Empirically testing the effectiveness of thermal imaging as a tool for identification of large mammals in the African bushveldt

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Abstract

Monitoring animal populations often relies on direct visual observations. This is problematic at night when spotlighting can cause misidentification and inaccurate counting. Using infrared thermography (IRT) could potentially solve these difficulties, but reliability is uncertain. Here, we test the accuracy of 24 observers, differing in experience and skill levels, in identifying antelope species from IRT photographs taken in the African bush. Overall, 38% of identifications were correct to species level and 50% were correct to genus/subfamily level. Identification accuracy depended on the confidence and skill of the observer (positive relationship), the number of animals present (positive relationship), and the distance at which it was taken (negative relationship). Species with characteristic features, horn morphology, or posture were identified with ~80% accuracy (e.g. wildebeest, kudu, impala) while others were considerably lower (e.g. blesbok, waterbuck). Experience significantly improved identification accuracy but the effect was not consistent between species and even experienced observers struggled to identify red hartebeest, reedbuck and eland. Counting inaccuracies were commonplace, particularly when group size was large. We conclude that thermal characteristics of species and experience of observers can pose challenges for African field ecologists but IRT can be used to identify and count some species accurately, especially <100m.

Keywords: Antelope identification; infrared thermography; nocturnal surveying; species monitoring; survey tool

Introduction

Effective management and optimal conservation strategies depend on having detailed knowledge of the species present within an area and, in many cases, of the number of individuals (Sutherland *et al*., 2004; Gregory, Ohlson & Arvai, 2006). It is also necessary to have accurate survey data in order to determine the effectiveness of conservation-led interventions through ecological monitoring, especially in the case of specific species of conservation concern, and testing ecological hypotheses may also require knowledge of species' presence and abundance.

When surveying terrestrial vertebrates, technologies such as automated camera traps (O'Connell, Nichols & Karanth, 2010; Welbourne, 2013), cameras mounted on unmanned aerial vehicles (UAVs: Anderson & Gaston, 2013; Bryson *et al*., 2014) and use of satellite imagery (Fretwell & Trathan, 2009) have been of enormous benefit to ecologists, biologists and conservationists seeking accurate and precise ecological survey data. However, despite technological developments, in many cases direct surveying using ground-based methods remains the primary tool for determining presence, inferring likely absence, and quantifying populations (Sutherland, 2006). Trapping is an effective surveying strategy for small mammals (e.g. Longworth traps: Stromgren & Sullivan, 2014) and birds (mist netting: Balmer *et al*., 2009) but as animals increase in size trapping becomes more problematic, both logistically and ethically. Direct surveying without trapping is useful for larger mammals and birds and can be undertaken using a transect method including walked (Rovero & Marshall, 2004), driven (Olson *et al*., 2005), flown (Buckland *et al*., 2012) or point-count (Sauer, Pendleton & Orsillo, 1995), and recording opportunistic sightings can also be useful. Direct survey methods can be supplemented by indirect methods, such as surveying footprints, dung, or and hair (Boddicker, Rodriguez & Amanzo, 2012).

Surveying large mammal species in the African bush provides a unique set of challenges. Terrain, vegetation and resources can obviously hamper attempts to detect and count large mammals from the air, while the large area over which individuals of many species roam, often at low densities, provide substantial challenges for land-based surveying using traditional sighting techniques. Land-based sighting techniques are further complicated by the presence of high sward and thickets, cryptic behaviour and camouflage. Use of interventional capture methods, such as herding animals into game capture bomas (Ebedes *et al*., 2002), is complex and often prohibitively resource intensive if the purpose is surveying rather than capture prior to translocation. These challenges are particularly important given that there is often a need to monitor large grazers and browsers to prevent overstocking.

The challenges inherent in surveying large mammals in the African bush become still more difficult to address when surveying species at night. This might be necessary because species are nocturnal or, conversely, because they are diurnal and more likely to be grouped together in predictable locations at night. Large mammals can often be detected at night using a flashlight to provoke eye shine, a phenomenon whereby eyes appear to glow because of light reflected from the *tepetum lucidum*, a reflective layer of tissue lying behind the retina in the eyes of many animals (Brown, 1972). Although useful and widely used, it can be impossible to identify species on the basis of eye shine alone or to count individuals since only those looking at the correct angle relative to the observer will be seen. Furthermore, using a flashlight at night can disturb animals and cause them to move away from the light or into vegetation cover, making the prolonged observations necessary to determine group size very difficult.

Traditional surveying techniques rely on visible wavelengths of light but animals, especially mammals, emit infrared radiation characteristic of warm objects (McCafferty, 2007; Cilulko *et al*., 2013). Thermal imaging, or infrared thermography (IRT), uses a sensor that is sensitive to infra-red radiation to produce an image in the same way that a conventional digital camera produces an image with visible light. Consequently, thermal imaging technology can and has been used for surveying, including detection of nocturnal, cryptic and burrowing species (Boonstra *et al*., 1994; Ganow, Caire & Matlock, 2015) and surveying mammals and birds at night (e.g. Dunn, Donnelly & Krausmann 2002; McCafferty *et al*., 1998).

