How camera traps work and how to work them

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How camera traps work and how to work them

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Abstract

Camera traps are very widely used to monitor the presence of animals and record their behaviour. Setting them up properly enhances their performance and data yield. The paper describes how camera traps work and gives basic advice on camera selection, setting up camera traps for various purposes, protecting them from animals, keeping them working and troubleshooting. A camera trap's capture of a still image or video is triggered by a passive infrared detector that responds when something hotter or colder than the background moves in its detection zone. Target detection is camera traps' weak point, and they need to be set up so that animals move across their detection zone rather than towards or away from the camera. Short trigger and recovery times are preferred. After dark, camera traps illuminate the subject with infrared light that is difficult for animals to see, or white light if colour images are required. During the day, stills and video are captured in colour, and at night in monochrome under infrared, or in colour with white illumination. Where cameras need to be sited depends on study design. Camera performance is sensitive to the height and angle that they are mounted at; maximum detections come from cameras just below the target's shoulder height, aimed horizontally. To avoid large numbers of false triggers, trim vegetation in the detection zone that might be moved by the wind. Keep cameras clean and change batteries frequently.

Résumé

Les pièges photographiques sont très largement utilisés pour surveiller la présence d'animaux et enregistrer leur comportement. Le fait de les placer correctement améliore leurs performances et la collecte de données. Cet article décrit comment ils fonctionnent et donne des conseils de base pour le choix d'un appareil, l'installation des pièges en fonction des objectifs visés, et la façon de les protéger des animaux, de les maintenir en état de fonctionner et de résoudre divers problèmes. La prise d'une photo ou d'une vidéo par un piège photographique est déclenchée par un détecteur infra-rouge passif qui répond lorsque quelque chose de plus chaud ou de plus froid que l'arrière-plan se déplace dans sa zone de détection. La détection d'une cible est le point faible des pièges photographiques, et ils doivent être placés de façon à ce que les animaux se déplacent d'un côté à l'autre de la zone de détection et non vers l'appareil ou à partir de lui. Un déclic rapide et un temps intermédiaire court sont préférables. Dans l'obscurité, les pièges photographiques illuminent le sujet au moyen d'une lumière infra-rouge difficile à voir pour l'animal, ou d'une lumière blanche s'il faut des images en couleurs. Pendant la journée, les images fixes et les vidéos sont captées en couleurs et, de nuit, en monochrome sous la lumière infra-rouge ou en couleurs avec une illumination blanche. Les endroits où les pièges doivent être placés dépendent du but de l'étude. Les performances d'une caméra sont sensibles à la hauteur et à l'angle de sa position, et le maximum de détections viennent de caméras placées horizontalement à hauteur d'épaule des cibles visées. Pour éviter un grand nombre de déclics non désirés, il faut dégager, dans la zone de détection, toute la végétation qui pourrait être agitée par le vent. Il faut garder les caméras propres et changer les batteries fréquemment.

KEYWORDS

Africa, behaviour, how to, passive infrared detector, population, trail camera

1 | INTRODUCTION

A camera trap has a simple job: to wait in the field until an animal passes by, then take a picture or video of it, and save the data. To do that, it has a camera that is triggered by an animal detector, a flash or floodlight for operation after dark, and an *SD* card. Most camera traps are designed to meet the needs of their main market, deer hunters in northern temperate zones, and getting good research data from camera traps under most African conditions means having to work within and around their limitations. Here, we offer some basic guidance so that new entrants do not need to pick up the practical skills from scratch or repeat mistakes that have already been made by others.

It is impossible to offer step-by-step instructions for every possible application of every make and model of camera trap, but all off-the-shelf camera traps have similar components and operate on the same principles, and if you know how camera traps work, you will be able to make them work for your purposes. Detailed general guidance is widely available (Meek, Fleming, & Ballard, 2012; Wearn & Glover-Kapfer, 2017), and of course, you should read the instructions that come with the cameras; the focus will be the challenges that are most significant in Africa. The target audience is people who are inexperienced with camera trapping, or who want to extend the applications that they use it for and who will be targeting mammals and birds. The advice is not aimed at experienced camera trappers.

