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Effective detection methods for medium-sized ground-dwelling mammals: a comparison between infrared digital cameras and hair tunnels

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Abstract

Context. Conservation planning for threatened species depends on improved knowledge of the whereabouts of critical populations and thus the development of optimal detection methods.

Aims. To compare the effectiveness of infrared cameras and hair tunnels for detecting small to medium-sized ground-dwelling mammals in south-eastern Australian forests.

Methods. Reconyx PC90 cameras were paired with Handiglaze hair tunnels at 110 stations in south-eastern New South Wales. All devices were baited using rolled oats, peanut butter and pistachio essence and left *in situ* for a minimum duration of 30 days. Camera detection data were analysed for the first 15 and 30 days, whereas hair-tunnel detection data were analysed for the entire duration of deployment. Linear mixed models with site as a random effect and device as a fixed effect were developed for mammal species richness. Linear mixed logistic regression models for binary data were developed for detection probabilities of five taxa of interest, namely, *Isoodon*, *Perameles*, *Potorous*, *Trichosurus* and *Wallabia*.

Key results. Hair tunnels detected eight mammal species, whereas cameras detected 18 species. Modelled detection rates using cameras were 3.16 ± 0.21 species per site after 15 days and 4.24 ± 0.23 species per site after 30 days, whereas hair tunnels detected 0.34 ± 0.21 species over the entire deployment. Cameras were therefore approximately 9–12 times better at measuring mammal richness than were hair tunnels, depending on survey duration. In all calculations, the probability of detecting the five taxa of interest was significantly greater using cameras than using hair tunnels.

Conclusions. Infrared cameras and hair tunnels offer ethical advantages over direct detection methods such as cage trapping for small to medium-sized ground-dwelling mammals. Cameras also offer practical benefits because they work for protracted periods, without frequent checking by field researchers. Cameras are more effective at detecting a wide range of species than are hair tunnels and are significantly better for detecting the taxa we examined. Unlike hair tunnels, cameras sometimes allow for the identification of individual animals, and provide information about frequency of habitat use, reproductive status and aspects of behaviour.

Implications. On a unit by unit basis, infrared cameras are a far more efficient way to census a broad spectrum of ground-dwelling mammals than are hair tunnels.

Additional keywords: bandicoots, detection probability, fauna monitoring, indirect methods, potoroos.

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Introduction

In the face of the current global mass-extinction crisis (Thomas *et al*. 2004), there is an urgent need to improve knowledge of where species occur so that critical populations can be identified and managed appropriately. Reliable data on the whereabouts of animals are often difficult to obtain, either because they are rare or otherwise cryptic and difficult to detect (Buckland *et al*. 2000, 2005; Gu and Swihart 2004; Vine *et al*. 2009). This presents a major impediment to conservation planning. Species distribution modelling is one way of confronting this dearth of data; however, for many organisms, particularly those of greatest concern, there is simply insufficient baseline information to accurately predict their occurrence (Anderson *et al*. 2003; Engler *et al*. 2004; Pearson *et al*. 2007). Given this poor state of knowledge, increasing emphasis is being placed on the development and evaluation of optimal methods for detecting and monitoring fauna in the wild.