The ability to survey species at night with minimal disturbance is a potential major advantage of thermal imaging and IRT techniques have been shown to be almost twice as effective for locating white-tailed deer (*Odocoileus virginianus;* Zimmermann, 1780) as using a spotlight (Collier *et al*., 2007). However, for it to useful as a surveying tool IRT needs to go beyond simple detection to the identification of species from thermal images and, ideally, also to the quantification of the number of individuals present with a high degree of accuracy. Although thermal imaging has been investigated previously in terms of its detection abilities (e.g. Collier *et al*. (2007) for deer; Kissell & Tappe (2004) for humans simulating resting animals), to date there have been no systematic studies of the effectiveness of thermal imaging in identifying animals to species level in multi-species communities or in the accuracy with which abundance can be quantified. Here, we test whether users of different experience levels are able to identify various African antelopes to species level and to determine the number and sex ratio of groups of antelopes using typical thermal images taken at different ranges and under different conditions in the African bush.

Methods

Study site

This study was undertaken at Mankwe Wildlife Reserve, Northwest Province, South Africa in May 2016. The site has a bushveldt landscape characterized by a matrix of grassland dominated by curly leaf grass (*Eragrostis rigidior*; Pilger) and spear grass (*Heteropogon contortus;* Linnaeus) and *Acacia* scrub. It supports >40 species of large- and medium-sized mammal, including 14 species of antelope.

Thermal imagery

A FLIR T620 thermal imaging camera was used to take a series of 70 thermal images in the field. Each image showed one of 10 species of antelope but the number of individuals and the sex ratio differed between images (see Fig. 1 for example images). The species included were: (1) greater kudu (*Tragelaphus strepsiceros*; Pallas 1766), (2) tsessebe (*Damaliscus lunatus*; Burchell, 1823), (3) impala (*Aepyceros melampus*; Lichtenstein, 1812), (4) blue wildebeest (*Connochaetes taurinus;* Burchell, 1823), (5) waterbuck (*Kobus ellipsiprymnus*; Ogilby, 1833), (6) common reedbuck (*Redunca arundinum*; Boddaert, 1785), (7) blesbok (*Damaliscus pygargus phillipsi*; Harper, 1939), (8) red hartebeest (*Alcelaphus caama*; Saint-Hilaire, 1803), (9) common eland (*Taurotragus oryx*; Pallas, 1766), and (10) gemsbok (*Oryx gazelle*; Linnaeus, 1758). The images were taken at varying distances from 10m to 270m (mean = 79m; s.d. = 51m) as determined using a Bushnell v3 laser rangefinder (Bushnell Performance Optics, Surrey, UK). When distance varied due to the presence of several individuals at different distances, the distance to what was determined to be the most central animal of the group was recorded.

Although the aim was to test whether thermal imagery is a useful survey method at night, the thermal images used were taken in the day to allow positive identification of the species while in the field. Furthermore, the number of individuals and (where appropriate) the sex ratio could also be accurately determined at the time the image was taken. This meant that data derived from observers examining thermal images could be compared to definitive data, which would not be the case had the images been taken at night. This avoided the normal problems inherent in estimating the extent of measurement error in assessing thermal images because the actual population demographic remains unknown (see review by Cilulko *et al*., 2012 for more details).

The camera had a resolution of 640*480 pixels with a 30 Hz infrared detector. The measurable temperature range was -40 to 650°C with a thermal sensitivity of 0.04°C. The camera was set to lava colour palette so that the animals showed up white against a background that, depending on the thermal profile of the landscape, graduated from orange through red, purple, blue and finally to black (Fig 1a-f). A previous study showed that this camera was capable of detecting mammals as hot spots in African bushveldt field conditions during the day and night up to a distance of at least 300m (Hart *et al*., 2015), even in a thermal landscape complicated by frequent rocky outcrops and bodies of water that reflected the thermal signature of the surrounding area (Fig. 1b).

The thermal images were embedded into a PowerPoint presentation on consecutive slides with each sized to full screen. The unique photograph identifier number was added as was the distance between the camera and the animals shown (Fig. 1). The order of the slides was randomized using visual basic programming code. The majority of photographs were taken in grassland with a sward height of up to 1m such that the antelope individual(s) were shown clearly, without substantial interference from vegetation other than legs often being concealed. However, around 20% of images had some individuals at least partly concealed by taller grass or scrub (Fig. 1d, 1e). In all such cases, the individual(s) were visually partly concealed, such that it would not have been possible to obtain a clear colour photograph with a standard camera, but their thermal signature was not masked.

Data collection and volunteer observers

Each of the volunteer observers (see below) was shown all 70 images in a darkened room on a large (2m x 1.5m) screen set no more than 4m and no less than 2m from any participant. Before viewing the images, participants were informed that all the species were found at the study site and that only one species was shown per image. The fact that the distance to the animals was given on the image was highlighted. Observers were asked to give asked to provide details of the species and the total number of individuals shown. They were also asked to record the number of males and number of females present where this could be determined. Conferring was not allowed and observers were seated so that they could not inadvertently see what another observer was recording.

