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Authors: Meek, P. D., and Pittet, A.

Source: Wildlife Research, 39(8) : 649-660

Published By: CSIRO Publishing

URL: https://doi.org/10.1071/WR12138

CSIRO PUBLISHING
Wildlife Research, 2012, **39**, 649–660
http://dx.doi.org/10.1071/WR12138

Review

User-based design specifications for the ultimate camera trap for wildlife research

P. D. Meek[A,B,D] *and A. Pittet*[C]

[A]NSW Department of Primary Industries, PO Box 530, Coffs Harbour, NSW 2450, Australia.
[B]School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia.
[C]Department of Electronic Systems Engineering (formerly CEDT), Indian Institute of Science, Bangalore, Karnataka, India.
[D]Corresponding author. Email: paul.meek@dpi.nsw.gov.au

Abstract

Context. The adoption of camera trapping in place of traditional wildlife survey methods has become common despite inherent flaws in equipment and a dearth of research to test their fit for purpose. Overwhelmingly, the development of commercial camera traps has been driven by the needs of North American hunters. Camera-trap models and features are influenced by these market forces that drive the changes in designs as new technologies develop. This focus on recreation, rather than research has often frustrated wildlife professionals as the equipment has rarely met minimum standards for scientific application.

Aims. We investigated the demand for white-flash camera traps around the world to highlight the demand for such camera traps in wildlife research to the manufacturing industry. We also compiled the camera-trap specifications required by scientists through the world in an effort to influence and improve the quality of camera traps for research.

Methods. We carried out an internet-based survey of biologists, zoologists, conservationists and other wildlife researchers by using a questionnaire to gather baseline market data on camera-trap use and demand. We also conducted an informal survey of scientists via email and in person, asking for their preferences and features of an ultimate camera-trap design.

Key result. Infrared camera traps are widely used and more so than white-flash camera traps, although the demand for white flash remains significant. Cost, speed, size, ease of use, versatility and the range of settings were the key features identified in a good camera trap.

Conclusions. The present paper describes and discusses the desired features and specifications as defined by over 150 scientists using camera traps around the world. Data gathered also provide some insight into the market demand for camera traps by biologists, zoologists, conservationists and other wildlife researchers around the world. These design features are discussed under the guise of the *ultimate camera trap* for wildlife research, with the disclaimer that no such camera trap currently exists.

Implications. The information provided in the paper has and will be a useful guide to future camera-trap designs, although it is unlikely that all of the features required will ever be produced in a cheap camera trap.

Additional keywords: technology, remote camera, trail camera.

Received 24 July 2012, accepted 14 November 2012, published online 11 December 2012

Introduction

Even though camera traps are more than a century old (Shiras 1906, 1913), their use was rather limited until some two decades ago when the reduced size, weight and cost of such systems made them more attractive (Kays and Slauson 2008). A plethora of models from many brands is now commercially available, although many people have, and continue to build their own fit-for-purpose units. In the last decade, the scientific community and mostly wildlife specialists have increasingly used camera traps for research (Kays and Slauson 2008; Rowcliffe and Carbone 2008). This area of technology changes at warp speed, largely driven by market demands in the northern hemisphere, with a large component of the market being recreational hunters, as can be seen from camera-trap websites such as http://www.trailcampro.com (verified 28 November 2012), http://www.chasingame.com (verified 28 November 2012) and http://www.moultriefeeders.com (verified 28 November 2012). Consequently, most of the commercial systems are designed to satisfy this market demand; they are therefore best suited to relatively large target species from the northern hemisphere, e.g. ungulates and medium- to large-sized predators, that are the targets of the hunting fraternity. Despite this market demand, the same camera traps are being bought by wildlife researchers worldwide, with quite different needs and expectations, and the limitations have not been fully realised. As a result, some specialist groups have designed camera traps to suit their needs (KORA in Switzerland, CEDT in India, Panthera in USA, and others), but at the commercial scale, these camera traps are not readily available.

In line with market forces, much of the recent camera-trap designs use infrared (IR) light-emitting diodes (LEDs) for night photographs; this is mostly intended to avoid spooking potential quarry from a given hunting site. Although it has resulted in significant improvements in IR cameras, it has also led to a reduction in the availability of systems with visible-light (xenon or white LED) flashes, much to the disadvantage of some wildlife researchers who, in some cases, need high-clarity colour photographs even at night. Emerging camera traps are also designed specifically to cope with northern hemisphere weather conditions, rendering them less suitable in some arid or tropical environments.

As with other tools adopted for wildlife research purposes, field evaluation of camera traps has led many researchers to 'dream up' ideal modifications to their equipment. However, camera-trap technology is not easily customisable for those devoid of expert technical and engineering knowledge, leading to frustration and unachievable expectations when research needs cannot be met by technology. Equally, the expectations of a lone, frustrated researcher is not enough to convince camera-trap manufacturers of the need for design changes.

The present paper brings together the aspirations of experienced camera-trap users from the international wildlife research community. Individual contributions have been used to propose the features of the *ultimate camera trap* for scientific research purposes. These requirements are explicated and discussed in the context of what can be technically achieved, thus providing some insight into camera technology that may be used by researchers when choosing models that are fit for their purpose. The paper also serves as a user-based commercial portfolio for manufacturers interested in supplying appropriate equipment to the research market.

Methods

Information collection

The authors have been designing and developing ideas with their colleagues to define the *ultimate camera trap* for wildlife surveys over many years. Scientists, contacted via a camera-trap discussion group (Camera-trap Yahoo UK Group) and the authors' professional networks were asked for recommendations on features that they would 'like to see included into the design of camera traps to suit their needs'. The participants were not surveyed by questionnaire nor constrained in any way and were asked to ignore technical limitations and cost while framing what could be referred to as their 'wish specifications'. Detailed discussions were held with several camera-trap researchers during a Churchill Fellowship Study Tour by one of these authors (Meek 2012) and the suggestions from these meetings have been included. The features were added to an existing list of features developed by one of the authors (P. D. Meek), based on personal experience and discussions with colleagues. All the recommendations were placed in the following two categories: functionality (electronics and embedded software design) and enclosure design. This exercise started as a discussion topic intended for internal use by the members; however, eventually, the information collected began to highlight some specifications that we believed would be useful to disseminate. Each design feature has been critically reviewed to evaluate the technical feasibility of building the feature into a camera-trap product. Even though each researcher has specific requirements regarding their field equipment, we decided to further organise the proposed specifications into 'core features' and 'desirable options'. The suggestions and deliberations of over 150 camera-trap users were included into these specifications and are discussed in detail in the following sections.