2 | HOW CAMERA TRAPS WORK

A camera trap's two main components are a camera to capture images and a trigger to set off the camera.

2.1 | Triggering

To trigger image capture, nearly all off-the-shelf camera traps use passive infrared (PIR) motion detectors which respond when something with a surface temperature different from the background's moves in their field of view (Gabay, 2012; Welbourne, Claridge, Paull, & Lambert, 2016). Gradual temperature changes, such as clouds passing across the sun, do not generate enough localized temperature difference to make the PIR trigger the camera (Welbourne et al., 2016). Smaller targets are more difficult to detect because they radiate less heat, and more distant targets are more difficult to detect because less of the heat they radiate reaches the detector. As a result, bigger animals are detected at longer ranges than smaller ones (Anile & Devillard, 2016; Rowcliffe, Carbone, Jansen, Kays, & Kranstauber, 2011). Detection range is reduced when a hot background reduces the temperature difference between background and target. If the camera itself gets hot enough, and it can do if it is in the sun, the PIR sensor is blinded by being hotter than both the animals and the background, and it will not trigger at all until it has cooled down, which may take a few hours and lead to missed images until well after dusk. These two effects make high temperatures a major problem for camera trapping in Africa, and whenever possible, cameras need to be in the shade.

The passive infrared (PIR) detector has a window in the front of the camera with a pattern of lenses moulded onto its back surface.

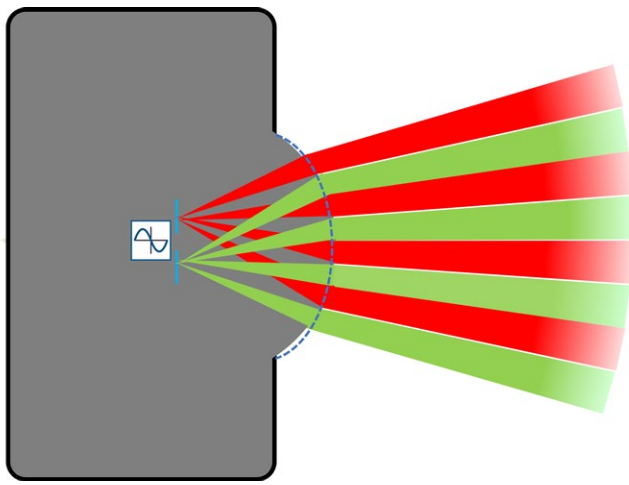

FIGURE 1 The heat images of alternating, adjacent zones of the passive infrared detector's field of view (red and green) are focussed onto different sensors of the pyroelectric chip (blue lines) by a curved Fresnel lens (dashed blue line) in the front of the camera [Colour figure can be viewed at wileyonlinelibrary.com]

These focus infrared energy from the detector's field of view onto a sensor with two or four pyroelectric elements that generate a voltage when their temperatures change. Each lens element covers a different zone of the detector's field of view, and the infrared from adjacent zones is focussed onto different elements of the PIR sensor so that as the target moves across the detector's field of view its infrared image moves from one element to the other (Figure 1, and see also Wearn & Glover-Kapfer, 2017, 23–25). with corresponding rises and falls in the temperatures and voltages of the PIR sensor elements. The rate of change of the voltage difference between the elements is double the rate of change of either voltage alone, and it is this rapid rate of change between two elements that signals movement in the field of view and is used to trigger the camera (Zappi, Farella, & Benini, 2010).

Nearly, all camera trap detectors have five to seven tall, narrow lenses running from the top to the bottom of the detector window, with each lens covering a long, narrow zone of the camera's field of view, fanning out from the camera to the far edge of its detection area (Figure 2), and some have additional lenses at the bottom of the element. Exceptions to the rule are Reconyxs whose detection zones cover only about a half of the vertical field of view, and Pantheracams which are designed to capture the animal in the middle of the image and have a single lens. The vertical arrangement of lens elements with detector zones fanning outwards makes the detector most sensitive to animals moving tangentially across its field of view at right angles to the camera trap's direction of aim, because that generates the sharpest changes in infrared sensor temperature and voltage. It also allows an animal to move radially towards or away from the camera trap without being detected because it does not cross from one zone to the next (Figure 2). If it moves diagonally across the detector's field of view, its transition from one zone to the next is slower than if it walks tangentially, and detection sensitivity is reduced. This biases detections according to the angle of the animal's movements relative to the camera; animals walking across the field of view are detected at longer range than those walking diagonally, towards the camera or away from it (Apps & McNutt, 2018).