Direct detection has been a common approach for locating threatened mammal species, particularly small and medium-sized taxa, for example by using traps or by visual identification of nocturnal species with spotlights. These methods, particularly trapping, are open to criticism for having a negative impact on the welfare of individual animals (Lemckert *et al*. 2006) and sometimes for being unreliable in their powers of detection (Claridge and Barry 2000). Some threatened mammal species, for example, are relatively shy about entering traps (Scotts and Craig 1988), whereas some nocturnal species are difficult to observe even by spotlight (Lindenmayer *et al*. 2001). In addition, live-trapping methods require frequent checking for captured animals, necessitating researchers to be in the field for protracted periods of time. Given these deficiencies, the development of effective, indirect and humane fauna-detection methods is being increasingly investigated. Indirect methods include, but are not necessarily restricted to, sand plots, which detect footprints left behind by passing animals (Catling and Burt 1994, 1997; Catling *et al*. 1997; Engeman *et al*. 2002), hair tunnels, which collect a sample of a mammal's fur on a sticky medium (usually double-sided adhesive tape) for subsequent microscopic identification (Brunner and Coman 1974; Scotts and Craig 1988; Lindenmayer *et al*. 1999; Lobert *et al*. 2001; Mills *et al*. 2002) and automated camera trapping, whereby covert digital images of animals are 'captured' on entering the field of view (Cutler and Swann 1999; Swann *et al*. 2004; Dajun *et al*. 2006; Kelly 2008; Lyra-Jorge *et al*. 2008; De Bondi *et al*. 2010). These last two methods are of particular interest to the current research because both types of device can be deployed to the field and left *in situ* for long periods of time (weeks or months) before recovery and analysis. This potentially offers significant cost savings to conservation and land-management agencies interested in monitoring wildlife and contrasts strongly with other detection methods that require frequent checking by highly trained field workers.

Recent experimentation using a range of wildlife survey methods in Australia has considered the cost-efficiency of different detection approaches (Garden *et al*. 2007; De Bondi *et al*. 2010), with a general conclusion being that combinations of complimentary methods may provide the most successful and cost-efficient approach for the detection of a range of species. However, there is still much to be learned about the relative abilities of different detection devices to detect species of management interest. Our research adds to this body of knowledge by considering which field-detection methods are optimal for locating and monitoring small and medium-sized, difficult-to-detect, ground-dwelling mammals.

We conducted a field-based comparison of the effectiveness of digital infrared surveillance cameras and hair tunnels for detecting bandicoots (Peramelidae), potoroos (Potoroidae) and other mammal species in south-eastern mainland Australia. Australia has the worst record of mammal extinctions in modern times (Johnson 2006). Since European settlement in 1788, at least 24 endemic species of mammals have become extinct. Most of these species fall within the so-called 'critical bodyweight range' of between 35 and 5500 g (Burbidge and McKenzie 1989); suggested reasons for their demise include the spread of introduced predators and competitors (particularly the feral cat, red fox and European rabbit), changes to fire regimes, clearance of native vegetation and severe droughts (Morton 1990; Johnson 2006; Dexter and Murray 2009; Bilney *et al*. 2010). The majority that went extinct were ground-dwelling, and among the worst affected were species of bandicoots and potoroos. Extant members of these two marsupial families, and some of which are the focus of this research, continue to be seriously threatened with extinction (Claridge *et al*. 2007; Strahan and van Dyck 2008). They are generally hard to detect using conventional direct approaches such as trapping, which hampers attempts to monitor their population trends against management activities (Claridge and Barry 2000; Claridge *et al*. 2010). Although prior research has gone into evaluating field methods for detecting these ground-dwelling mammals (see Mills *et al*. 2002; Sanderson 2004; Wang *et al*. 2006; King *et al*. 2007*a*, 2007*b*; Claridge *et al*. 2010; Paull *et al*. 2011), comparative trials using solely indirect techniques have so far not been undertaken. Our research is, therefore, important because it applies to relatively unstudied mammals of high conservation priority.

Materials and methods

Study area

Our comparative trials were conducted within the southern section of Ben Boyd National Park (Ben Boyd) and the northern half of adjacent Nadgee Nature Reserve (Nadgee), south of the coastal township of Eden in south-eastern New South Wales, Australia (Fig. 1). Previous related live-trapping studies had indicated the presence of bandicoots and potoroos, the focus of our work, although trap success was very poor (~0.5% for the long-nosed bandicoot (*Perameles nasuta*) and southern brown bandicoot (*Isoodon obesulus*) and 2% for long-nosed potoroo (*Potorous tridactylus*); Office of Environment and Heritage, unpubl. data). Further details about the study area can be found in Claridge *et al*. (2010) and Catling and Burt (1994).