Camera-trap market survey – wildlife research users

A limited market survey was carried out using Survey Monkey (USA). Invitations to participate were sent to users through the camera-trap discussion group (http://uk.groups.yahoo.com/group/cameratraps/?tab = s, verified 15 September 2012) and wildlife organisations throughout the world. Camera-trap users were asked general questions about their camera-trap choices and the quantities used in their research. All answers were anonymous. The survey questionnaire was designed to quantify the demand for specific types of camera traps in the market and as a comparison to the hunting camera-trap market. Ten multiple-choice questions (Table 1) were presented under broad categories and some constraints were placed on how participants could answer the questions to avoid ambiguity. Participants were asked which country they lived and worked in, the number of cameras they had bought over the past 4 years and the costs, which cameras they anticipated buying in the next 2 years, whether white flash or IR camera traps were preferred and which type they would buy. Participants were also encouraged to recruit their colleagues into the study by distributing the invitation to participate. Surveys were carried out under Human Ethics Research Approval UNE Permit HE12-091.

Results

Camera-trap market survey

The questionnaire was open for a 6-month period between 2011 and 2012. In total, 154 researchers provided responses to the questions, although not every participant answered each question. The participant demographic was ~65% southern hemisphere and ~35% northern hemisphere, with most responses from Oceania (38.6%), Europe (19.3%) and South America (16.6%). Irrespective of where scientists lived, the majority of participants' camera-trap study sites were in Oceania (39%) and South America (19%).

On average, researchers reported having bought more camera traps in 2007–08 than in more recent financial years, commonly buying between 1 and 10 units per year (Fig. 1). Very few researchers in this survey bought more than 30 camera traps per year, although 18 researchers had bought in excess of 100 camera traps at some point in time during the past 3 years. The majority of researchers using IR camera traps possessed between

Table 1. A list of 10 survey questions used in Survey Monkey (USA) to gather baseline data on wildlife research and monitoring camera-trap use and users

Question number	Question
1	What country and/or region do you live and work in?
2	What country/region do you use camera traps in?
3	How many cameras have you bought (2010–11, 2009–10, 2008–09, 2007–08)?
4	How much money in total did you spend on camera traps for wildlife research and monitoring (in $US) (2010–11, 2009–10, 2008–09, 2007–08)?
5	What demand do you have for infrared-flash camera traps in your program?
6	How many infrared-flash cameras do you have?
7	What demand do you have for white-flash cameras in your program?
8	How many white-flash cameras do you have?
9	For your next camera traps, would you like to have (infrared flash, white flash, dual flash)?
10	How many camera traps will you actually buy in the next 24 months?

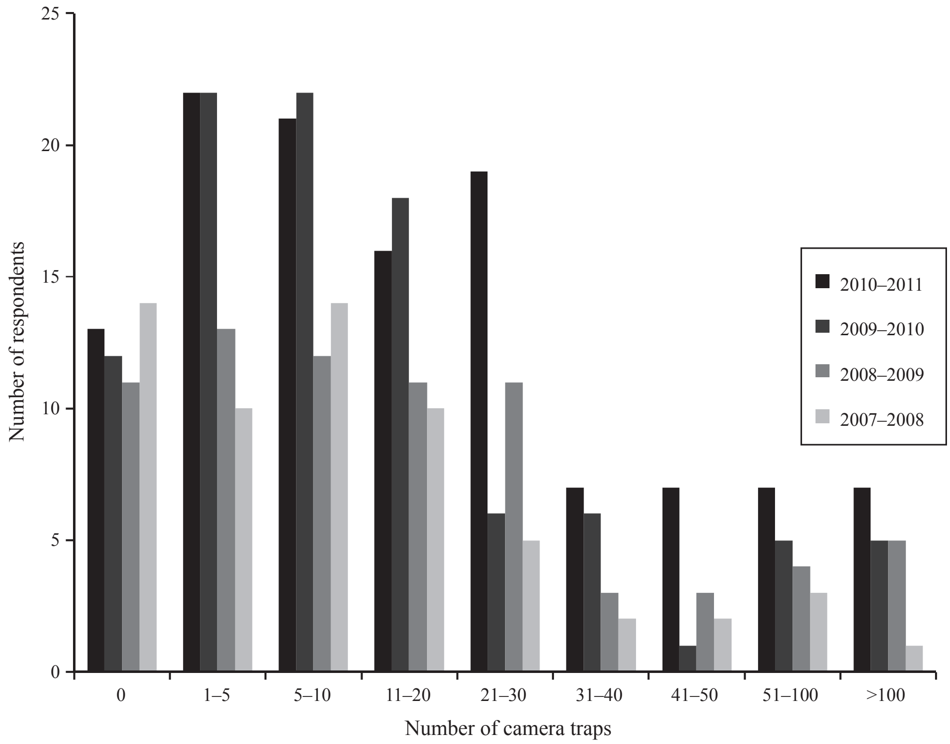

Fig. 1. The number of camera traps bought by respondents between 2007 and 2011.

1 and 30 cameras. Over 50% of respondents declared that they used white-flash cameras, and 7.3% of them reported owning 100 or more of these devices. Among respondents, 18% stated they had a high demand for white-flash camera traps, whereas 31% said they had no demand.

Although the present survey did not ask exactly how much money was spent each year between 2007 and 2011 on camera traps, it was reported that most of researchers spend between US$1000 and US$5000 per year on these devices (Table 2). The preferred type of camera traps used by researchers, on the basis of answers in this survey, were IR (63.2%), with only 3.3% of respondents stating that they had no use for them. In response to a question asking which of three camera-trap types researchers would like to use in the future research projects, 50% preferred IR, 42.7% selected a dual-flash (white flash and IR) camera trap and 11.3% preferred just white flash.

Almost half (47%) of the respondents said they were likely to buy between 1 and 20 camera traps in the next two financial years, whereas 40% stated they would not be buying any more in that period (Fig. 2).

Ultimate camera trap specifications

Core features

The features proposed by researchers for the *ultimate camera-trap* design have been subclassified under 'Functionality' and

Table 2. Camera-trap purchases by camera-trap researchers between 2007 and 2011
Costs requested are given in $US for ease of interpretation

Year	Cost						
	US$200–500	US$500–1000	US$1000–5000	US$5000–10 000	US$10 000–20 000	US$20 000–50 000	>US$ 50 000
2007–08	5	8	16	3	9	4	0
2008–09	8	5	17	4	12	8	3
2009–10	9	19	27	9	10	8	3
2010–11	9	15	35	19	12	11	6

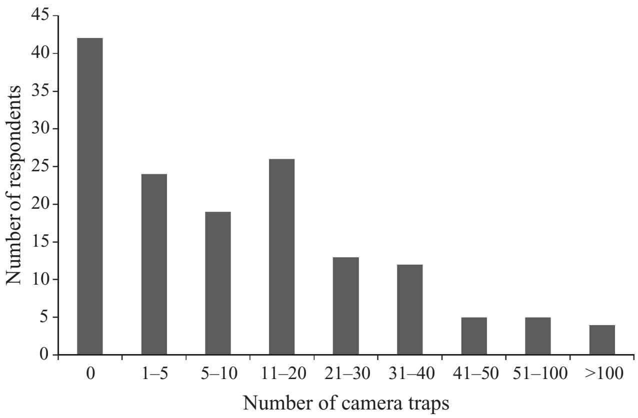

Fig. 2. The number of planned purchases of camera traps by respondents in the next two financial years.

