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Height-related detection bias in camera trap surveys: Insights for combining data sets

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Introduction

Camera trap surveys is a non-invasive method for monitoring wildlife (Royle 2011). Camera traps inevitably record non-target species (Burton et al. 2015) and this by-catch is potentially useful (Edwards et al. 2011; Hofmeester et al. 2020; Mazzamuto, Lo Valvo & Anile 2019). The usefulness of by-catch data is determined by the probability of capturing an animal within a given survey design (Findlay, Briers & White 2020). As described by Findlay et al. (2020), an animal has to pass in front of (encounter probability), trigger (trigger probability), be photographed by the camera (registration probability), and the image must be of sufficient quality to be able to identify the animal (capture quality probability). The probability of a camera trap being triggered differs between species and can be influenced by their body mass, size or behaviour, environmental variables (land cover, temperature), as well as camera trap brand, model and height of set-up (Apps & McNutt 2018; Hofmeester et al. 2019; Kolowski, Oley & McShea 2021; Meek et al. 2016a; Swann et al. 2004). To ensure the highest registration and capture probabilities for a target species or to maximise the diversity of photographed species, camera placement is crucial (Burton et al. 2015). Camera height is one of the critical settings, athough few studies have focused on it, whereas it has been shown to affect species detection (Anile & Devillard 2016; Burton et al. 2015; Hofmeester et al. 2019; Meek et al. 2016a; Palencia et al. 2021). Camera height settings usually differ between surveys aimed at monitoring human activities and surveys aimed at monitoring biodiversity (Burton et al. 2015). Little emphasis has been put on using by-catch data from surveys targeting humans for biodiversity monitoring purposes. The effect of camera height on detection probability of mammal species was tested by comparing a standard height for monitoring biodiversity (50 cm, used in the African Snapshot safari survey, Meek et al. 2016b; Pardo et al. 2021) with a height chosen to monitor human-related events (130 cm, used in a Human-Wildlife Interface Monitoring Project, Moolman et al. 2019). It was hypothesised that lower cameras would detect smaller mammals at higher frequencies than the higher cameras, but that no difference would occur between camera heights in detecting larger species. The aim was to assess if data sets from various surveys (humans or mammals as primary survey targets) using different camera heights could be combined. An investigation to test whether one of the height settings could maximise the detectability of both human and other mammal species activity in order to optimise camera trap survey design was also done.

Material and methods

Study site

Ten passive infrared-triggered (Bushnell Trophy Cam HD Aggressor No Glow) cameras were set up at five different locations in the Harkerville Section of the Garden Route National Park in South Africa (-34.046731, 23.209715; Online Appendix Figure 1-A1). All cameras were deployed in Afrotemperate forest, on hiking trails. Two cameras were set up at each location, at two different heights, on the same tree, no further than 1 m away from the hiking trails (Online Appendix Figure 1-A1). High cameras were placed at a height of 130 cm (± 5 cm) from the ground level of the trail, which was the set-up for the Human-Wildlife Interface survey, and low cameras at 50 cm (± 3 cm), which is the average shoulder height of the mammal species (mean height = 53.1 cm; height range: 15 cm to 80 cm) in the area. The two cameras were oriented and angled towards the same direction to photograph the same area. They were diagonally facing the trails, so that animals had to walk towards or away from the camera, to have a longer area of detection. The horizontal and vertical shift from the high camera compared to the low camera

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Note: Additional supporting information may be found in the online version of this article as Online Appendix 1.

was measured. Five points on the low camera image were identified and the relative position of these on the high camera was compared by measuring the relative deviation on the photograph (Online Appendix Figure 2-A1 [A]). The mean vertical deviation was 5% and horizontal deviation was less than 2% between low and high cameras (Online Appendix Figure 2-A1 [B]). The cameras used black flash (no glow), that is, infrared illumination, that prevents animals from being disturbed and being detected by humans at night. To reduce the risk of theft, cameras were protected by cable locks and metal casings. Cameras were active 24 h per day and were set up to take one eight mega-pixels image per trigger, with a delay of 1 s between subsequent triggers. The sensitivity was set on 'normal'. The flash intensity was set on 'high'. Data were collected from 09 March 2020 to 06 August 2020. Humans moved cameras at two sites. Data from after they were moved were excluded from the analyses. Cameras were visited every 3 months to change batteries and SD cards. The researchers ensured that the time set on the cameras was identical. When servicing the cameras, both cameras took pictures of the researchers walking towards them; hence, the differences observed in the study were not induced by a malfunctioning camera.