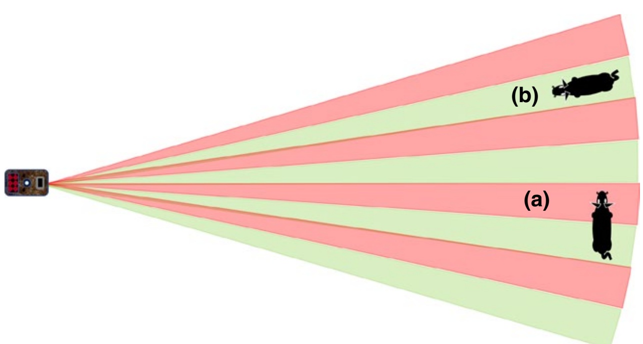

FIGURE 2 The typical passive infrared detector zone layout of a camera trap; animal A is detected as it crosses from one zone to the next but animal B can move almost to the camera without leaving a zone and so will not be detected [Colour figure can be viewed at wileyonlinelibrary.com]

Due to trigger delay (see below), an animal walking towards the camera can have gone right past it by the time the image is captured, while if it is walking away it will still be in the field of view, and this generates about twice as many images of animals walking away from as towards the camera (Apps, 2016). This problem is worse when camera sensitivity is already low due to high temperatures such as are experienced in exposed savannah or grassland sites during the day. For a given sensitivity, fast triggers reduce the bias because they catch approaching animals before they have walked past the camera.

Sensitivity is lower on the edges of the field of view because, although an animal entering the field of view is moving into a detector zone, it is not moving out of one, and maximum sensitivity depends on the signals from two PIR elements rising and falling simultaneously as the target moves into one detection zone and out of another. This low peripheral sensitivity increases the distance that animals penetrate the image field of view before the detector triggers and is a more significant problem when sensitivity is compromised by high temperatures. Delayed detection reduces the number of still images that can be captured, and the length of usable video, and reduces the angle of the detection zone, which is a parameter in random encounter models for estimating animal density (Cusack, et al., 2015).

The type of passive infrared detectors used in camera traps cannot tell the difference between animals and other moving objects whose surface temperature is different from the background's, and so they also respond to plants moved by the wind, and to the whole scene apparently moving if the camera trap moves. Empty images from false triggers do not compromise data, but they are a problem if there are so many of them that they fill up *SD* cards, drain batteries and slow down data processing, and mounting cameras so that they will not move and trimming vegetation in the detection zone are necessary precautions. Reducing the number of false triggers by reducing detector sensitivity is a measure of last resort because it increases the number of missed images, replacing a minor problem with a major one.

2.2 | Trigger and recovery speeds

After an animal has entered the detector's field of view, the detector will sense it when it moves from one zone to another and then send a signal to the camera to take a picture. The signal wakes the camera from the deep sleep that saves battery power between pictures, and the camera reads the light levels, goes to IR or flash after dark and opens its shutter to capture the image. The time between when the animal enters the image field of view and when the image is captured is the trigger delay, and if it is too long the image will not be captured until the animal is moving out of shot and all you will get is a picture of its rump and tail, or an image with no animal in it at all.

Many camera traps have specified trigger delays for still images of <0.5 s, with some around 0.2 s, about the duration of a human blink. Trigger delays for video are longer than they are for stills, 0.4–1.7 s. Unfortunately, deficiencies in passive infrared detectors, lower sensitivity along the edges of the field of view, directional bias, lower sensitivity when temperatures are higher (above) mean that short trigger times do not always result in animals being detected and captured soon after they enter the field of view, and even with fast triggers, animals may be leaving or have left the field of view when the image is taken, especially if they are close to the camera. Baits or lures in the middle of the field of view can keep animals in view, but they cannot be used in studies that assume random encounters with cameras, or for studies of natural behaviour.