'Enclosure design' and discussed in detail (Table 3). The authors and participants recognise that all of these features cannot be packaged into one affordable camera trap. As such, this information is presented to help guide future camera-trap designs.

Functionality

Passive motion detection (PIR). Motion detection is of prime importance for any camera trap to be effective. Most of the commercial traps today use pyroelectric IR detectors, also known as passive infrared (PIR). These devices react to heat and motion in front of the system where there is a differential between ambient and animal body temperature. A lens is placed in front of the detector to focus the IR rays onto the sensor. These are usually Fresnel lenses and they may be single lens or lens arrays. A single lens results in a relatively narrow conical detection zone, whereas a lens array covers a much wider area of motion detection. The area of each lens in a lens array is much smaller than that of the single lens and, consequently, single-lens detectors are usually more sensitive because they allow more IR rays to be focussed on the sensor. The detection zone for a single-lens system is also close to the centre of the image. Therefore, the system must have a very low latency between motion detection and image capture to ensure that the target animal does not move out of the frame when the camera is triggered. Conversely, a curved-lens array, with a much wider detection angle, allows a longer latency before triggering the photograph, which is why many commercial camera traps use curved-array lenses; to compensate for a relatively slow triggering system (see section on 'Initial time to trigger').

The sensitivity of a PIR-based motion detector depends on many factors, including the distance of the moving target, the temperature differential, the size of the animal, its speed and background light. These detectors are prone to false positive images where a photo is taken with no apparent animal in the frame. This can occur if the camera trap is facing moving pockets of hot air, a rising sun or a shadow during the noon hours of hot days and is more likely to occur in grasslands, deserts and beaches.

Given these considerations, the *ultimate camera trap* must be equipped with a passive motion-detection system that ensures detection of a small–medium size-class species (60–1200 g) at a distance of at least 5–10 m, and 1.5–6 m for smaller species such as small rodents. The motion detection must be matched to the image capture system in such a way that an animal walking by the camera traps results in a well centred photograph. If the system is intended for a burst mode of photography or for video, a wide-angle multi-lens array may be more effective, possibly combined with a narrow-angle single lens.

Initial time to trigger. There is always a delay between the instant that a motion is detected and the time at which the picture is taken. This is sometimes referred to as 'trigger latency' or simply 'initial trigger delay'. Many commercial camera traps have a very long 'initial time to trigger', often a few seconds, making them inadequate for trail monitoring, and better suited to a food plot or bait that causes the animal to stop for a short period of time. Comments from users suggest that they require an initial time to trigger of not more than 200 ms to give maximum chance for good photographs of animals, even if they pass at a fast walking pace close to the camera trap. However, a delay of 500 ms is acceptable because this correspond to a displacement of only 50 cm for an animal walking at 1 m s^{-1} (= 3.6 km h^{-1}).

Variable trigger delay. Most scientific applications require photograph to be taken as soon as possible after the motion is detected. However, there are some cases where an initial delay is required and the *ultimate camera trap* shall have the option for the user to set a delay. A typical example of such applications would be for large-cat census, where the distance from the system to the target is usually set at ~3 m and the cat moves at ~2 km h^{-1} or ~55 cm s^{-1}. With a fast motion detector and a low initial time to trigger, the user may like to force a delay to initial trigger to ensure a centred photograph of the cat. Similarly, a delay setting in a camera trap set at a food plot or bait station may reduce unwanted photos of approaching animals and maximise more composed

Table 3. Ultimate camera-trap design specifications summary
IR, infrared; Mp, megapixels

Feature	Specification
Camera functionality	
Trigger speed	Latency to first photo 0.5 s, two photos per second (near-video speed).
Photo speed	Up to two frames per second IR LEDs; LED flash one image per second.
Image resolution	Programmable resolution 1.3–12 Mp (12 Mp, 8 Mp, 5 Mp, 3 Mp, 1.3 Mp).
Frame-rate intervals	0–60 s between images.
Photos per trigger	Programmable 1–100.
Delay after triggering	0–60 min at intervals of 1 s min^{-1}.
Programmable time-lapse trigger	Ability to program in standard or time-lapse mode, which allows the programming of the camera to take a picture at even time-lapse intervals until it picks up a motion, after which it switches to standard mode, recording the events, and back to time lapse at the end of the motion. Capacity to program detection-time periods to just day or just night or between selected hours of the day.
Image settings	Choice of two aperture settings of *f*4 and *f*16. This is a photography term commonly used f-stop.
Image	Colour day and colour night (no filter), monochrome night (IR LED).
Image data stamp	Image JPEG with minimum JPEG EXIF content; time, date, temperature, longitude and latitude, ID stamp and moon phase. Programmable settings for dd/mm/yy or mm/dd/yy format.
Dual-flash system	White LED- and IR LED-flash system, allows dual-flash capabilities with greater illumination and clarity at night when needed. 990–1000 nm IR LED spectrum.
Flash range	0.5–50 feet, with manual dimming-control system for distance setting to enable close-up deployment, thus avoiding white-out exposures. Range 1.5–20 m.
Video length	HD high definition video in MPEG4 format, duration adjustable between 10 and 60 s or can be programmed to continue until the motion stops.
Sound	Sound is recorded during video.
Remote viewer	Remote wireless live viewer to aid camera setting, including detection-zone water mark (below). Viewer also allows programming and downloading to secure digital (SD) cards.
Detection-zone watermark	This function can be programmed to allow set up photos to be taken with the detection zone watermarked over the image to assess detection zone in the field of view of the camera trap.
Battery type	Rechargeable lithium-ion battery (45 days and/or 30 images and/or 15 flash).
Battery charge	Accurate inbuilt battery-level meter that can be accessed via wireless remote viewer (above); a power-plug connection is provided.
Battery charging	An induction charging system has been included to enable multiple charging capacities without the need for battery removal. Alternatively, a docking-station recharger can be used.
Memory-card type	Secure digital (SD or SDHC).
Memory-card capacity	2–32 GB.
Operating temperature range	–20°F to +120°F.
Anti-theft deterrence	Pass-code protection.
Image alert	SIM card and/or daisy-chain system that allows cameras to be set in series and to communicate through a main-beacon camera. At first motion, an image is sent to the preferred mobile phone.
Sensors	Three PIR sensors (45°, 90°, 135°) with adjustable sensitivity to reduce false triggers, with multi-zone lens for increased sensitivity and the ability to choose whether the PIR reacts to one or two triggers. Detection zone 1.5–40 m.
Test function	A test LED has been fitted to enable correct camera placement and field testing.
Programming screen	The programming functions are offered in eight main languages. Date and time conventions can be altered according to individual preferences. Custom setting options are available to suit your specific survey needs and can be locked in using a code lock.
Camera unit design	
Anti-theft and placement features	Anti-theft cable holes through the top and bottom of the camera housing to enable carbon-fibre cable (python lock) and elastic-strap fitting. A locking bracket allows the front door of the housing to be locked with a padlock.
Angle-adjustment bracket	A bracket mechanism is located at the rear-top of the camera housing, with an adjusting knob to allow the camera to be angled downwards when setting.
Camera dimensions	This small slim-lined and light-weight camera is built to pack into field bags with ease (12 × 9 × 6 cm).
Camera-finding sevice	Beacon-locator alarm and hand-held button-activated finder system – range 20–30 m.
External connections	External battery supply as well as external flash, radio beacon and/or repeater or logger terminals.
Door seal	The seal is water tight and insect proof, which prevents moisture, ants and small invertebrates accessing the camera circuitry.
Desiccant holder	Inside the camera housing is a small linear chamber for placement of a desiccant package. Desiccant storage package that prevents moisture absorption until before deployment is included.
Weight	Light weight only 400 g per unit (without battery).