In total, 24 observers took part in this study. Of these, 16 observers had limited experience working with African ecology (10 days' experience of fieldwork in the African bush at a reserve where all the focal species occurred) and together formed the inexperienced group. Another 4 observers had some previous experience of working in Africa on projects that required mammal identification (6-12 weeks' duration within the previous 2 years, plus 10 days' experience of fieldwork immediately prior to this study) and together formed the intermediate group. The final 4 observers all had several years' experience in the African bush as guides or trackers and had worked with all focal species for >12 months prior to the study; they formed the expert group. In addition to being put into one of these overarching experience groups, observers were also asked to rate their perceived confidence in identifying African antelopes on a scale of 1 (very low confidence) to 10 (very high confidence). Finally, to provide an objective estimate of actual identification skill, all observers were shown a series of 30 colour photographic images of African antelope and asked to identify the species shown.

Statistical analysis

To assess what parameters affected the success rate of observers in identifying species, a multiple linear regression analysis was undertaken. This used the number of occasions out of 70 each observer had been able to identify species correctly as the dependent variable. There were 24 cases (one case per observer). Four predictor variables were entered: (1) observer gender; (2) experience (inexperienced, intermediate, expert); (3) confidence in identifying African antelope (rank 1-10); and (4) identification skill measured by testing with colour photographs (% correct). Collinearity between the predictors was within acceptable limits (actual VIF <7.871 in all cases; threshold = 10) (Field, 2000).

To assess what photographic parameters affected the success rate of observers in identifying species, a multiple linear regression analysis was undertaken. This used the number of times the species in each image was identified correctly out of 24 attempts (the number of observers) as the dependent variable. There were 70 cases in the analysis (one case per photograph). Three predictor variables were entered: (1) distance between the animals and the photographer (m); (2) the number of animals in the group; and (3) whether or not males were present in the image (0 or 1). The rationale for entering the final variable was to determine if the presence of horns (prominent in males only in greater kudu, impala, waterbuck and common reedbuck; notably thicker in males in gemsbok) assisted species identification. Collinearity between the predictors was within acceptable limits (actual VIF <1.051 in all cases).

Results

Baseline results

In total, 1680 identification attempts were made (24 participants assessing 70 thermal images each). Across all species and experience levels, 38% of identification attempts were correct to species level and 50% were correct to genus/subfamily level. However, there was substantial variation between species (Fig. 2). For wildebeest, 89% of identification attempts were correct to species level, which rose to 96% at genus/subfamily level. For kudu, gemsbok and impala, the majority of identification attempts were correct to species level (66%, 65% and 60%, respectively). Conversely, some species proved to be hard to identify accurately. Red hartebeest was never identified correctly to species level (and only rarely to the correct genus/subfamily) while reedbuck and eland were also extremely problematic (1% and 10% accuracy in classification to species level, respectively). Tssebee, waterbuck and blesbok were intermediate in terms of identification accuracy (Fig. 2).

There was a consistent pattern of improvement in identification accuracy with increasing experience: inexperienced = 45% accuracy for genus/subfamily and 34% accuracy for species; intermediate = 54% accuracy for genus/subfamily and 36% for species; experienced = 71% accuracy for genus/subfamily and 51% for species. Again there were clear differences between species in the effect of increased experience on identification accuracy. For example, kudu identification accuracy was fairly consistent between the three experience levels (ca 70%), while tssebee, impala and waterbuck all showed clear and substantial improvement with experience (Fig 2).

Misidentifications

The overall patterns of species confusion are shown in Fig. 3 with the most common mistakes being: hartebeest misidentified as impala, reedbuck misidentified as waterbuck and eland misidentified as wildebeest. In the cases of eland, misidentification as wildebeest was especially common amongst inexperienced observers (58% of occasions) but was notable even within the experienced group (38%). This pattern did not occur in reverse: very few wildebeest were misidentified as eland. There were other differences in misidentifications relative to experience levels. For example, among inexperienced observers, tssebee were frequently misidentified as wildebeest (28% of occasions) but this error decreased considerably with experience (12% for intermediate experience and 10% for expert). Waterbuck were frequently confused with both impala (22%) and kudu (20%) among inexperienced observers; this dropped to 15% and 8%, respectively, among experienced observers.

Observer effects on identification accuracy

There was a significant relationship between the number of times an observer correctly identified species in the series of thermal images and their: (1) previous experience; (2) confidence in identification; and (3) objective identification skill: all relationships were positive. The overall model was highly significant (regression $F_{4,20} = 8.749$; $R^2 = 0.753$; $P < 0.001$); each variable was also significant alone (experience $P < 0.001$; confidence $P = 0.002$; skill $P < 0.001$). There was no significant relationship between identification accuracy and gender ($P = 0.197$).The best single predictor of identification accuracy when variables were added individually was objective identification skill ($R^2 = 0.540$), but this was closely followed by experience ($R^2 = 0.504$). Thus it is possible to explain >50% of the variation in an observer's accuracy by objectively testing their species identification skills using a series of colour images or, more simply, by assessing their previous experience. The effect of experience of identification accuracy for individual species can be seen in Fig. 2.

