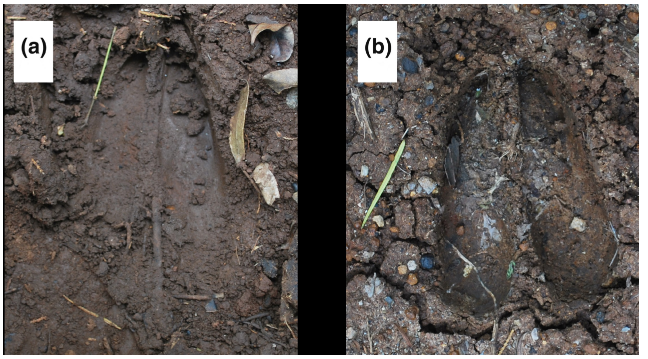

FIGURE 2 Tracks from bongo (a) and waterbuck (b) are difficult to distinguish without extensive expertise or a quantitative system.

To assess any significant difference in measurements and find a good predictor for species identification we implemented a stepwise approach: errors of every variable (length, width, aspect ratio) were screened for normality, while homoscedasticity of data between the two groups (bongo and waterbuck) was also tested. Variables with equal variance were then tested for significant differences using a two-sample *t*-test. The measurements found to differ significantly between the two species were then implemented in a logistic regression model to test the efficacy of the measure in discerning bongo and waterbuck. The predictive ability of the model built using a training dataset containing 70% of all observations was assessed on a test dataset (remaining 30% of observations) using the area under the curve (AUC) of a Receiver–Operator Characteristics (ROC; Fielding & Bell, 1997). Such measure spans from 0.5 (predictive ability equal to random assignment) to 1 (maximum accuracy in prediction). To further assess model reliability compared to random chance we implemented Cohen's kappa (Cohen, 1960). Moreover, the 95% confidence intervals of the mean of measurements in each species were calculated. In case of no overlap between the confidence intervals, the measure was deemed safe to implement in the field. All analyses were conducted in R (R Core Team, 2019).

3 | RESULTS

3.1 | Identification system

Five rounds of coding (i.e. elimination of a character of a visual feature and recoding) were necessary to find a set of characters effective in distinguishing MKWC individuals using the three chosen features (horns, stripes and facial markings). We identified the

TABLE 2 Values of Light's kappa amongst 15 naïve observers and average information content (expressed in bits) of each feature of the ID system.

Feature	Light's kappa	Information
Horn state	0.52	4.24 (±1.66)
Facial markings	0.72	4.12 (±2.16)
Stripe pattern	0.44	4.96 (±1.23)

following: facial marking count (*two* or *three*), shape of the uppermost facial marking (*r* round or *nr* not round), horn condition (*hn* normal, *hcr* crossed, *hbr* broken or *hb* bent; l or *r* indicates whether the left or right horn was broken or bent or which horn crosses over the other) and the stripe pattern. Figure 1 illustrates the main features of the identification system with two exemplary bongo flanks.

3.2 | Information content

The visual features we assessed varied in information content, with the stripe pattern being the most informative. The average information content of each of the three features included in the ID system is shown in Table 2. Mean information retained in each individual code is $I = 10.24$ (±SE 2.5) with a minimum value of 6.07 and a maximum of 18.57, as shown in Figure 3. More than half of the individual flank codes ($N = 63$) retain enough information to result in a <0.01% chance of duplication in a population of 50 individuals. We found that 80% of all codes ($N = 99$) have an information content $I > 8$, which results in a <1.0% chance of duplication in a population of 50.

3.3 | System reliability

IRR analysis on 15 naïve observers on 10 pictures of bongo shows a substantial agreement (mean $\kappa = 0.66 \pm 0.14$). The lowest individual score is 0.45, a moderate agreement, with the highest being 0.84, almost perfect agreement. More specifically, five of the 10 bongo pictures show a moderate agreement amongst observers ($0.4 < \kappa < 0.6$), three a substantial agreement ($0.6 < \kappa < 0.8$) and two an almost perfect agreement ($\kappa > 0.8$). All identifications in our survey showed a substantial level of agreement, that is higher than would be expected by chance ($\kappa = 0$). Our results show that the developed ID system is consistent amongst different naïve observers and fits our need for a reliable system implementable for use in the field with minimal training.

3.4 | Spoor identification

Of the three measures retrieved from tracks (length, width and aspect ratio), only the latter is heteroscedastic between bongo and waterbuck and is sufficient to distinguish between the two species (Two-sample *t*-test $p < 0.05$). The different variance in both length and width between the two species was expected, as bongo tracks were sampled covering multiple age classes and sexes, whereas most of the 50 waterbuck tracks were of adult individuals.