(*continued next page*)

Table 3. (*continued*)

Feature	Specification
Laser pointer	A series of lasers that represent the detection-zone extremes to assist in camera placement.
Weatherproof front panel	Standard side-opening front door, optional top-hinge system allowing the camera to be opened in inclement weather without rain and snow entering the internal section of the device; a stabilising hinge mechanism allows the front panel to lock open for ease of setting.
Lens hood	These inbuilt hoods protrude slightly over the lenses to reduce rain drops and shadow interference and can be retracted for packing. The lens is flush with the camera housing to prevent accumulation of rain and water in front of the lens.
Mounting screws	Durable plastic tripod-mounting studs are located at the rear and bottom of the camera housing to allow for tripods or screws to be fitted to aid in camera placement.
Compass rose	A small compass rose is built into the top of the camera housing to aid camera-direction placement.
Label sleeve	On the side of the housing, a 50 × 50 mm sleeve for insertion of laminated information cards to notify visitors of camera ownership and project aim (theft deterrent) is provided.
Camouflage	A range of camouflage options is available to suit different habitats, including white for snow habitat.
Anti-theft tracking system	An anti-theft tracker is inbuilt and uses the telecommunications network to locate the stolen camera trap.
Optional design	A wireless remote-sensing unit can be programmed to the main unit so that the camera lens and PIR sensors can be placed separately; when a motion is detected, the photos are sent to the camera unit via wireless within 10 m (direct line of sight). A useful anti-theft accessory.

images. The delay programming needs to be versatile and range from 0 to 60 min, with 1-s and 1-min intervals for maximum control.

Number of pictures per event. Most camera traps allow settings of more than one photo per trigger event to record a series of photographs per event. This feature can be used to confirm identification or compose quasi video recordings, often referred to as *rapid-fire* or *burst* mode. It can also be used with longer delays, as has been done, for example, to study the removal of fruits or seeds from a patch (Miura *et al*. 1997; Prasad *et al*. 2010). In *burst* mode, a minimum interval of 500 ms is adequate, although for some studies the interval may need to be set in minutes. To satisfy this requirement, the *ultimate camera trap* needs to allow delay settings in steps of 0.5 s to 1 min and then in steps of 0.5–10 min. The number of photos taken per event must also be user defined, allowing settings from 1 to 100. With current technology, it may be challenging to offer a large number of photos at a high resolution and very low intervals between pictures. In low-light or night conditions when a flash is required, taking multiple photographs in burst mode presents other challenges – this will be discussed in the flash options section.

The *ultimate camera trap* will need to have customising features that allow normal PIR sensing images to be taken in combination with time-lapse mode, so that a photo is taken at predetermined intervals in the absence of motion-triggered events, but is also triggered by a motion event. This mode setting enables researchers to confirm that the camera trap was operational throughout the duration of the deployment; this is especially important when no photos have been taken. This function also allows time-lapse programming for day and night or just day or just night.

Image resolution. The *ultimate camera trap* needs to offer a choice of resolutions from 12 megapixels (Mp), down to as low as 1.3 Mp. The past few years have seen a steady increase of the resolution of digital cameras on the market as Mp seem to have become an important marketing parameter. In the case of camera traps for scientific applications, the clarity and pixilation of images can be critical to some researchers whose studies rely on the sharpness of images for identification of features, especially where the use of pattern-recognition software can be used for identification. Other researchers may not necessarily care about the image quality, just as long as the species can be identified. However, the higher the resolution the slower the shutter speed because more pixels are packed in the same image-sensor area, resulting in less energy hitting each pixel. This, in turn, results in longer exposure time for each photograph and often blurred photographs in low-light conditions. This can be compensated by 'binning pixels', for example, if a 12-Mp sensor is set to capture images at only 3 Mp. In some current models it is also possible to reduce the sensitivity to improve the image quality.

Video. In the *ultimate camera trap*, users will have the option of both still and video. The length of each video clip will be programmable from 10 s to 1 min with no delay, and the system will keep recording as long as motion is detected. Video resolution will be set from 702 × 480 pixels to high definition in MPEG4 format and including sound.

Flash options. *A priori*, there are two basic options for flashes, including visible (LED white flash) or invisible (IR). Whereas older camera traps had the standard visible (white light) xenon flash, the advent of digital system opened up the option to work in IR light because most image sensors are sensitive to IR. This results in monochrome photographs at night. Such flashes are almost invisible to human and are assumed to be invisible to all animal species, although this is not the case. Consequently, many researchers tend to prefer IR flashes to avoid biasing their data as a result of the animal developing 'camera shyness' linked to their reaction to the flash (Wegge *et al*. 2004; Schipper 2007). The use of IR flash can also render the system much less noticeable to humans, thus reducing the risks of theft in some circumstances.