Data processing

The images were processed using the CameraBase software (Tobler 2007). For each image, the species name and the number of individuals were manually tagged, while the software automatically extracted the time and date of each photo. Humans, their activities (walking, motorcycling), vehicles and dogs were tagged as such (Online Appendix Table 1-A1). When an image was dark, the brightness was adjusted. When it was not possible to identify a species because a part of it was visible, the photo was tagged as ***non-identified***.

In order to test the impact of camera height setting from these two types of surveys on the analysis of a potential combined data set and because there was an average of 9.5 photos for each event, only photos from the same camera and with the same species that had a minimum period of 30-min between image time stamps were retained. This procedure is standard practice to obtain a list of independent capture events for camera trap data analysis, and the authors wanted to position their comparison within commonly used practices. Similar events of both camera heights for a given location was merged by date and time ('merge' function, 'base' R package), in order to produce a comparative list of all the different capture events per camera. When the two cameras were triggered simultaneously and successfully captured the same event, the pair was classified as ***identical***. Events that could not be identified on either camera were deleted (Hofmeester et al. 2020). For the events that were not similar between the two cameras, the remaining capture events were manually processed by comparing the images of both cameras. When only one of the two cameras was triggered, meaning that one could not find any photo for the other camera at that time, the capture event was classified as ***not triggered***. When the image of one of the two cameras was empty (i.e. only background vegetation is visible but no mammal or human), corresponding to a lack of capture, the photo was coded as ***empty***, and when a camera was triggered but it was not possible to identify any species, for example, because the image was too dark even after adjusting the brightness, corresponding to a poor image quality, it was classified as ***dark.*** For each non-identical event (i.e. events classified as not triggered, empty or dark), the species that was detected by the other camera was classified as ***specified.*** The information was noted in Excel. Finally, each capture event was categorised according to whether it was taken during the day or at night based on the sunset or sunrise time ('sunrise.set' function, 'StreamMetabolism' R package).

Data analyses

All statistical analyses were performed in R (R Core Team 2020) and all the graphics were plotted using the 'ggplot2' R package (Wickham 2016).

General detection model

To compare the detection similarity of different species and human activities between the two treatments (low camera vs. high camera), a 0 was assigned to events classified as not triggered, empty or dark, and a 1 was assigned to identical events. A generalised linear model was built to perform a logistic regression, that is, with a binomial distribution of the response variable, to explain the detection of the cameras. The 'MASS' package (Venables & Ripley 2002) was used and the site was included as a variable to control for deviation between two cameras at the same site. The authors also tested the influence of the period of the day (day vs. night) on the detection probability. For each detected species, the average weight and height were compiled to test how they could affect the variation in detection between camera heights (Child et al. 2016; Hofmeester et al. 2020) (Online Appendix Table 1-A1). Weight and height were log-transformed to conform with parametric modelling constraints. Thereafter, a backward stepAIC model selection procedure ('stepAIC' function, 'MASS' package) was used to search for the best combination of variables to get a simplified model. The predicted detection probabilities were calculated ('predict' function, 'car' package) and plotted ('ggpredict' function, 'ggeffects' package, Fox & Weisberg 2019; Lüdecke 2018).

Species detection and by-catch frequency

For each event, a McNemar test ('mcnemar.test' function, 'stats' package), which compares the proportions of paired data to highlight species for which there were differences in the number of detections between the two camera heights, was independently performed.

The authors plotted the type of non-identical events (not triggered, empty, dark), coloured by species to describe the causes behind discrepancies between paired cameras.