Photograph effects on identification accuracy

There was a significant relationship between the number of times the species in the different thermal images was correctly identified and the distance at which the photograph was taken (negative; closer images were easier to interpret) as well as the number of animals in the image (positive; images with more animals were easier to interpret). The overall model was highly significant (regression $F_{2,67} = 7.088$; $R^2 = 0.175$; $P = 0.002$); each variable was also significant alone (distance $P = 0.001$; group size $P = 0.040$). The effect of distance and group size on identification accuracy is shown graphically in Fig. 4. In general, classification accuracy was unaffected by distance within 100m and accuracy then decreased for images taken 100-200m and decreased again for images taken over 200m. In terms of group size, images with >10 animals were much easier to identify (70% accuracy) relative to images with single animals or groups of 2-4 animals (accuracy 40%-45%). There was no significant effect of whether or not there were males in the image on accuracy ($P = 0.612$).

Assessment of number of animals

There was some inaccuracy in assessing the number of animals in an image in all image types (Fig. 5). Inaccuracy was lowest when the actual number of individuals was small: in other words, it was less likely for images with 1 or 2 animals to be miscounted compared to images when there were, say, 12 animals. The magnitude of miscounting also increased with the actual number of animals present. For example, for one image depicting 3 animals observer estimates ranged from 1 to 5, whereas for one image depicting 31 animals observer estimates ranged from 19 to 44 (Fig 5). Interestingly, observers were much more likely to underestimate group size than they were to overestimate it (over = 1; under = 7; tied = 1; sign test $P = 0.35$; Fig. 5). There was a significant negative relationship between the accuracy with which group size could be determined correctly and distance (logistic regression Wald 54.632, d.f. = 1, $P < 0.001$).

<u>Discussion</u>

We have shown that it is sometimes possible to identify antelopes to species level and to record the number of individuals using still photographs derived from ground-based, hand-held, thermal imaging. However, we have also revealed a number of problems with relying on the technique for surveying. The accuracy of species identification depends on the experience, confidence and skill of the observer and on the number of animals shown in the image, as well as the distance at which that image was taken. As might be expected, experience significantly improved the likelihood of an observer correctly identifying the species present but even experienced observers struggled to identify some species: red hartebeest, reedbuck and eland being the most problematic.

Species with characteristic horn anatomy or posture, such as wildebeest, or that had a physically distinctive feature (such as large ears in the case of kudu), were generally identified correctly more often than species that had a less distinctive profile when in silhouette: reedbuck and blesbok, for example. Unfortunately the characteristic coat patterns that are often critical in the identification of species (or even the identification of specific individuals (e.g. Hiby *et al.*, 2009; Gibbon, Bindemann & Roberts, 2015)) do not always show up as effectively, or in some cases at all, under thermal imaging even at relatively small distances. This is especially true when animals are in the shade since the differential solar heating between areas of dark coat and areas of light coat that can sometimes show up on thermal images is usually only evident when an animal is in full sun (as seen in zebra: Benesch & Hilsberg, 2003; McCafferty, 2007). This is problematic as some of the more diagnostic features of the antelope species studied here relate to coat pattern: for example, the facial blaze on blesbok and the white circle around the posterior of waterbuck.

The lack of being able to use normally-obvious features such as coat colour and patterning when identifying species from thermal images was a particular issue for a number of observers, particularly those in the inexperienced group, commented that the lack of such features made identification difficult and prone to error. More experienced observers were able to make use of the presence of other features to distinguish species, for example the size of individuals, horn size and shape, body morphology and posture. This has been shown previously; for example, a study by Dunn *et al*. (2002) indicated that red deer (*Cervus elaphus*; Linnaeus, 1758) were distinguishable from cattle, horses and other deer species in thermal images because their longer coats gave better insulation around their necks and this was discernable using thermal imagery. However, the confusion between some species even by experienced observers in this current study (e.g. reedbuck for waterbuck, red hartebeest for tsessebe, eland for wildebeest when at a distance) suggested that even use of subtle features was not always possible. This agrees with Franke *et al*. (2012), which showed that some species are indistinguishable based on thermal images and that using thermal imagery on its own was insufficient to distinguish between red deer and fallow deer (*Dama dama*; Linnaeus, 1758).

Although identification accuracy usually improved with experience, it is worth noting that, for some species, identification accuracy was lowest for the intermediate group (e.g. wildebeest = 64% versus 89% for inexperienced and 96% for expert). One reason for this could be habituation. The inexperienced group were novices in field-based identification of antelope species, and had seen large numbers of wildebeest prior to testing, whereas the intermediate group were more likely to identify less abundant species, for example eland and tssebee. A similar scenario occurred in the accuracy of observers taking biometrics of birds, when, with a bit of practice, novices and experts were more accurate than observers with enough experience to overestimate their capabilities and rush the task but insufficient experience to be truly expert (Goodenough *et al*., 2009).