The use of LEDs for invisible flash does not allow the same level of energy to be released in a very short burst. This typically results in a relatively long exposure time for IR LED-based photographs, with somewhat blurred pictures, a limitation that many users have experienced with commercial camera traps. This has been a very serious limitation for their use in deployments aimed at population estimates based on capture–recapture of marked species like tigers, as the stripe pattern cannot be clearly established from such photographs. Because a regular xenon flash emits a significant amount of IR light, there is the possibility to combine them with an IR filter to retain the energy density of the flash light, while working in the IR domain. Conversely, IR LED lighting allows operation in burst mode where pictures are taken at very short intervals, which cannot be easily done with a xenon flash; the advent of white-flash LED camera traps in 2012 have overcome this limitation. IR flash also allows night video without too much disturbance to the target animals. However, for those situations where image detail and colour are required for nocturnal animals, the most suitable option is to have a white flash (Nelson *et al*. 2009; Meek 2010). This ensures that pelage colour and morphological features can be distinguished more clearly than with a monochrome image. On the basis of total market availability, the demand for white flash-camera traps is lower than that for IR, but this is certainly not the case in Australia and parts of Europe where coexisting nocturnal species with similar morphology can be identified only with colour images.

The choice of flash type depends on the type of research being carried out; however, having one type of flash can limit the species that can be studied. This can be resolved by using a dual-flash system in the *ultimate camera trap* where both IR and xenon flash systems can be selected in the one unit. Moreover, the intensity of light should be automatically adjusted depending on the distance of the subject from the camera because such close subjects will receive less illumination from the flash to reduce over-exposure. If such an automatic exposure is not implemented, then a manual setting should be available to reduce the flash intensity for setups where the target animal is expected to be very close to the camera (<3 m).

Battery monitoring. Battery replacement is a tedious and considerable time cost in research projects and often the charge is unknown or the reading is unreliable. An inbuilt battery-charge meter would be a highly valued feature because checking individual batteries in the field is cumbersome and time consuming. Also, the addition of an 'expected battery-life' according to programmed settings would allow users to predict more accurately how much usage is left from a set of batteries. At present, users are more inclined to change batteries if less than 50–60% of the charge is left, just in case the batteries expire before the next survey period is completed, leading to a serious waste of resources. By using the battery-charge and expected-life functions, users would be able to read the remaining charge and maximise battery use.

Image-data storage. For ease of data management and interpretation, each image file will be in jpg format and have attached metadata stored in the EXIF section, e.g. time and date the picture was taken, the temperature, possibly the moon phase and geo-coordinates of the trapping station. Having such data integrated in the EXIF section of the jpg file ensures that they are retained while making copies and backups, and makes it easy to extract them for further processing with simple utilities such as EXIFTOOLS (Phil Harvey Version 8.89, USA). A firmware program will need to be written to allow the user-defined label together with the time- and date-stamp data as the file name of the image and to stamp the image with this file name. The *ultimate camera trap* requires the option of US and UK date format as well as 24-h and AM/PM options for time because the US format is confusing to non-US users. The *ultimate camera trap* will also have the option of choosing from one of eight languages.

Camera-trap housing. Camera-trap housing designs have improved in recent models and some are much smaller and easier to pack for field deployment than are earlier models. A compact camera housing with no sharp edges or protrusions is an important attribute of the *ultimate camera-trap* design. Being able to bundle 15–20 cameras in a back pack is an important trait.

Enclosure design

Dimensions. The dimensions of the *ultimate camera trap* will need to be ~$12 \times 9 \times 6$ cm so that it is light weight and easy to pack into storage boxes and carry in the field in carry packs. A hood over the camera lens and PIR sensors will ensure that rain and snow do not compromise the camera or the quality of the picture. The hood will be retractable to avoid problems during packing and transport.

Camouflage. Camouflage is an important feature and although no design will be suitable for all ecosystems, the ability to select a colour design to suit a range of habitats from deciduous to sclerophyll to tropical rainforests and even snow habitats is necessary. The camera-trap housing must be robust and withstand 'attacks' by some species.

Weather proofing (humidity and temperature). Camera traps need to face all extremes of weather conditions in terms of temperature, humidity, rain and snow. The *ultimate camera trap* will be able to operate in temperatures ranging from –20°F to +120°F (−30°C to 50°C) and with extreme humidity levels. The housing and seals need to be resistant to dust and water ingress according to IP65 standards, and impervious to small insects as they are often known to squeeze between the door and main housing seal.

Ease of installation. Camera traps are usually deployed by tying them to trees, stakes or mounted on tripods or using brackets. The placement of the camera trap is critical to obtaining good pictures. In the housing of the *ultimate camera trap* there will be two shafts at the rear, one for a security cable and the other for using an elastic strap. These shafts need to be well positioned to ensure balancing of the system. On the rear and underside of the camera-trap housing, a 1/4–20 tripod stud resistant to corrosion will be fitted to enable deployment with a standard tripod or for attaching to positioning brackets. A spindle and bracket mechanism at the rear-top and both sides of the camera housing with an adjusting knob can be used to adjust the angle of the camera trap during placement. The designs by Cuddeback (Green Bay, WI, USA) and Leopold (Beaverton, OR, USA) are among the most appropriate systems currently on the market.

Access for settings and replacement of batteries and memory card. The *ultimate camera trap* is designed to provide easy access for battery and card replacement. The side-opening door will give access to the setting screen and battery cartridge, with no disturbance of the station setup. The camera-trap housing will also be designed so that the door can be hinged from the top to prevent rain or snow entering the system in poor weather. The door will feature a locking mechanism, allowing it to remain open to free both hands for setting the functions and changing batteries and cards.

Compass. On the top of the main camera housing, a small compass rose will be fitted to provide a quick reference guide to the direction of the sun and a cardinal bearing to be recorded. This expedites the setting process and ensures that camera traps are placed according to the best direction. This is also helpful when analysing animal movements and passage along transects and reduces the chance of misinterpretation of photo data.

Desirable options

Provision for external power and flash. The camera trap housing will have external terminals for connecting external power sources (batteries or solar panels). At the bottom of the housing will be grommets that cover an auxiliary terminal for an external flash or external triggering device.

Communication for data access. Some of the burdens of camera trapping are setting the device accurately, checking and uploading images and checking battery levels ahead of changing batteries and cards. Often the user will set the camera to the preferred placement; however, in most cameras the programming buttons and screens are behind the front or bottom door. As a result, the positioning can be changed when the doors are closed. The *ultimate camera trap* will have a wireless programming controller, where all settings and image transfer can be carried out without the need for cables or interfering with the device, as long as it is turned on before placement. The controller uses the standard proximity radio interface Bluetooth or Wi-Fi, and could be tailored to operate from a smartphone running an Android application. The device would allow full-picture download, as well as checking key settings such as e.g. the battery-charge level, the number of pictures taken, spare capacity on the memory card. It would also allow card formatting, setting date and time, changing operational parameters, setting folder name on the memory card and embedding the GPS coordinates in each jpg file. The controller also allows the user to position the camera detection zone accurately through the projection of a 'watermark detection zone' over a live visualisation of the field of view, as seen by the camera. This feature superimposes the detection-zone image of the limits of the detection zone of the motion detector to optimise camera placement and ensure maximum detection.