After a camera trap has captured an image, it needs a recovery time before it can capture another one, which limits the number of still images that can be captured from one passage of an animal in front of a camera trap, and leaves gaps in video records of continuous behaviour. Recovery times are usually longer than trigger times, 0.5–3.4 s for still images and 0.7–5 s for videos. Unless the camera trap in burst mode (see below), the minimum gap between images is the recovery time plus the trigger time; they run consecutively not concurrently. Species can nearly always be identified from single images, even if they do not show the whole animal, but recognizing individuals needs images that show their distinguishing features. The probability of capturing an image that shows individual features can be increased by shooting multiple images after the first trigger without the need for the PIR detector to trigger again (usually called burst shooting). Alternatively, image capture can be delayed until the target is approximately in the middle of the frame in order to capture an image of the whole animal. To save file storage space, set the number of shots per burst to the minimum needed to get one good image; start with a high number and then reduce it on the basis of the evidence from the images you capture. To get the target in the middle of the frame, some models of camera trap provide a built-in or adjustable trigger delay or mask the edges of the detector window with a movable mask. On other cameras, the edges of the detector window can be masked with sticky tape. Centring image capture is the only option with xenon flash cameras (see below) because their recharge times are too long for burst shooting. When capturing video, there is no reason to wait for the animal to be in the middle of the frame and the faster the trigger and higher the peripheral sensitivity, the better. Because gaps between videos may miss brief behaviours or make it difficult to measure times spent in activities, fast recovery is also desirable.

3 | IMAGES

Most camera traps now produce both stills and video, some do both at once. Cameras with xenon flashes cannot do video at night, but some of them can shoot video during daylight.

Practical camera trapping hardly ever needs very high image quality, and all current camera traps produce adequate images in daylight. On the other hand, infrared image quality is very variable between brands, and not all of them are suitable for research applications. Price tends (with exceptions) to rise with image quality, and it does not make sense to spend a lot of money on high-quality images if all you need is to identify species, or if the cameras will get covered in dust from roads or game trails in the dry season, or mud from rain splash or passing vehicles in the wet season, or from being rubbed on by animals near mud wallows, which will degrade images anyway.

If your camera trap allows a choice of image resolution, set it equal to or slightly higher than the pixel count of the image sensor; the inflated image pixel counts given by manufacturers are reached by interpolating the raw images without adding extra resolution, and saving interpolated files extends recovery time and wastes storage space on the *SD* card and in archives. If you shoot videos, experiment with video formats and resolution with a human or animal target before the camera traps go to the field, and then start in the field with the maximum video length your camera traps will record, and, if you can still get the records you need, shorten it to avoid filling up cards and draining batteries.

3.1 | Illumination

For shooting in poor light, camera traps come with white xenon flash, white LEDs or infrared LEDs at wavelengths of 850 or 940 nanometres (nm), each with its own strengths and weaknesses.

Humans and animals can see both the light source and the reflected light from xenon flash and white LEDs. This disturbs behaviour and makes animals avoid camera sites, and a need for clear colour pictures is the only reason to use white lights. Humans can see 850 nm IR, usually called "low glow" as a blood-red colour only when looking at the light source: they cannot see the IR reflected back from the scene. Most mammals can also see the light source in the camera, and this sometimes affects their behaviour; they stare at the light, retreat or hurry past. "No glow" or "covert" 940 nm IR is nearly invisible to humans; some people can see a faint deep red glow when they look directly at the light. It may not be invisible to some animals; African wildcats and elephants both behave as if they can see the light (Meek et al., 2014; Wegge, Pokheral, & Jnawali, 2004). No glow draws more power than low glow and may limit the choice of batteries to NiMH and lithium ion.

Xenon flash and white LEDs give reasonably accurate colour images. Infrared images are grey monochrome, with limited contrast and low resolution, and are usually not good enough for recognition of individual animals from natural markings. Some animal markings that are visible in daylight or white flash disappear in IR; the white patches on African wild dogs look the same as the tan background.

White light and low glow cameras are easily found by poachers and thieves, and in some areas, this limits the choice to no glow.