Identification accuracy among observers at all levels of experience decreased as the distance between the photographer and the animals increased. In conventional photography, antelope a range of greater than 100m would require a telephoto lens to obtain a clearer image and such lenses are available (albeit at a relatively high price) for some thermal image cameras. Use of such lens would likely make a considerable difference to the usefulness of thermal imagery in the field, for example Zehnder *et al*. (2001) and Desholm (2003) showed that birds were visible from altitudes of up to 3000m using a Long-Range-Infrared System and horizontal distances of up to 450m with the use of a telephoto intrared lens. Mulero-Pazmany *et al*. (2014) concluded that the best results in surveillance using a thermal imaging sensor without the aid of expensive telephoto lenses were achieved at distances under 100m. Group sizes also affected identification accuracy (groups >10 animals were easier to identify) and this agrees with other studies (see Franke *et al*., 2012) which found that groups of the same species were easier to identify than individuals. In group shots it is likely that animals will present at different angles giving observers more characteristics to use for identification. Also, the group presents characteristics that are themselves useful for identification; wildebeest, for example, typically form groups that are strung out along an approximate line whereas impala form tighter groups.

Timing is important in increasing the effectiveness of thermal imagery in species identification. This study took thermal images in the day in order to remove any ambiguity in terms of species, number and sex but taking images during the day will likely not produce images with maximum resolution of characteristics that may be helpful in identifying species. Previous studies have found that using thermal imagery for surveying was more successful where the surveying was done at dawn, early morning, or at least an hour after sunset to enable a reduction of the background radiation emittance (Graves, Bellis & Knuth, 1972; Boonstra *et al*., 1994; Havens & Sharp, 1998; Grierson & Gammon, 2000; McCafferty, 2007) (although note that surveying in the day would have increased the amount of coat patterning visible on the images for the reasons explained above).

The best images were taken where vegetation was open (as per Naugle, Jenks & Kernohan, 1996) or where variability in habitat was low (as per Graves *et al*., 1972). Many factors can therefore help to make the subject stand out against the background although in practice even good knowledge of a species' thermal characteristics and an awareness of the ideal habitat to maximize clarity can be thwarted by the conditions being experienced at the time when the image must be taken. The angle of the animal to the camera, the amount of cover from foliage and the distance from which the image was taken can all lead to thermal images that are far less clear than conventional images might be under the same conditions. Conversely, the thermal image can be far more apparent under some conditions such as in Fig 1d. In these cases, thermal imaging could offer benefits even in daylight, especially in habitats with dense vegetation.

It should be noted that all findings reported here was based on observers looking at still IRT photographs. This was the only way to sensibly standardize data collection so all observers saw the same situation in the same way for the same amount of time, as was necessary to disentangle the effects of observer experience and distance to the animals, as well as to directly compare the ratio of successful and non-successful identifications between species. However, although all photographs were taken under in field conditions and every effort was made to ensure that they were typical of the scenarios that occur (e.g. a range of distances, complex thermal environments, partial concealment by vegetation etc.) this standardization does mean that observations were not fully reflective of real-world use of IRT technology. Generally, IRT would be used real-time so that the observer(s) would be able to view animal subjects from multiple angles, as well as watching them move and, in the case of groups, watch individuals interacting with one another. This could enhance identification accuracy considerably, but might have a negative effect on the accuracy of estimates of group size since counting can be harder when individuals are moving. One useful avenue for future research would be to ask observers to identify species based on thermal video clips rather than still photographs, which would be more realistic relative to typical use of IRT technology in the field.

In conclusion, thermal imaging is a useful tool for the accurate surveying of wild antelope populations. It can allow surveying to be undertaken in conditions where surveying using visible light is difficult or impossible, for example in the early morning or at dusk. For many species the time when thermal imaging is best undertaken neatly corresponds with highly desirable times to undertake surveying and here we show that using the technique it is possible to identify the species, number and sex of antelope. However, some species are far more readily identified than others and the ability to use the equipment without training varies greatly both with experience and with measured ability to identify antelope using visible light. However, as with any identification task, experience and training using thermal imaging will likely increase users' accuracy and the ability of thermal imaging to work during the day (as with this study) allows users to train in-real time and with photographs of unambiguously identified and characterized individuals and groups. This study used ground-based, hand-held thermal imagery but aerial surveying using thermal imaging is increasingly used (e.g. Boonstra *et al*., 1994; Garner, Underwood & Porter, 1995; Gill, Thomas & Stocker, 1997; Dunn *et al*., 2002; Kissell Jr. & Nimmo, 2011) and reserves already using aerial systems might consider making use of thermal imaging alongside existing aerial surveying (see Lavers *et al*., 2005).