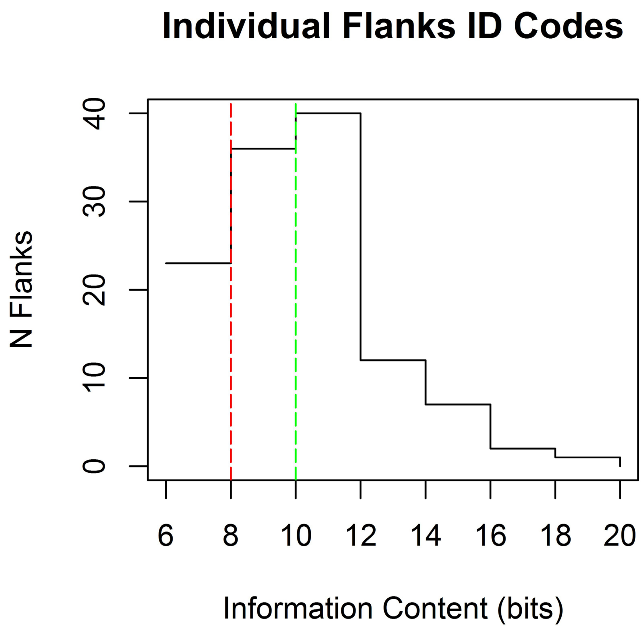

FIGURE 3 The graph shows the information (expressed in bits) retained in individual ID codes of the Mount Kenya Wildlife Conservancy bongo (left and right flanks). The dotted red and green lines indicate the threshold for encountering duplicates in a population of 50 with a risk of 1:100 and 1:1000, respectively.

To test the predictive ability of aspect ratio, we developed a logistic regression including aspect ratio as a predictor of species. This model shows a good predictive ability (AUC > 0.80) and a kappa of 0.77. An analysis of the results from the ROC plot, shown in Figure 4, identifies a value of 1.3 as an adequate aspect ratio for the identification of bongo tracks (true positives rate = 0.81, false positive rate = 0.1). Although measured aspect ratios overlap in part of the sample, Figure 5, the confidence intervals of the mean do not (bongo = 1.22 ± 0.08; waterbuck = 1.49 ± 0.10).

4 | DISCUSSION

We developed two field identification tools to aid monitor wild populations of the critically endangered bongo. Access to captive individuals allowed the development and rigorous assessment of a visual ID system that performs adequately to estimate individual counts with high accuracy for the purpose of identifying bongo in the wild. We discuss the robustness of identification schemes for field applications below. Whereas access to areas exclusive for the target species allowed the recovery of reliable measures of their spoor. This resulted in the generation and evaluation of a metric (hoof aspect ratio) to distinguish between bongo and syntopic waterbuck in the field.

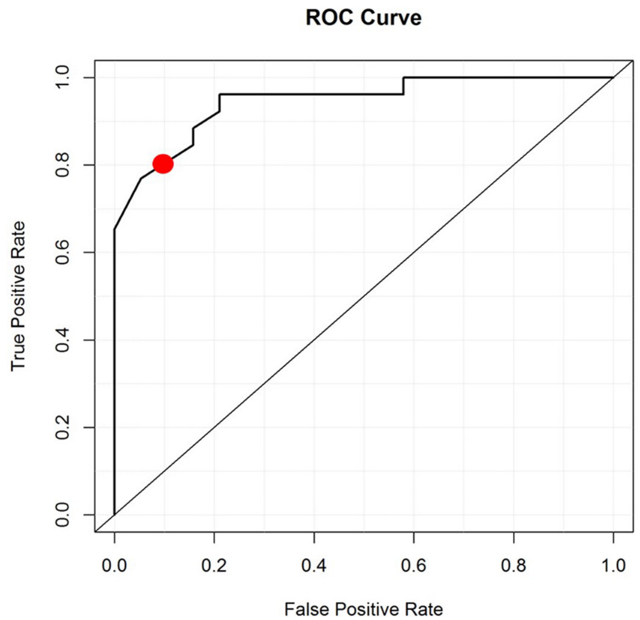

FIGURE 4 Receiver–Operator Characteristics plot showing the efficacy of aspect ratio in classifying bongo and waterbuck tracks. The red dot indicates the position along the curve of the chosen threshold (1.3).

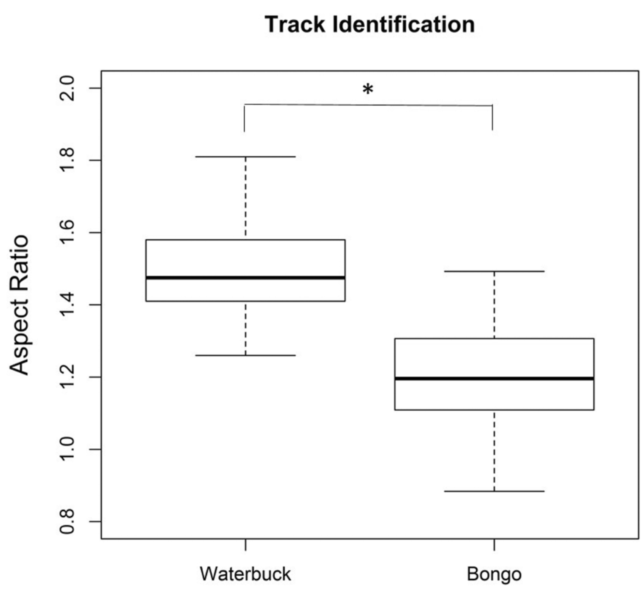

FIGURE 5 Boxplot showing the difference in aspect ratio (length/width) of bongo and waterbuck tracks. Difference was found to be significant with a two-sample *t*-test ($t = 12.102$, $df = 148$, *p*-value < 0.001).