Camera system and bait

The camera system used for this comparative study was the Reconyx RapidFire PC90 (Reconyx Inc., Holmen, WI, USA), described at http://www.trailcampro.com/manuals/reconyx.manual.pdf (verified 30 November 2011) and illustrated in Fig. 2. Powered by six C-Cell batteries, the Reconyx RapidFire PC90 takes 3.1-megapixel colour images during daylight and monochrome images of the same resolution at night. Movements of infrared sources (heat and motion) within the coverage area of the camera are detected by a sensor that automatically triggers within 1/5 s. At night time, the frame is illuminated by an infrared flash, effective to 20 m. To better allow for species identification, we set cameras to take a sequence of 10 Reconyx RapidFire (up to one frame per s) JPEG images for each trigger, with no delay between trigger events, 24 h a day. Images were stored on a 2-GB SanDisk Ultra Compact Flash (CF) card (SanDisk Manufacturing Limited, Dublin, Ireland).

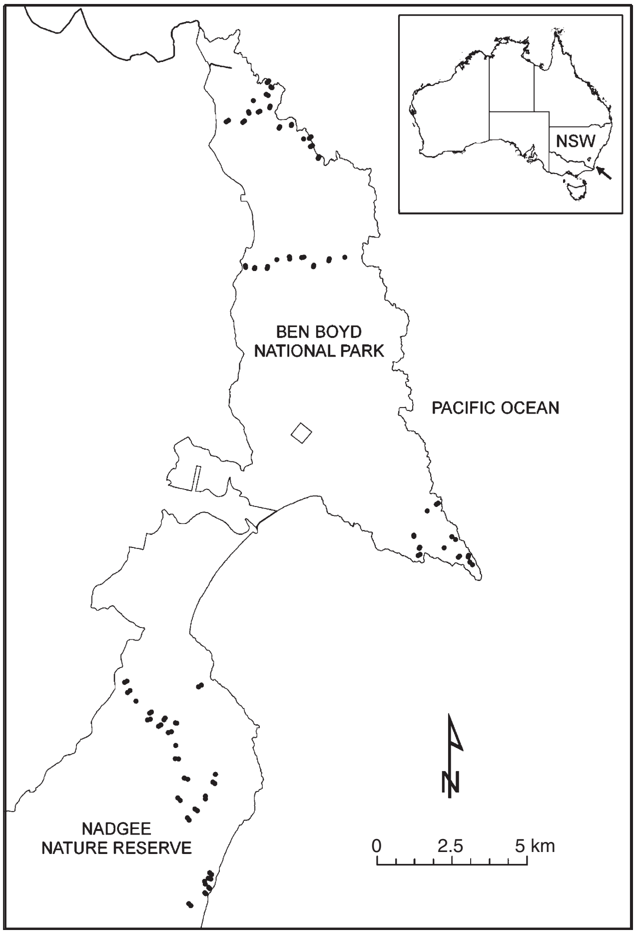

Fig. 1. Location map, highlighting the general location of survey points in Ben Boyd National Park and Nadgee Nature Reserve in south-eastern New South Wales, Australia.

Fig. 2. Reconyx RapidFire PC90, mounted on 10-mm diameter stainless-steel rod using Thunderbolt mounting block. PVC-bait holder in foreground.

In the field, each camera was affixed to a 1-m-long 10-mm-diameter stainless steel rod via a Thunderbolt mounting block (Reconyx Inc.). Once on this mounting arrangement, cameras were set with their lens ~20 cm above the soil–litter interface and at 1.8–2.0-m horizontal distance from a bait holder. The bait holder comprised a 50-mm PVC vent cowl (Vinidex Pty Ltd, Bohle, Queensland, Australia) set into the ground with a steel tent peg (Fig. 2). A bait mixture of peanut butter, rolled oats and pistachio essence was placed inside. These ingredients, in combination with other additives such as honey, are widely used in ecological studies of small and medium-sized mammals and are considered a standard bait type for this purpose in Australia (Menkhorst and Knight 2004; Garden *et al*. 2007; Paull *et al*. 2011).