Results

The camera trap survey ran over a period of 150 days. Camera pairs were collectively active for a total of 595 trapping days and produced 15 623 photographs, corresponding to 987 captures. Most of the photographs were taken during the day (70% for high cameras and 62% for low cameras). Low and high respectively accounted for 53% (519) and 47% (468) of the captures. These corresponded to 559 unique independent events recorded during the trapping survey. Low and high cameras respectively captured 90% and 81% of the events. The high cameras missed 16% of the events (90) compared to 9% for the low cameras (48). The percentage of empty photos was fairly low for both heights, but was twice as low for the low cameras (0.6% for low cameras and 1.8% for high cameras). The most frequently captured species were bushbuck ($n = 146$) and humans ($n = 147$). Cape grey mongoose ($n = 2$), vervet monkey ($n = 6$) and vehicles ($n = 5$) were the rarest (Online Appendix Table 1-A1). Ten wild mammal species were identified from the survey: (1) chacma baboon (*Papio ursinus*), (2) honey badger (*Mellivora capensis*), (3) bushbuck (*Tragelaphus sylvaticus*), (4) bushpig (*Potamochoerus larvatus*), (5) caracal (*Caracal caracal*), (6) South African large-spotted genet (*Genetta tigrina*), (7) Cape leopard (*Panthera pardus*), (8) vervet monkey (*Chlorocebus pygerythrus*), (9) Cape grey mongoose (*Galerella pulverulenta*), and (10) Cape porcupine (*Hystrix africaeaustralis*).

General detection model

High cameras detected more humans than low cameras (respectively 146 and 124), whereas high cameras detected less wild mammal species events than low cameras (266 and 330 respectively). The best model includes three significant interactions. Low cameras were more efficient in detecting smaller species (weight and height) than high cameras (p: 0.00539; Online Appendix Figure 3-A1 and Table 2-A1). Additionally, lower cameras were more efficient for detecting species at night ($p = 0.00940$; Online Appendix Table 2-A1), especially smaller species (p: 0.00798; Online Appendix Figure 3-A1 and Table 2-A1). The site was not part of the selected variables, so it was assumed that it had no effect on the difference in detection probability between the two camera heights (Online Appendix Table 2-A1).

Species detection and by-catch frequency

The only species not detected by high cameras, the Cape grey mongoose, was detected only twice by low cameras. It was found that high cameras were less effective at capturing porcupine (p: 0.014), large-spotted genet (p: 5.35E-13) and honey badger (p: 0.059), compared to low cameras (Online Appendix Table 3-A1 and Figure 1). Low cameras detected most of the human-related events (i.e. vehicles, motorcycles and dogs with humans) but had a lower detection success for humans (p: 7.10E-06).

Furthermore, for some species (bushbuck, human, bushpig, large-spotted genet and honey badger), the total sum of detections (in grey on Figure 1) was greater than the maximum number of detections for each camera, proving that both cameras missed some images.