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Figure 1: Thermal images of African antelope: (a) eight wildebeest at 38m; having some individuals side-profile and others front-profile helps with species identification; (b) four female waterbuck at 60m against a complex thermal landscape of rock exposure (in foreground and immediately below the individuals) and water reflecting the surrounding thermal signature; (c) three kudu at 80m with each individual standing out clearly and species distinguishable by the characteristically large ears, however, the prominent horns of the central male do not stand out and all participants who recorded sex ratio incorrectly recorded an all-female group; (d) one male kudu at 40m with horns showing clearly despite the animal being semi-concealed by vegetation and the tree trunks in full sun showing up as hotspots on the image; (e) a large group of 31 impala at 73m, some semi-concealed; (f) single gemsbok at 100m in side profile such that the characteristically straight horns and the angle at which they are carried show clearly.

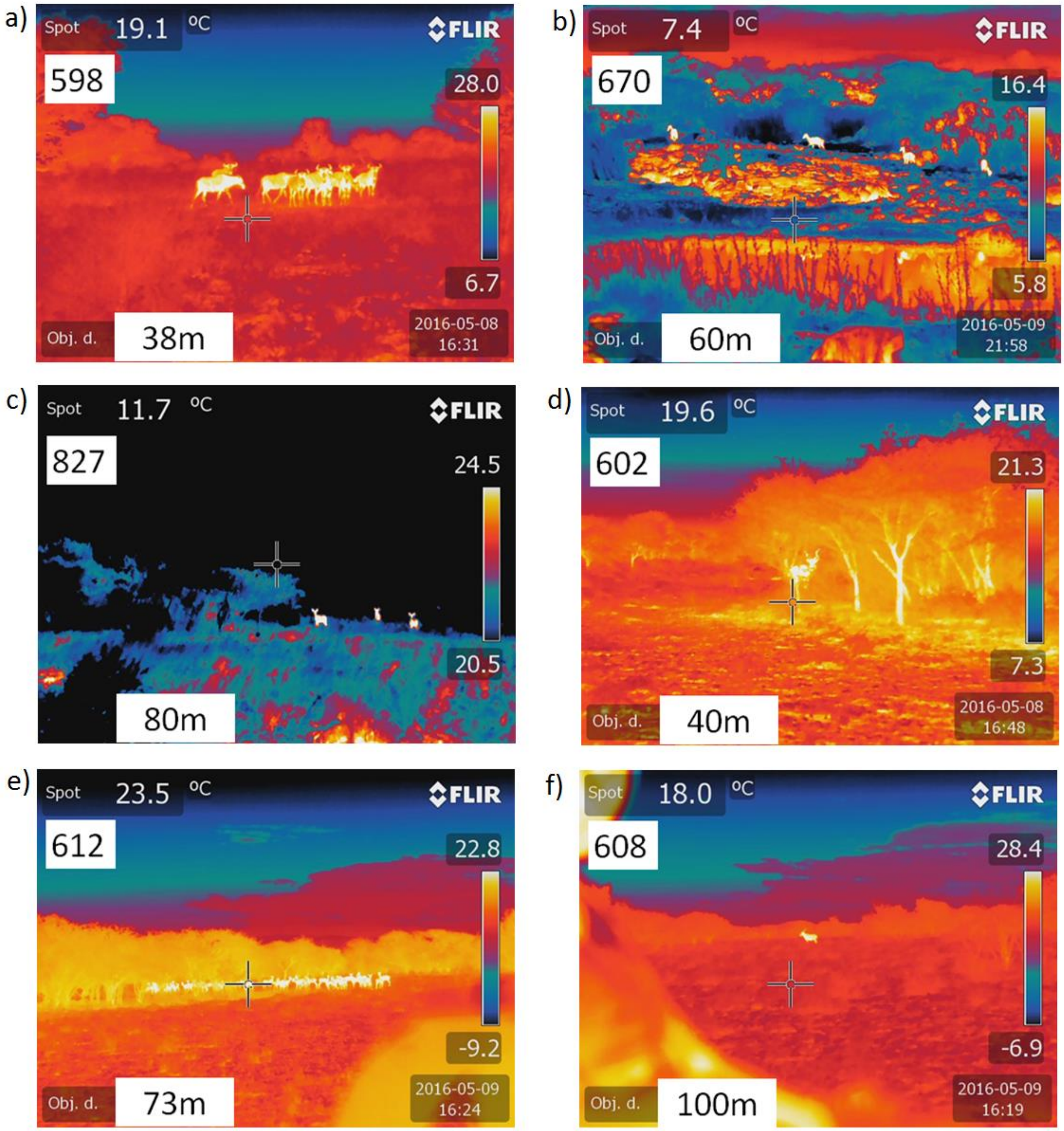

Figure 2: Accuracy of species identification from thermal images expressed as a percentage for each species for: a) inexperienced observers; b) intermediate observers; and c) experienced observers. For all species except impala and gemsbok, there were congenera within the focal species so the percentage occurrence of recorders misidentifying animals at species level but ascribing them to the correct genus (or subfamily) is also shown. The species shown in parentheses are species for which there was a limited number of photographs from which to judge competency.