4 | CAMERA SITING, MOUNTING AND AIMING

If you are estimating population parameters, the study design dictates how camera traps must be sited (Rovero, Zimmermann, Berzi, & Meek, 2013; Wearn & Glover-Kapfer, 2017); otherwise, you can put them where they will capture the maximum number of useful images. Within the constraints of the study design, camera sites that take into account the habits of study animals, along paths, or at burrow entrances, water holes, wallows, rubbing posts, scent-marking sites and carcases, or anywhere else that animals travel or spend time, will increase the quantity and quality of camera trap data. If you have the option, put the camera trap where it will be in afternoon shade to protect the PIR from heat.

Mount and aim cameras so that animals are detected as soon as possible after they enter the field of view (see Detection and Trigger Speed above) to maximize the length of available video or the number of still images in either burst mode or by repeated triggers. If you need still images in the middle of the frame, adjust the camera trap settings to get them.

Because of the way passive infrared detectors work, camera traps are surprisingly sensitive to the height and angle they are mounted at; a 20 cm difference in height or a 2° difference in angle can produce data that are not strictly comparable and cause a high rate of missed images (Apps & McNutt, 2018). For maximum detections, mount camera traps just below the target animals' shoulder height, aimed level with the surface (Apps & McNutt, 2018). To check for horizontal aim, use a small spirit level to check that the front of the camera trap is vertical. To maintain sensitivity and detection range, camera traps should not be mounted more than 40 cm above the targets' shoulder height, or angled more than 5° towards the ground (Apps & McNutt, 2018), but you may have to adapt this to circumstances; when animals are in groups, such as African wild dogs (*Lycaon pictus*) at a marking site (P.J. Apps, personal observation), or honey badgers (Apps, Rafiq, & McNutt, 2018), those close to a camera trap mounted at shoulder height can obscure those further away, and so cameras must be mounted higher and angled downwards, so that they look over the backs of animals in the foreground (P.J. Apps, personal observation). Cameras near waterholes may need to be mounted above the shoulder height of large species so that they do not get smeared with mud, and cameras may need to be mounted above vegetation to obtain a clear view and avoid spurious triggers from moving plants. Mounting cameras higher loses sensitivity because they have to be tilted downwards to cover the same area and are then pointing at the hot soil surface. It also increases the size of the dead zone below the bottom edge of the sensor field and decreases maximum range (Figure 3) (Apps & McNutt, 2018).

During the rainy season, the lens windows and sensors of cameras mounted below about 30 cm can get splashed with dirt by the heavy rainfall that is characteristic of much of Africa. If you have to put them that low, put something below the lens and sensor to stop the splashes, or cover the ground in front of the camera with something that will stop mud from splashing up.

Conventionally, camera traps are fixed to tree trunks, which is convenient (but may be biased Cusack et al., 2015) in forest or savannah as long as precise location is not critical. Choose the sturdiest tree or, for preference, a stump, so that the camera trap does not move and cause false triggers. Where there are no suitable trees in the right places, camera traps can be fixed to fences or fallen branches, wedged between rocks or mounted on poles or stands. Cameras are less conspicuous on natural objects than on poles out in the open, which makes them less likely to be interfered with by people and is reputed to reduce the rate of damage by elephants. Metal housings

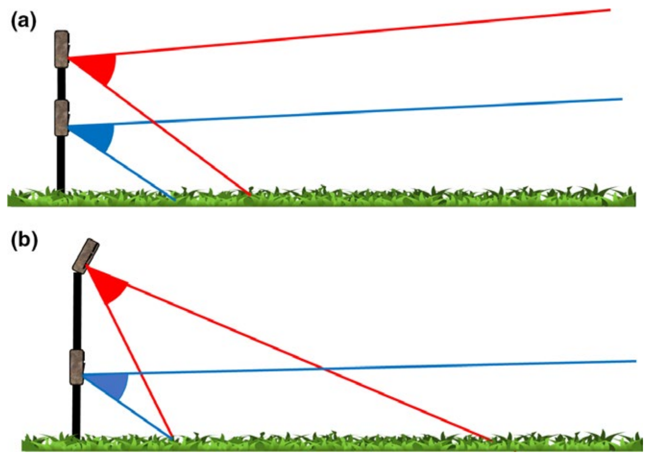

FIGURE 3 (a) When camera traps are aimed horizontally, the size of the dead zone between the camera trap and the bottom of the field of view increases with height.(b) If a higher camera is dipped forward to bring the nearest edge of the field of view back towards the camera, the maximum range is reduced [Colour figure can be viewed at wileyonlinelibrary.com]