One limitation in our assessment of the information content of the system is the assumption that the variation found in the captive population in MKWC represent similar patterns found in the wild. Although captive breeding has been known to influence the phenotype of certain species (O'Regan & Kitchener, 2005; Snyder et al., 1996), bongo captive breeding is relatively recent (40 years), equating to around 12 generations in captivity (Bosley, 2016), so we do not expect adaptation to have significantly affected the appearance of this antelope, and it is unlikely that there is a significant difference in markings between wild and captive bongo.

Results from IRR analysis suggest that our ID system is reliable, with an overall substantial agreement amongst 15 naïve observers ($\kappa > 0.60$). While these results are very promising, we would anticipate higher values of kappa with fieldworkers or those familiar with bongo footage. The system, therefore, responds to the need for a reliable tool to implement for long-term monitoring with little or no need for experienced observers. Overall, the system presented here fulfils the need for an inexpensive, reliable and readily adoptable tool for monitoring of wild bongos.

The bongo individual identification system we describe here fulfils the need for an inexpensive, reliable and readily adoptable tool for monitoring of wild bongos. The application of our ID system to photographic records collected by BSP allowed the transition from surveillance monitoring to detailed population monitoring using available data and with no change needed in BSP monitoring routine (Sandri et al., in press). This tool could be particularly effective if included in an adaptive management framework (Lindenmayer & Likens, 2009, 2010a, 2010b). Here, we used this approach for developing an ID system that could facilitate the monitoring of a critically endangered antelope. Nonetheless, any species with individual-specific visual features could benefit from a comparable ID system. In case of large felids, while software tools are ever more available, the implementation of an approach like ours could help in limiting reliance on observers' expertise and thus heighten the likelihood that monitoring programs will be sustainable in the long term (Legg & Nagy, 2006).

The finding of a measure (aspect ratio) which can help to assign tracks to bongo can be of great help to both practitioners and researchers involved with this antelope. The use of a quantitative method provides fieldworkers with a tool that can help in spoor identification, even in case of limited experience with the target species. Field workers can incorporate this measure with their expertise or that of their team when identifying tracks. This is particularly relevant for bongo, as local expertise is limited to a handful of former trackers (Prettejohn, 2008). For some values in our sample, there is an overlap between bongo and waterbuck, as shown in Figure 5. Nevertheless, the use of this variable as a predictor not only proved to be significant but also highly predictive and reliable. Therefore, we consider it a safe approach to assign any track with an aspect ratio below 1.3 to bongo. Higher thresholds would allow for a higher true positive rate but with the cost of a high false positive rate. Considering that waterbuck is common in areas inhabited by bongo, we prefer to suggest a threshold that retains a minimal risk of misidentifying waterbuck tracks as belonging to bongo. On the other hand, a threshold of 1.26 would provide a false positive rate of zero, but it would also lower the true positive rate to 0.77; therefore, we consider the threshold of 1.3 as an optimal compromise for effective use in the field. Although no field validation was attempted for this study, in two occasions TS, when working with bongo trackers, was able to identify bongo tracks through their aspect ratio and, in both cases, the trackers had independently identified them as bongo. The approach here used to discern bongo and waterbuck tracks could have been applied to dung; however, the free-roaming nature of waterbuck in MKWC would not allow for unambiguous retrieval of dung piles, and during our study, only one dung pile could be assigned to waterbuck with certainty. Moreover, differences in diet between captive and wild individuals may limit the reliability of dung measures.

The access to a relatively large captive population of bongo was vital in obtaining our results. The development of an informative and reliable ID system would not have been possible without known individuals. Many endangered species are currently hosted in zoos and collections worldwide. While few have large enough populations to allow a replicate of our approach, images could be pooled from multiple institutions to increase sample size. The same can be said for spoor, as images rather than field measures could be used. This further demonstrates the relevance of captive populations for their wild counterpart, not only for their immediate conservation value but also because they can be a resource for developing tools and methods to then implement in the field, an integral part of the one plan approach (Byers et al., 2013).

5 | CONSERVATION IMPLICATIONS

The Identification system we developed can be implemented to monitor the remnant populations of Mountain bongo in the wild, and it could also be used to follow individuals post-release in future translocations. Whereas the intended use of the spoor identification measure we provide is to facilitate monitoring in areas where bongos are known to be present through camera trap records or previous research (Faria et al., 2011). Genetic species assignment of dung should be implemented whenever evidence of presence comes from novel areas.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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