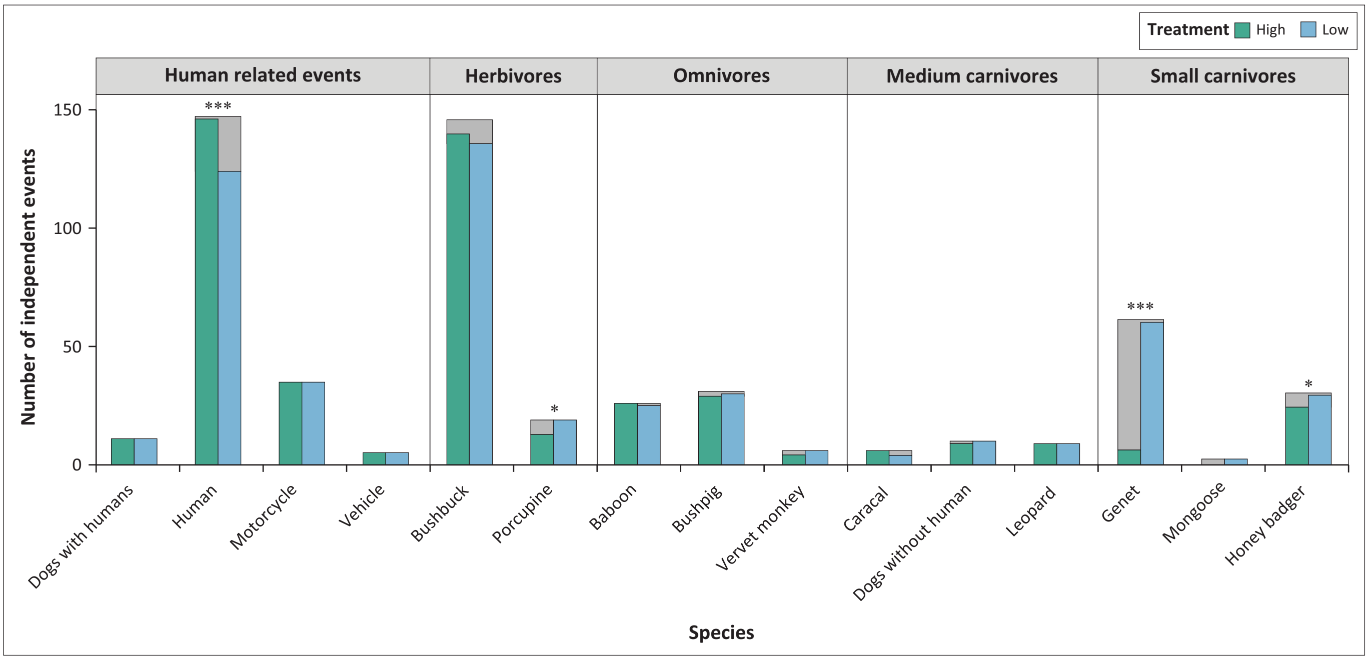
The non-identical events were mostly due to cameras not being triggered by a by-catch species, which concerned small mammal species for high cameras (e.g. 63% of genets not detected) and humans for low cameras (56% of the non-detected events; Figure 2).

Discussion

Lower placed cameras were more effective for capturing small and nocturnal mammals, while higher cameras did marginally better at detecting humans and large nocturnal species. Low cameras detected most of the human-related events successfully, but to a lesser extent than the higher cameras, which may be because humans are bipedal and have a higher centre of gravity than quadrupedal species, with the bulk of their mass being higher (Alexander 2004; Soni et al. 2020). Moreover, the high cameras missed the detection of most large-spotted genets and all Cape grey mongooses, which were by-catch species. This might be because species walked under the triggering sensor of the camera or that the latter was too far to detect smaller species, which is consistent with other work showing that missed detections were the result of failed triggers that increased as species size decreased (Jacobs & Ausband 2018). This supports that a setup height which is not adapted to the target species misses most of its detections, mainly because the cameras are not triggered, and not because of the registration or capture quality probability (Findlay et al. 2020). As the cameras from both heights were oriented to photograph the same vertical and horizontal area (Online Appendix Figure 2-A1), the non-identical events were mostly due to the blind spot from the high camera (near the ground at the bottom of the tree) or because the individual moved outside of the range of detection of the motion sensor. Empty photos were due to species triggering the camera and moving out of the detection zone too quickly to be photographed (Findlay et al. 2020).

This study concurs with other studies that found a significant effect of the camera height on species detection (Findlay et al. 2020; McIntyre et al. 2020; Meek et al. 2016b) and that the probability of detection for cameras positioned at different heights depends on the species size-class (Palencia et al. 2021). It confirms the necessity to adapt the height and the angle of the camera according to the targeted species or community of species to optimise detection rate (Hofmeester et al. 2020; McIntyre et al. 2020; Meek et al. 2016b). The results of this study were obtained in a dense forest, which can limit the potential area of movement for the species and the detection range of the cameras, yet they are similar to results found in open landscapes (McIntyre et al. 2020; Palencia et al. 2021). Failure to take into consideration the effect of camera height on animal detection will lead to poor-quality data, and will likely bias analysis, interpretation and conservation outcomes.