are often necessary to protect camera traps from large predators, of which African wild dogs and hyaenas (*Crocuta crocuta* and *Hyaena brunnea*) are the most likely to cause problems, primates, large herbivores or vultures. African elephants damage large numbers of camera traps in deliberate attacks. The "bear" housings supplied by camera manufacturers with 1.65- to 2.1-mm steel (16- or 14-gauge) are sufficient protection against all species except elephants, but for camera traps to survive elephant attacks, their armour needs to be made from 2.4-mm (12-gauge) or thicker mild steel with at least a 10-mm gap around the camera to allow the box to flex without transmitting the stress to the camera inside, and mounting brackets need to be 40x40x5 mm angle iron, connected with 12-mm bolts.

Adjusting the aim of camera traps attached to natural objects, fences or wooden poles may need some ingenuity. Wedge pieces of wood or a pad of flexible foam plastic behind the camera trap, and use the tension of straps or ropes to adjust angles. Use rope with some stretch, or bungee cords, so that it does not work loose and let the camera trap move out of position. The quickest and most straightforward way of aiming camera traps very precisely and repeatably from site to site is to mount them on metal poles and brackets with lockable swivel joints. Whatever you fix them to, make sure that they cannot move.

If your data model allows it, you need to aim your camera traps to maximize the quantity and quality of images. Siting and aiming camera traps are a compromise; for sensitive detection, the camera trap needs to be close to where the animals will be, especially if sensitivity is reduced by heat, but it also has to be far enough away for them not to move right across the field of view during the trigger delay. Due to the directional bias of their detectors, camera traps aimed across paths (Figure 4) have maximum sensitivity, but then they cover the shortest length of path. You can increase the length of path covered by a camera trap and decrease the amount of potentially interfering vegetation between the camera trap and the target, by putting the

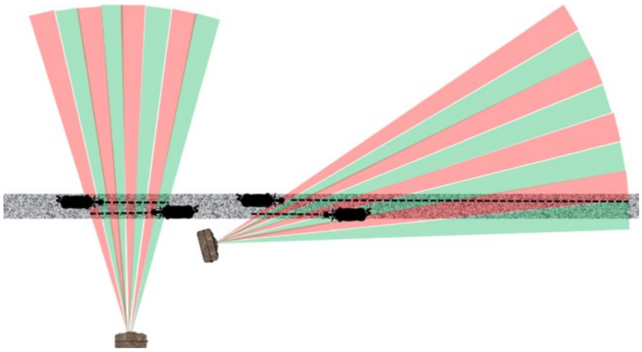

FIGURE 4 A camera trap aimed across a track has the maximum sensitivity, but targets are in the detection zone and field of view for only a short distance and time, which increases the chances that they will move out of view during the trigger delay. A camera at an obtuse angle to the track has a directional bias, but animals moving away from it can be videoed for an increased distance and time [Colour figure can be viewed at wileyonlinelibrary.com]

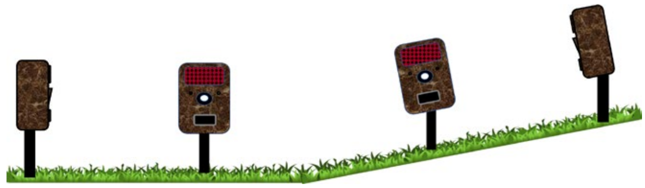

FIGURE 5 For maximum detections, camera traps must be angled to match the slope of the ground [Colour figure can be viewed at wileyonlinelibrary.com]

camera closer to the track and aiming diagonally across it (Figure 4). Due to the layout of detection zones, and reduced sensitivity in the outermost zones, animals walking along the path from behind the camera will trigger an image just after they pass it, those approaching from the front will trigger it just before they reach it. With slow triggers, there will be a directional bias but that is offset by being able to capture video as animals walk away along the path, and possibly react to baits, lures or natural scent marks. The drawback is that animals walking towards the camera are detected only just before they pass it, so for data that are not biased by direction of travel, you need two cameras pointing in opposite directions. Camera traps covering open areas catch animals that are not using paths, but are biased with respect to the directions in which they are moving (Figure 2). Two cameras aimed at right angles to one another can be used to reduce this bias. Whenever you use multiple cameras aim them so that they do not dazzle one another with their lights.