Beacon locator. To assist in locating camera traps in homogenous habitats, an audio beacon could be activated from a remote hand piece at a distance of 20–30 m, being similar to a car key-beacon locating system.

Geographical positioning system (GPS). The geo-coordinates of each trapping station are essential data for any scientific deployment. At present, they are collected with a handheld GPS and later embedded in the EXIF section of the jpg files. The *ultimate camera trap* needs an inbuilt GPS module in each unit that is used to acquire a fix at the time of installation and is embedded into the EXIF data file. The GPS may be combined with a group special mobile (GSM) module to enable communication with the telecommunication system in case of theft.

Group special mobile (GSM). The integration of a GSM module in the camera trap allows the transmission of basic data through short-message service (SMS) alerts. These alerts enable the programming options of delivering the first image taken in a series automatically through GPRS or message alerts when the device has low batteries or memory-card space. The camera trap can also be reprogrammed remotely. The device can be daisy-chain linked to all cameras through a beacon unit and/or repeater. The limitations of the systems are constrained by forest type, geography and the telecommunications network of the home country. In many locations in Australia, the Next G or 4G systems are not adequate to communicate in some remote parts of the country; however, having this functionality provides a new dimension to camera trapping.

Laser pointers. A single laser beam that points at the centre of the photograph will provide a backup system to a wireless watermark-detection zone. An additional two beams could be used to delineate the limits of the detection zone to assist in fine-tuning the placement.

Discussion

In the space of 120 years, the transition from trip-wire glass-plate camera traps designed by George Shiras (Sanderson and Trolle 2005; Kucera and Barrett 2011), the Oliver Pearson camera traps (Pearson 1960) to the Swiss Mickey Mouse trap of the late 1980s (Fridolin Zimmerman, pers. comm., 2012) and now the modern day, fully programmable still- and video-camera traps, have come a long way. However, as we have outlined, there are still many functions and attributes that need to be adapted for the special needs of current-day camera-trap researchers. Camera traps are now recognised as an important tool in a new era of data collection (Swann *et al*. 2004; Kays and Slauson 2008; Rowcliffe and Carbone 2008; Kucera and Barrett 2011; O'Connell *et al*. 2011; Swann *et al*. 2011*b*). Their deployment applications provide us with data that were previously unavailable by using conventional surveys techniques (Kucera and Barrett 2011; Swann *et al*. 2011*a*). Furthermore, because of their battery life in the field, camera traps can be set and left until they can be retrieved, saving considerable time and costs especially in remote areas. Camera traps can also be set by field staff, by using detailed but simple protocols and with limited training, which is attractive for scientists working in foreign countries where accessibility to study sites is difficult and expensive. In a study tour of Europe and the USA, (Meek 2012) reported that two key features driving the choice of camera traps by researchers are cost per unit, and simplicity of use. In essence, researchers are forfeiting quality for quantity on the basis of the premise that more camera traps cover a greater area and more sites, and increase replication while trading off rigour (Meek 2012). Yet, what is almost comical is that we all expect the best possible product for the lowest possible cost.

It is apparent that designing and manufacturing the *ultimate camera trap* with all or even most of the design functions described is highly challenging, if not impossible, even more so given cost is so important to researchers (Meek 2012). Although the design suggestions of the *ultimate camera trap* provide great insight into the aspirations of researchers, the full suite of demands may not be integrated into one device today. It is noted that some of the features recommended in the present paper have been explored by private manufacturers (Pittet Camera in India, Ross Meggs in Australia, KORA Designs in Switzerland and Panthera in the USA), although these are not discussed in detail for proprietary reasons. Camera-trap technology is moving rapidly and, coincidentally, some of the manufacturers have very recently addressed some of the deficiencies in camera traps outlined in the present paper, with some new designs that mimic the functions listed in the *ultimate camera trap*.

For example, programming some camera traps can be confusing, irrespective of the guidelines presented in manuals. The assumptions of menu-driven programming by manufacturers can be misleading and can result in lost field time. The language and format of the programming functions is mostly set to English by default and in some camera traps, American English, including date and time stamps that are foreign to all non-US users. In countries where English is not the main language, and even in English-speaking countries, users can be confused by the mm/dd/yy format of the USA system (Meek 2012). Where English is not the first language, programming cameras can pose enormous problems for field staff and researchers. Camera-trap brands such as Leupold have addressed this deficiency by adding multi-language options in the programming, although the choice of some languages is confusing.

For the most part, camera traps were designed to detect large game, such as e.g. deer, with the exception of Reconyx (Holmen, WI, USA) camera traps that were designed originally for small mammals (Meek 2012) and the small-mammal camera traps built by (Pearson 1960). However, the sensitivity of camera traps need to be quite different in countries such as Australia, Asia and parts of Europe where many species are of medium- to small-size classes. Using sensors designed to detect animals with high body mass (50–150 kg) for animals with a smaller body mass of 90–2000 g poses many challenges for research. Modifying PIR sensors and detection-zone arrays for smaller prey would go a long way towards resolving ongoing problems of using camera traps for detecting animals such as e.g. small- to medium-sized mammals and birds. Some companies have attempted to redress this issue; Reconyx offers a specially designed cone-shaped detection-zone system in the Professional range (PC800 & 900) that can be customised especially for small-mammal surveys. Pixcontroller (Export, PA, USA) uses components and design features to maximise detection of small animals and customised camera traps can be ordered. Leupold RCX-2 has an adjustable PIR that enables the user to set the detection zone on a wide or close-up setting. Others have attempted to compensate for the latency of triggering through the use of three PIR sensors; two of them aim at the edge of the field of view and serve to 'wake up' the system, whereas the third one, usually a narrow-angle PIR sensor, actually triggers the photography when the target animal is in the centre of the frame. The LTL Acorn 521OMC, 521OMMS and A940MC camera traps (LTL Acorn, Green Bay, WI, USA) have introduced a 'tri-sensor' technology which claims to have the ability to detect a trigger before it enters the optimum photo range of the camera. The design includes dual-side 'Prep Sensors' and a main front sensor, although it is not a true tri-sensor because it has only two PIRs that focus through three Fresnel lenses.

In 2011–12, Pixcontroller designed and released a separate PIR and lens system contained in a PVC tube that is placed separate to the main camera trap connected by a cable. This option was a positive step towards a wireless system that allows the device to be separate from the detection mechanisms and easier to hide and camouflage. This design feature not only improves the versatility of the user's placement, but it also reduces the chance of theft and may reduce animal interest in the device because of its size and low detectability. Whereas some features are being recognised by manufacturers as important to the user groups, some features are less available.