Wherever possible, animals were identified from image files to the species level. Species identifications were generally not problematic, except for small mammals within the genus *Antechinus* and *Rattus*; images of animals within these genera could have been either the agile antechinus (*A. agilis*) or the dusky antechinus (*A. swainsonii*), and bush rat (*Rattus fuscipes*) or swamp rat (*R. lutreolus*), respectively. In these cases, we classified animals to the genus level. For ease of comparison with data obtained from hair tunnels, we also categorised images of brushtail possums to the genus level *Trichosurus*, even though it was clear from cameras that we detected only the common brushtail possum (*T. vulpecula*). For each deployment then, we were able to define the range of taxa detected by each camera.

Hair-detection device and bait

The type of hair-detection device we used for comparison with cameras is commonly referred to as the 'Handiglaze' hair tunnel. This device was chosen in the present study because of its published reputation for detecting medium-sized ground-dwelling mammals (Murray 2005). The 'Handiglaze' hair tunnel comprises a 250 mm × 300 mm piece of thin, clear plastic sheeting, bent into a tunnel shape and secured to the ground with a U-shaped steel peg. Four lengths of 10-mm black plastic garden hosepipe, each ~40 mm long, are affixed to the inner sides of the tunnel, using strips of double-sided adhesive tape (Schaeffer and Co., Melbourne, Australia; Product Code K5300). The hosepipe functions to increase the surface area of tape on which hair is retained and reduces the diameter of the entrance of the hair tunnel, theoretically allowing for more effective capture of hair (Murray 2005). A double-spoon tea infuser, loaded with the same peanut butter, oats and pistachio essence bait, was placed within the confines of the hair tunnel and attached to the securing peg.

At the end of each deployment, the tapes on each hair tube were inspected for the presence of hair. Those tapes containing hair were removed from the hair tunnel, and then placed on an appropriately labelled card, over which a sheet of non-stick grease-proof paper was placed. All samples were sent to a specialist hair analyst (Barbara Triggs, 'Dead Finish', Genoa, Victoria, Australia) for later identification using the techniques developed by Brunner and Coman (1974). Where possible, hair was identified to species level, although in the case of samples from *Antechinus*, *Rattus* and *Trichosurus*, this was not always possible. For data-analysis purposes, samples from these groups were treated at the genus level, consistent with data from the infrared cameras.

Site layout and duration of deployments

Cameras and hair tunnels were set at each of 59 widely spaced sites (Fig. 1), allowing for broad coverage of the study area across a range of vegetation types. Sites were separated from each other by a minimum distance of 162 m (350.4 ± 24.3). At each site, two separate 'stations', each 39–154 m (79.2 ± 2.4 m) apart, were established consistent with the methods of Claridge *et al*. (2010). These stations were typically located 50–100 m from the edge of minor vehicular trails, allowing for detection equipment to be hidden from view but enabling ready access. A single camera and single hair tunnel were then set at each station, with minimum distances between the two devices being ~20 m. This design allowed pair-wise comparisons of the effectiveness of cameras and hair tunnels in detecting mammals. The layout described here was selected mainly for logistical purposes and we recognise that individual animals of some species may have been detected at adjacent camera or hair-tunnel sites and stations within the deployments. In this respect, sites and stations were not truly independent. However, because our intent was to compare the effectiveness of the two tools at detecting target species, the lack of independence is not relevant.