Local topography affects how camera traps need to be aimed. If a camera is aimed along a slope, tilt it to bring the ground surface parallel with the top and bottom of the field of view (Figure 5). If it is aimed up or down a slope, angle it to follow the slope. In open habitats, cameras facing within about 30° of east or west will pick up flare from the rising or setting sun (Figure 6a), and if they have autoexposure, the brightness of the sky at those times will cause underexposed foregrounds (Figure 6b). Lens flare is also a major problem if there is a light source anywhere close to the field of view and is much worse if there is dirt, dew or raindrops on the lens window. The lens hoods on camera traps are very wide and shallow, and attaching deeper lens hoods is worth testing, or you can make a hood for the whole camera at the cost of making it more conspicuous.

Confirm a camera trap's aim by taking an image and viewing it, and adjust if necessary. An onboard screen is a huge help when aiming; it is much quicker than taking test shots, removing the *SD* card to view them, moving the camera, taking another set of tests etc. A "live" screen that shows where the camera is pointing without you having to take an image is by far the fastest way of getting a camera aimed properly. To get images during set-up, you can usually trigger the camera trap by moving your hand in front of the detector window, but if you are setting up cameras during the heat of the day the detectors may not detect a hand and you may need to rub your palms together to heat them up, or use something that has lain in the sun to get hot. Walking or crawling in front of a camera trap gives only a very rough and optimistic test of its ability to detect real animals (Apps & McNutt, 2018).

5 | HOUSEKEEPING

To reduce false triggers, clear the field of view of vegetation that can be moved by the wind, without removing so much that it affects the

FIGURE 6 (a) Flare from the setting sun when a camera trap is aimed too close to westward. (b) The bright evening sky makes a camera trap's autoexposure underexpose the foreground. (c) Grass close to a camera trap is brightly lit by the infrared floodlight and makes the autoexposure underexpose the background. (d) Dew or raindrops on the lens window of a camera trap seriously degrade image quality [Colour figure can be viewed at wileyonlinelibrary.com]

subjects' behaviour. Anything between the camera and where the subjects are likely to be must be removed, and some gardening in the background can also help. Plants are more likely to trigger empty images when they are close to the camera, large or against a thermally contrasting background of hot ground or cool sky. These conditions are most common during the day in savannah, grassland and arid areas where there is direct sunlight and large temperature differences between night and day. Vegetation in the foreground causes problems with images taken at night because it is brightly lit by the camera's flash or floodlight and produces a burned out glare at fixed exposure or an impenetrably dark background with autoexposure (Figure 6c).

Clean the detector and lens windows at set-up and every time you swap batteries or *SD* cards. Cleaning should be done as carefully as clearing an ordinary camera's lens; blow off the dust, then squirt the surface with water that contains a couple of drops of detergent, then wipe very gently while it is still wet. Wet wipes are ideal for this. Use a fresh one for each camera. Passive infrared detector windows are especially susceptible to scratches because they are made from soft polyethylene. Dew or raindrops on the lens window seriously degrade images (Figure 6d). Wiping the lens window with a surfactant will help.

If accurate aiming is important, you need to check every time you visit that the camera has not shifted. The most accurate way is to check that the edges of the image have not moved relative to the background. In areas where there are high densities of animals that interfere with camera traps, camera alignment needs daily attention.

It is good practice to scan through images as soon as possible, ideally on site, certainly before the next visit, rather than days or weeks later by which time malfunctioning or poorly set cameras will have missed data that can never be recovered.

6 | TROUBLESHOOTING

The best time to troubleshoot is before the cameras go out to the field. Do at least a walk test with a human target on all of them, and check that their range of detection is long enough (keeping in mind that a human will be detected at longer range than most animals), that the image is sharp enough, and that the lights are bright enough. Any that are not working properly need to be fixed.