These features are being phased out by perceived market demands, being largely driven by hunters. The availability of modern camera traps with white-flash technology is almost non-existent, despite the demands being high in some areas in the Oceania and Europe. In Australia, there are many species of similar appearance that coexist, so using features such as pelage and feet colour are essential for identification. These features cannot be distinguished using IR monochrome images, which also lack clarity because of insufficient light and consequently high pixilation. Similarly, in Europe, Africa and Asia, camera-trap images need to highlight pelage patterns for individual recognition of naturally marked species (Karanth and Nichols 1998; Zimmermann *et al*. 2005; Marnewick *et al*. 2008; Kays *et al*. 2009), and white-flash cameras provide the greatest clarity in this regard. The design of a dual-flash camera trap would seem to be a useful specification for an *ultimate camera trap*. The results of our surveys confirmed that IR camera traps are in higher demand than are white-flash cameras. However, there remains a market for white-flash camera traps, with 50% of respondents stating that they use white-flash cameras and 42% stating that they would buy a dual-flash camera if it was fit for purpose. In 2011 (unrelated to our surveys), Scoutguard (Bolyguard, Shenzhen, China) released the SG-560DF and Duck Lick Creek (Lewisburg, KY, USA) introduced the DLC Deuce unit. These very similar-looking camera traps offer a white flash and a small row (22) of IR LEDs, enabling the camera to be set manually on either flash type. In 2012, as a result of discussions with one of the authors (P. D. Meek), Reconyx introduced their PC850 and HC550 white LED-flash camera. There is little doubt that the number of models of white-flash cameras available on the market is declining and this will have serious implications for wildlife research globally. Having the ability to adjust the white-flash intensity is an important design feature of the *ultimate camera trap*. There is only one camera trap currently on the market that self-adjusts the flash output (DigitalEye, Pixcontroller), and this is because it is built around a regular commercial digital camera. The Reconyx PC850 can manipulate illumination through programming, but all other cameras emit a bright flash, often causing white out of animals when set at close range. The Scoutguard SG580M has the ability to choose from two flash outputs, namely 6 or 12 m, although a choice of down to 2 m would be preferable. Recent Scoutguard firmware upgrades (Nov 2012) have enabled xenon and white flash camera traps to be programmed through the SD card for close flash settings. The Moultrie M100 (Moultriefeeders, Alabaster, AL, USA) has a three-setting adjustable zoom lens (see below), allowing the subject to be further from the camera trap and therefore reducing white out. If IR technology is going to be the design focus of the future, then serious attention must be given to the clarity of the images produced at night. Adjusting the sensitivity of night images can improve quality and reduce blurring in some cases. Moultrie has released the Game Spy M-80xt which has motion-freeze technology that changes the exposure time from 1/8th s to 1/20th s to maximise clarity. However, such an exposure may still be too long for obtaining the sharpness of pictures required for some applications such as individual identifications of naturally marked animals. Interestingly, this model also allows the use of a 32-GB secure digital (SD) memory card, which is invaluable for data storage in high-volume camera-trap study sites.

The adoption of wireless technology in camera trapping is a significant but important requirement of camera-trap researcher, because it can reduce download time and provides a useful security alert system, in the event a device is being stolen. Many manufacturers have now released live picture messaging that can also be used outside of the USA; Pixcontroller has the Raptor Cellular and Wi-Fi, Scoutguard has the SG550VP-31 with a wireless remote and the SG580M with telecommunication capabilities, whereas LTL Acorn has the 521OMMS and A940MC models. Spypoint (Quebec, Canada) has the LIVE model that not only sends images at trigger time to a smart phone, but also allows wireless access to settings and the Tiny-W that has a wireless black box receiver that stores data remote from the camera trap. The Pixcontroller Raptor has a camera trap unit separate from the sensor and lens, thus reducing the visual appearance of the camera and enabling safe placement of the image-storage unit. BuckEye Cam (Athens, OH, USA) has the Orion XIR with internet-protocol capabilities and the X7D that is wireless and sends pictures to computer or telephone networks. Despite these progressive steps using advances in telecommunication technology, no one manufacturer has yet released on the market a wireless hand-held programming remote that allows live screen view for setting up the unit, review of photos taken and full setting access, although the Pixcontroller Raptor and BuckEye Cam allows camera-trap settings to be programmed via the telecommunication system direct to your PC.

Setting cameras is critical; however, despite the live-preview functions of Leopold and Uwey NT50 (Uway, Norcross, GA, USA), and walk test functions to aid camera placement, accuracy remains problematic. Exact placement of camera traps depends on many factors including PIR types, Fresnel lens type, animal size, distance of the camera from the animal, time of day, ambient temperature and sensitivity settings. Similarly, a thorough understanding of the detection zone and how it applies to each site is paramount. The recommendation of a wireless remote with a projection of the detection zone superimposed over the live scene would be a significant step towards maximising detection rates. The Uwey NH80-HD has come one step closer by having a live screen on the front of the camera; however, this poses some challenges when setting up because you need to be in front of the camera to see the screen while trying to assess the field of view.

Similarly, camera traps always have a preselected camera lens that has a set focal length and field of view, which is rarely, with the exception of Reconyx cameras, equal to the PIR field of detection (see http://www.trailcampro.com/reconyxdetectionzones.aspx, accessed 20 September 2011). Since camera traps are used for a diversity of projects and species, the focal length and field of view are rarely perfect and in some situations it would be helpful to zoom in on a specific site. A design specification suggested in the *ultimate camera trap* is to have a zoom control function so that the user can adjust the lens. Pixcontroller and Reconyx have been offering inter-changeable components to customise camera traps for many years; recently, this has been included in the Moultrie Gamespy M100, Leopold and BIRDCAM (Moutriefeeders). The Moultrie Gamespy has the ability to program for no zoom or ×1.5, ×2 or ×3 zoom, the Leopold allows for two detection-zone settings of 10 degrees of 45 degrees and the BIRDCAM has adjustable focal-range settings of >2.5 m, 2.5–1 m, 1–0.6 m and 0.6–0.45 m. So there is a general progression towards more complex components and functions in camera traps; however, these improvements come at a financial or functionality cost.

A feature sought after by some researchers has been the time lapse-programmable feature that could allow preselected time-interval images to be taken throughout a period while also being triggered when motion is detected. The Moultrie M-80XT has a function called Plot Cam Mode that enables video to be taken at intervals after sunrise and before sunset, along with limited photos taken during the day. Reconyx professional series and the Uovision UV555 (Uovision, Shenzhen, China) camera traps have time-lapse mode with programmable intervals, the number of pictures and on and off time selection. The demand for time-lapse functions seems to be increasing on the basis of our discussions with researchers.