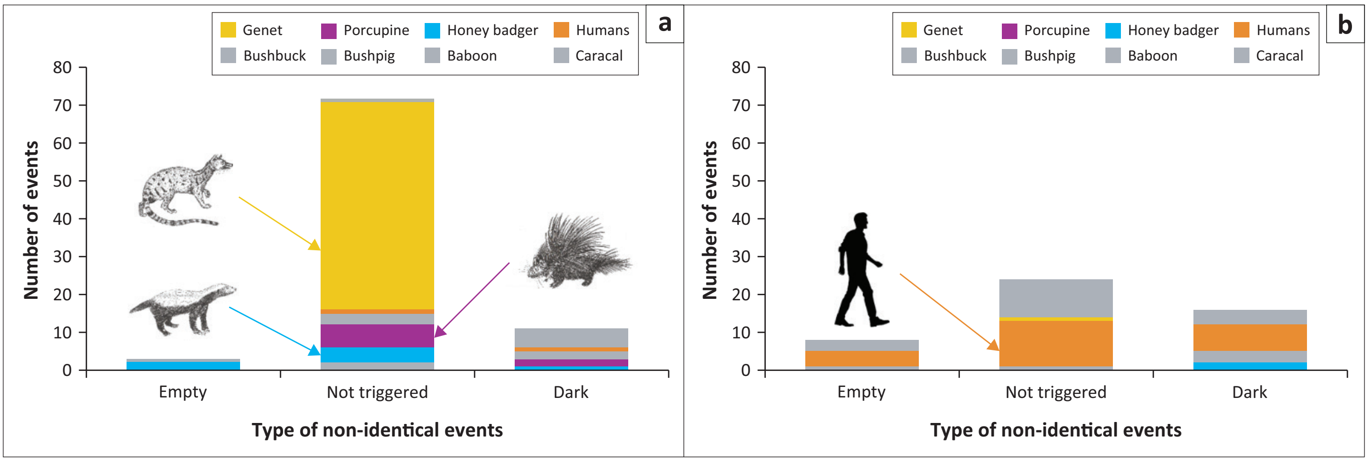
The survey focused on a single camera trap model at five sites, all distributed in the same habitat and at the same



Grey represents the total number of independent detection event.

p: 0.05 > * > 0.01 > ** > 0.001 > ***.

FIGURE 1: Number of independent detections by low (blue) and high (green) cameras for each species photographed in the Harkerville forest, Garden Route National Park, Western Cape, South Africa.



Note: Drawings done by Justin Bellengé.

FIGURE 2: Type and number of non-identical events for (a) high camera and (b) low camera, coloured by species and sorted by empty images, not triggered events, and technical issues.

distance of a trail, in order to test for the effect of camera height on detection. Other survey designs that might impact the detection were not taken into consideration. The results showed that cameras set up higher from the ground are not suitable for studying small mammals (under 30 cm and 10 kg); however, the by-catch data can be used for studying human activities and large mammals (above 50 cm or 20 kg). Furthermore, the low cameras appeared to be the most relevant for studying the biodiversity of small to medium-sized mammals (mean height = 53.1 cm, height range = 15 cm to 80 cm). Using cameras set at a low height is suitable for the study of human and wildlife coexistence, as they performed similarly to high cameras in recording human-related events. The study expands knowledge on how to incorporate by-catch data into camera trap studies by providing a case study comparing human-focused surveys with mammal-focused surveys in forest habitat. Camera trap by-catch should not be carelessly used to address a multitude of research objectives. Pilot studies are paramount before merging data sets acquired from surveys with differing objectives and camera trap setups. Although imperfect detection needs to be accounted for when combining different studies of camera traps (Hofmeester et al. 2019), by-catch data can play a crucial role in providing valuable information on management, conservation and environmental processes (Edwards et al. 2018; Hofmeester et al. 2020).

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

L.M. and H.F. conceived the original idea. A.B., L.M. and M.A.M. carried out the experiment. A.B. wrote the manuscript with support from all the authors. A.B. performed the analysis. H.F. and C.G. provided critical feedback on the analysis. All authors discussed the results and contributed to the final manuscript.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

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Data availability

The data that support this study will be available from the corresponding author, A.B., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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