At each station, cameras and hair tunnels were left *in situ* for a minimum period of 30 days (32–67 days, mean 45.7 days, s.e. 1.4 days). Ordinarily, hair-detection devices are left in the field for periods of about a fortnight, although some researchers have deployed them for as short periods as a few days, whereas others have left them in the field for as long as a few months (Catling *et al*. 1997; Lindenmayer *et al*. 1999; Murray 2005; Garden *et al*. 2007). In contrast, cameras can be left in the field for many months at a time (see Claridge *et al*. 2004). The ≥30-day deployment period chosen in our study was a compromise between these lengths of time. Regardless, by the end of each deployment, all baits used were considered to be no longer effective, even though adhesive tape on hair tunnels was still mostly tactile enough to capture hair. Of the 118 cameras deployed at 59 sites, eight variously malfunctioned and failed to work for the entire 30-day duration, so those particular camera and hair-tunnel pairs were removed from the final dataset. Therefore, in total, 110 camera and hair-tunnel pairs were available for analysis. For the purpose of detailed analysis, the following two camera periods were analysed on the basis of the time stamps affixed to captured images: a 15-day period was considered to be from 1200 hours on the day a camera was deployed to 1200 hours on Day 16 and a 30-day period was considered to be from 1200 hours on the day a camera was deployed to 1200 hours on Day 31.

Statistical analysis

A comparison of detections of number of species (i.e. 'richness') between the two devices was made in addition to the relative efficiency of cameras and hair tunnels for detecting five commonly detected species (*P. nasuta*, *P. tridactylus*, *I. obesulus*, swamp wallaby (*Wallabia bicolor*) and brushtail possum (*Trichosurus*)) by examining the proportion of devices with positive records of each species. Other commonly detected genera, *Rattus* and *Antechinus*, were not analysed in this way because we could not routinely identify them to species level. Similarly, the likelihoods of detecting echidna (*Tachyglossus aculeatus*) and common wombat (*Vombatus ursinus*) by hair tunnels and cameras were not compared because they can be routinely detected in the field by other methods (i.e. McIlroy 1977).

In the present study, the interest was solely in comparing detection probabilities for two methods of capture. As occupancy did not play any role in this comparison, we first conditioned on occupancy by excluding all records where there was no capture by either method. Further, we removed station differences in occupancy probabilities by fitting station as a fixed effect. However, because the cameras had a very high detection rate (sometimes perfect, given presence), the fitting process was often numerically unstable. We therefore chose to fit station as a random effect. These analyses were suitable after 15 days, but again would not fit for 30-day records. We, therefore, included in our summary results for all data (including unoccupied sites and so ignoring different occupancy rates) and our conditional analysis after 15 days. Models for richness were linear mixed models, with station as a random effect and device as a fixed effect. For individual species, the equivalent model was linear mixed logistic regression for binary data, with random and fixed effects as above (Galwey 2006). All analyses were conducted using GENSTAT Version 14 (VSN International Ltd, Oxford, UK).

Results

Species richness

During the deployments, a total of 16 mammal species were detected by cameras after 15 days, and 18 mammal species after 30 days. In marked contrast, for the entire duration of the exercise, a subset of just eight of these species was detected by hair tunnels (Table 1). The performance of hair tunnels in detecting mammals across a range of size classes that included both native and introduced taxa was poor. Some of the taxa that were shown to be common by the cameras were completely missed by the hair tunnels, particularly small-bodyweight mammals. *Antechinus* spp., for example, were detected at 46 of 110 stations by cameras but at none of 110 stations by hair tunnels. Other small mammals detected by cameras but not hair tunnels were the eastern pygmy possum (*Cercatetus nanus*) and an unidentified *Sminthopsis*. Similarly, *Rattus* spp. were detected by more than half of the cameras deployed but were about one-fifth as likely to be captured on hair tunnels (Table 1).