Many of the options listed in the *ultimate camera trap* come with a hefty price tag, particularly security options. Fitting a GPS system to a device can be cost prohibitive in some countries and is unlikely to be commonly fitted to all camera-trap models. Pixcontroller has designed a GPS system for the Raptor Cellular camera trap that sends a phone message when the camera is moved. At the time of writing, this additional component was US $200. Pixcontroller has also designed components that can be separate from the camera device, such as a wireless remote PIR sensor and slave flash options that trigger in synchronism with the regular flash. Likewise, the Reconyx professional series and Spypoint Tiny-W offer a two unit package where the sensors are separate from the main device. A professional deer hunter in the USA did design a small GPS system for camera traps (Bancroft 2010); however, it is not commercially available. In the *ultimate camera-trap* design, researchers specified having GPS for allowing cameras to be tracked if stolen, and also to enable auto storage of the geographical locations of the devices, with upload capacity to the EXIF file.

Powering camera traps is an ongoing challenge and is resource hungry when large numbers of camera traps are being deployed. The ongoing costs of battery replacement, chargers and time needed to recharge each survey set are considerable. An alternative greener power option to batteries is required. The use of alkaline, lithium and even rechargeable batteries in camera traps worldwide is having a significant impact on the environment because of the toxic by-products and waste from batteries. As an interim measure, AA lithium batteries are much more efficient to use in camera traps than other battery types and sizes and all models should allow the use of alkaline, NiMH or lithium and not be constrained by one type. Moving towards a battery system similar to those found in laptops (lithium-ion batteries) that can be charged via a cable or, preferably, that can be charged through an induction charging platform is desirable. A failure in the current lithium-ion batteries is their intolerance of cold temperatures, rendering them a liability in cold climates. If a suitable battery system could be developed it would reduce battery waste and save human resources that are used in charging batteries between deployments; however, a suitable solution seems unlikely in the immediate future.

The design features of camera-trap housings vary greatly among brands and models and choosing the right one to suit a need can be impossible in some habitats. In wildlife research, we desire light-weight, small compact-sized, well camouflaged, water-proof and sturdy housings. In difficult terrain where camera traps are deployed from back packs, well shaped housings are paramount because lens hoods and protruding sections make packing complicated. Manufacturers such as Reconyx and Pixcontroller will customise particular camera-trap models to solve specific design requirements where it is possible. For example, a researcher working in a European alpine habitat had difficulties with snow gathering on the lens hoods and wanted to camouflage the devices. The company specifically had the housing made without any protrusions and made the housing white to blend with the snow landscape. So, although some of the housing requirements of the *ultimate camera trap* may not suit all users, the option to customise the needs provides a solution to the individual requirements of some researchers.

The management of large datasets of images is an enormous liability for researchers and their organisations. Downloading and coding the data is time consuming and prone to human error. Software programs that record the pre-programmed camera code, number of images per event/setting taken, date, time and moon phase to the EXIF section of each jpg file and then to a database are an enormous time-saving tool. There are four database programs that provide some of this functionality; these include the DeskTeam database (Ahumada *et al*. 2011; Fegraus *et al*. 2011), Reconyx MapView, software by Jim Sanderson (Harris *et al*. 2010) and Camera Base 1.5.1 (http://www.atrium-biodiversity.org/tools/camerabase, verified 28 November 2012). The later program was freeware designed by Mathias Tobler and includes some statistical applications, as does the Sanderson program. All four of these programs have some excellent design features and all are still being updated on the basis of end-user requirements.

The use of camera traps in science and natural resource management is yet to be fully realised, and as scientists we need to be aware of the limitations of the equipment. Designing camera traps for deer-hunter markets in the northern hemisphere does not fully recognise the demands of a growing wildlife research and management market. The results of our small survey indicated that the wildlife research market is considerable and growing. It is hoped that camera-trap manufacturers acknowledge the demand of this market and future trap designs reflect the needs of science as well.

Some of the functions and specifications presented in the current paper have already been provided to a couple of the camera-trap manufacturers who responded to invitations by one of the authors (P. D. Meek) to meet with them in 2011. We know that some of our results were immediately embraced by two of the manufacturers and have influenced their new models. We hope the information provided in the present paper will assist other manufacturers with some valuable ideas for the next generation of equipment, with a specific bent towards wildlife research and management markets. We also hope that the information and deliberations regarding the preferred features of camera traps provide some insight into the range of features available and features to consider when users are choosing a camera trap for research and monitoring purposes. Although to quote Don Swann 'even the *ultimate camera trap* will never actually be the *ultimate camera trap*'.

Acknowledgements

We thank the following camera-trap users for their input into the design features of the *ultimate camera-trap* design: Robert Thomson, Andrew Claridge, Euan Ritchie, Paul Whitehead, M Firoz Ahmed, Peter Fleming, Guy Ballard, Phil Redpath, Luke Woodford, Charles Foley, Jeremy Lindsell, Jackie Willis, Alejandro Gonzalez, Deanna Dawn, Jorge Ahumada, Kerry Kilshaw, Marcus Rowcliff, Chris Carbone, Sarah Durrant, Alex Diment, Murray Collins, Oliver Wearn, Jeremy Cusack, Kirsty Kemp, Mohammad Farhadinia, Paul de Ornellas, Ben Cullen, Fridolin Zimmerman, Kristina Vogt, Jakub Kubala, Andreas Ryser, Mathias Blanc, Elias Pesenti, Erwin van Maanen, Fokko Bilijam, Bill Powers Jr, TJ Stenger, Darrel Van der Zee, Jamie Ratajczek, Dan Luebke, Justin Thiner, Don Swann, Nick Perkins, Mathias Tobler, Megan Jennings, Andrew Bridges, Sarah McCullah, Matt Anderson, Colleen Wisinski, Mike Wallis, Sarah Mutherell, Read Newman, Sue Townsend, Russ van Horn, Mike Mooring, Tandora Grant, Jim Sanderson and Rich Howe. Paul Meek thanks Bill Powers Jr of Pixcontroller, Justin Thiner and the Reconyx team (listed above) and Rich Howe of TrailcamPro for having the aptitude to see the value in meeting with him to hear what wildlife research-based camera-trap users need in a camera trap. Thanks also go to the Winston Churchill Memorial Trust for providing Paul Meek with a scholarship to travel overseas and discuss camera trapping with experts; he was able to glean further ideas for the *ultimate camera trap* from these meetings. Paul is also indebted to the Invasive Animals CRC (Glen Saunders and Andre Glanznig) for being supportive of his scholarship overseas. Comments by Guy Ballard improved this manuscript.

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