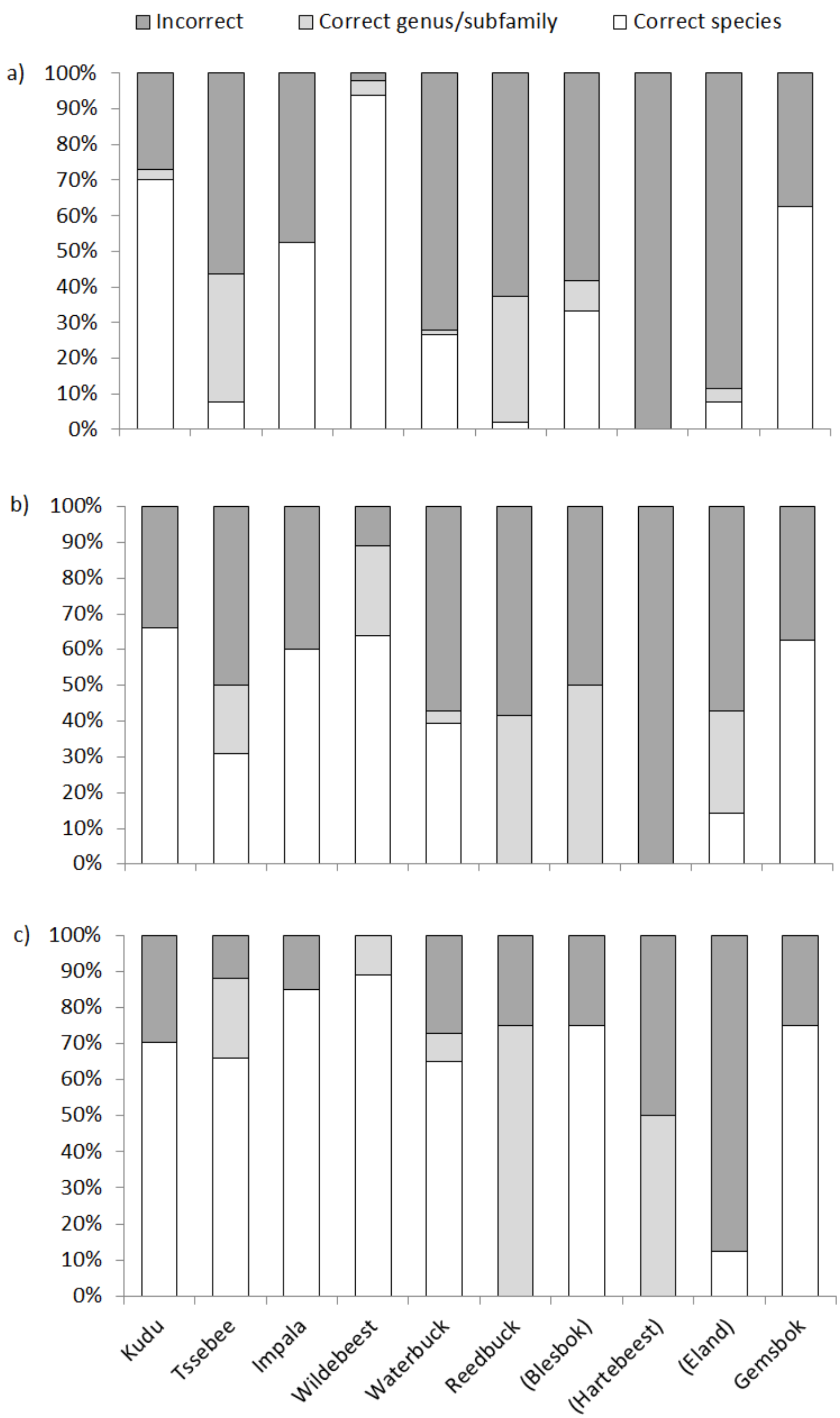

Figure 3: Common misidentification mistakes of observers studying thermal images of African antelope. Line thickness shows prevalence of misidentifications and arrow shows direction of mistake; species in the same subfamily are grouped.