If the only images that are captured are rumps and tails, the trigger speed of the camera is too slow, and if you have already set the trigger speed to maximum, you will need to change your set-up. You can move the camera trap further back from the line of travel so that it takes the animals longer to walk across the field of view, at a cost in sensitivity and the pictures of the animals being smaller, and a larger area in front of the camera trap having to be kept free of obstructions (see Housekeeping above). Alternatively, you can aim the camera trap diagonally across the line of travel at a cost in directional bias (Figure 4), and/or add a lure or bait to keep the animal in the field of view if your study design allows it.

6.1 | False triggers and empty images

Empty images with no animals in them are to be expected and are much better than missed images. Unless the camera trap is malfunctioning, the three main causes of empty images are the camera trap itself moving, vegetation moving in the detector's field of view or animals moving too fast for the trigger speed or being detected just as they leave the image field of view. These can all be minimized by setting cameras up properly.

False triggers caused by vegetation or the camera trap itself moving are easier to recognize on videos than on still images because the video shows the movement. Keep in mind that if the sensor window is below the lens it can be affected by plants that do not appear on the images. How fast an animal has to move to be out of the image field of view by the time the image is captured depends on its direction of movement relative to the camera (see above) and the width of the image field of view. The animals most likely to cause empty images move quickly relative to their body size and are close to the camera trap or moving directly towards it. Vehicles move faster than animals and can be a major source of empty images; sometimes you will see the dust they raise on the image or hear engine noise on the soundtrack of a video.

By far the most likely reason for images that are too dark to see the target is depleted batteries that cannot power the light. The problem gets worse as more images are taken, long videos are darker at the end, and the camera trap still works in daylight. Put in fresh batteries. At night, vegetation in front of the lens reflects the camera's light and leaves the background in darkness (Figure 6).

False colours, spots scattered across the image and lost time and date settings are electronic malfunctions that you are unlikely to be able to fix. Contact the manufacturers.

6.2 | Missed images

The number of missed images must be reduced by all means possible because the lost data can never be recovered. The main difficulty with troubleshooting missed images is recognizing that they were missed, since in the field there is hardly ever an independent record of what animals passed the camera trap. The only direct evidence you will get of a missed image is if the camera trap is one of a multi-camera trap array, and another camera captures images of animals in the faulty camera trap's field of view. Otherwise, you have to rely on circumstantial evidence; signs of animal activity in the field of view with no corresponding pictures (Ballard, Meek, Doak, Fleming, & Sparkes, 2014) or periods when images of the usual common species are not captured or false triggers do not happen.

Images can be missed for a variety of reasons: poor detector performance, camera malfunctions, poor set-up, and ambient conditions. By far, the most common reason is probably flat batteries, and this is also the easiest to recognize; the camera will have captured images up to a certain time, and then stopped, and the batteries will be run down. It is also the easiest to fix; replace batteries proactively. Heat can shut camera traps down; if you get images in the morning and late at night but not in the afternoon and early evening, then move the camera trap to a shady spot. Small changes in aim can lead to missed images, especially on camera traps like Reconyxs that have restricted detection zones (Apps & McNutt, 2018). Check recent images against older ones when the camera was working properly—are the edges of the field of view in the same place relative to the background? If not, put the camera trap back into its proper position. Eyeballing height and angle may not be accurate enough.

The easiest and quickest way to get a site's camera trap up and running again is to swap the faulty camera trap for one that is known to be working, and troubleshoot the faulty one back at base under controlled conditions.

7 | SUMMARY

Camera trap designs are improving but their weak point is still their passive infrared detectors' vulnerability to camera trap height and angle and high temperatures. If possible, place camera traps just below the targets' shoulder height, aimed so that animals walk across their field of view, and, if daytime temperatures are high, where they will be in afternoon shade. In the parts of Africa that have high numbers and densities of animals that can damage and displace camera traps, put the cameras in armoured boxes and mount them securely to sturdy supports, preferably away from areas frequented by animals likely to interfere with them.

Camera trap placement and housekeeping in the field are at least as important as camera design in determining data yield and quality.

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