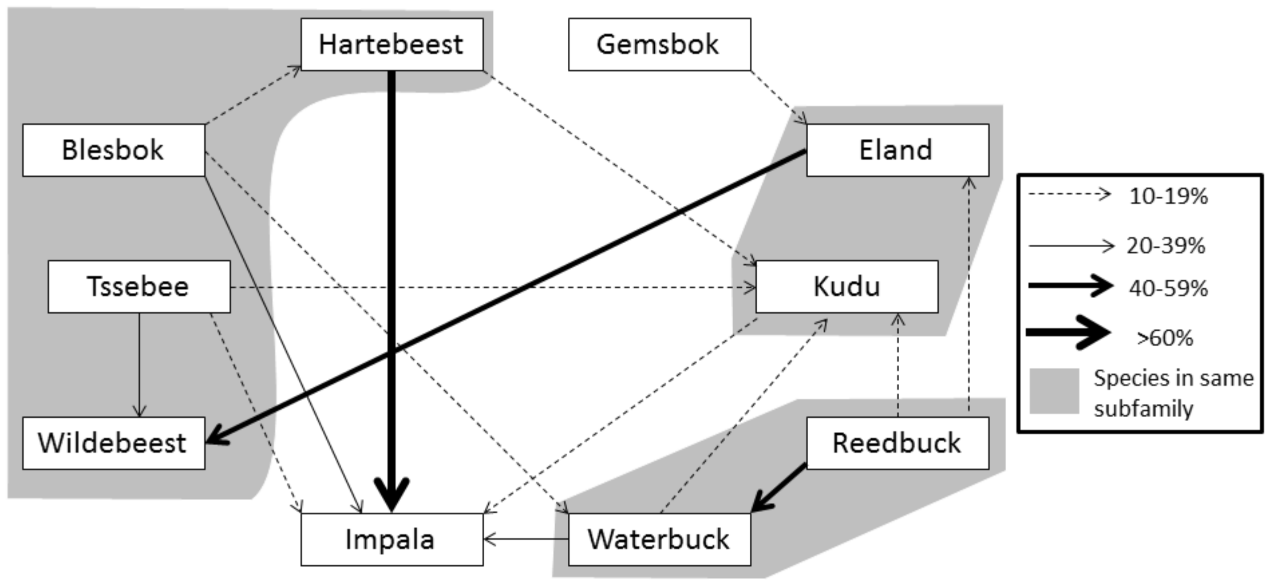
Hartebeest
Gemsbok
Blesbok
Eland
Tssebee
Kudu
Wildebeest
Reedbuck
Impala
Waterbuck
10-19%
20-39%
40-59%
>60%
Species in same subfamily

Figure 4: Effect of distance (left) and group size (right) on species identification accuracy

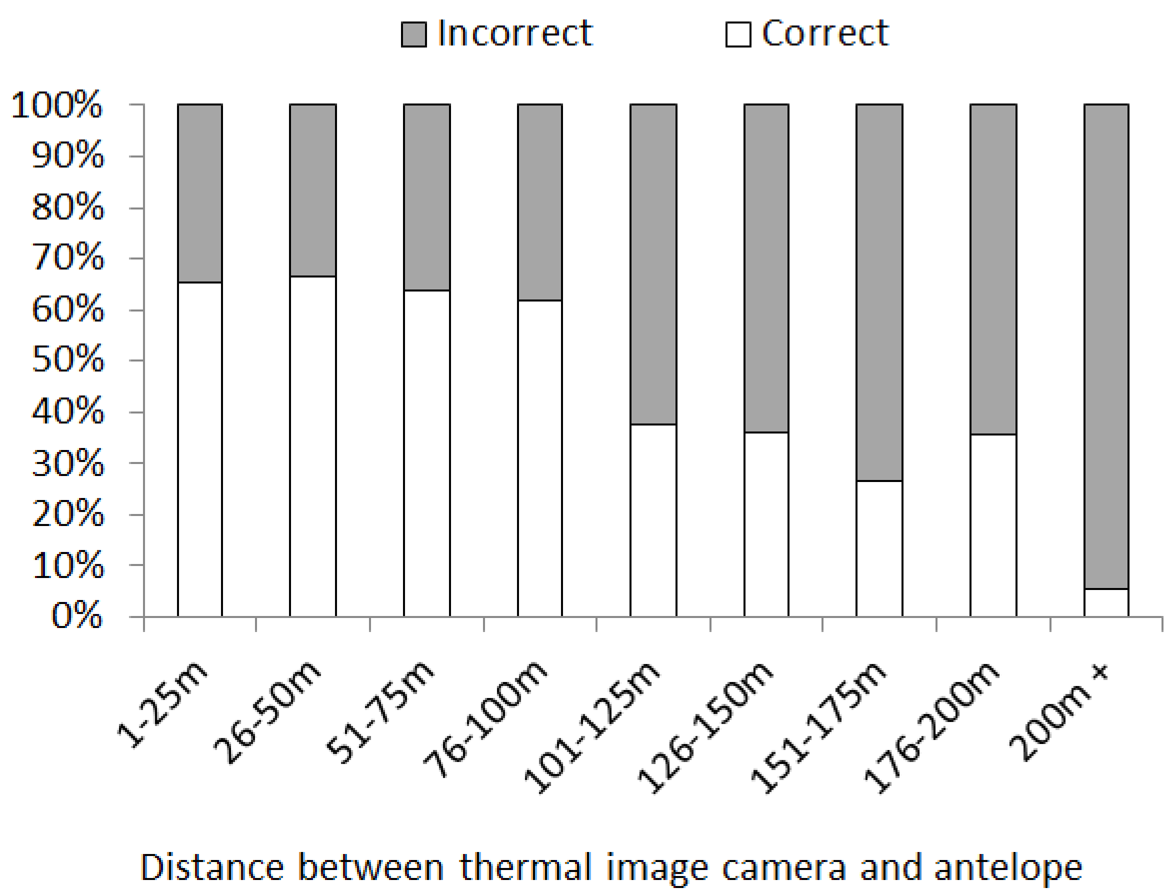

Figure 5: Correlation between the actual number of individuals in an image and the number estimated by observers. The frequency of underestimates and overestimates are indicated by the arrows. Note that both the prevalence of mistakes and the magnitude of those mistakes increased with group size. Observers were more likely to underestimate than overestimate on average.