In terms of adding presence information to the dataset, the hair tunnels contributed one unique station record for feral cat (*Felis*

Table 1. Number of stations of a total of 110 where mammal taxa were detected by cameras and hair tunnels in Ben Boyd National Park and Nadgee Nature Reserve, south-eastern New South Wales

Camera detection results represent the first 15 and 30 days (in parentheses) of data collection, whereas hair-tunnel detection results represent a minimum deployment of 30 days

Taxon	Cameras only	Hair tunnels only	Both devices
Antechinus spp.	33 (46)	0	0 (0)
Canis lupus	0 (3)	0	0 (0)
Cercatetus nanus	6 (9)	0	0 (0)
Cervus unicolor	1 (1)	0	0 (0)
Dasyurus maculatus	2 (2)	0	0 (0)
Felis catus	0 (1)	1	0 (0)
Isoodon obesulus	22 (28)	1	1 (1)
Oryctolagus cuniculus	2 (3)	0	0 (0)
Perameles nasuta	38 (52)	0	7 (8)
Potorous tridactylus	24 (28)	0	2 (3)
Pseudocheirus peregrinus	5 (10)	0	0 (0)
Rattus spp.	49 (59)	2	8 (8)
Sminthopsis spp.	2 (3)	0	0 (0)
Tachyglossus aculeatus	34 (45)	0	0 (0)
Trichosurus spp.	7 (14)	0	1 (2)
Vombatus ursinus	23 (47)	0	1 (1)
Vulpes vulpes	1 (2)	0	0 (0)
Wallabia bicolor	68 (82)	0	9 (10)

catus), one unique station record for *Isoodon obesulus* and two unique station records for *Rattus* spp.; they therefore contributed very little locality information to the dataset beyond that gathered by cameras.

The linear mixed models for species richness showed that each camera detected 3.16 ± 0.21 species per station after 15 days and 4.24 ± 0.23 species after 30 days. By contrast, hair tunnels detected only 0.34 ± 0.21 species per station over the entire deployment (Fig. 3). As a conservative estimate, for the species we analysed, cameras were therefore approximately 9–12 times more effective at measuring mammal species richness at stations than were hair tunnels, depending on the duration of deployment.

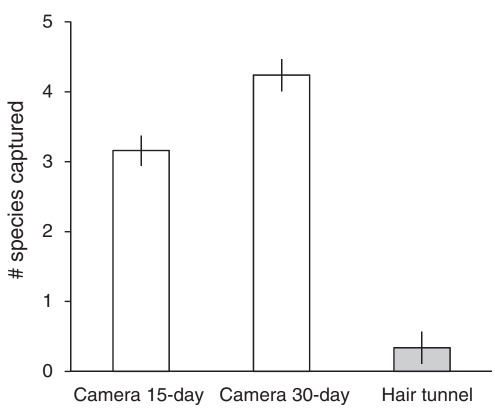

Fig. 3. Number of species detected by cameras after 15 and 30 days, compared with hair tunnels over the entire deployment. Standard error bars represent 95% confidence intervals about the mean.

Probability of detection

The probabilities of detecting five select taxa were significantly ($P < 0.001$) greater in all cases with cameras than they were with hair tunnels (Fig. 4). The model for species detections during the first 15 camera-days compared with hair-tunnel detections overall conditional on station occupancy showed that the probability of detection by cameras ranged from 0.89 for *Trichosurus* to 0.99 for *Wallabia*. In contrast, hair-tunnel detection probabilities for the same five taxa were much lower, ranging from 0.08 for *Isoodon* to 0.22 for *Trichosurus* (Fig. 4*a*). In the 15-day model unconditional on occupancy, camera detection probabilities ranged from 0.07 for *Trichosurus* to 0.71 for *Wallabia*, whereas hair-tunnel detection probabilities ranged from 0.01 for *Isoodon* to 0.08 for *Wallabia* (Fig. 4*b*). Finally, in the 30-day model unconditional on occupancy, detection probabilities by cameras ranged from 0.13 for *Trichosurus* to 0.86 for *Wallabia*, whereas hair-tunnel detection probabilities ranged from 0.01 for *Potorous* to 0.08 for *Wallabia* (Fig. 4*c*). Depending on the taxa and statistical model under consideration, cameras returned 4.0–21.5 (10.2 ± 1.2) times greater probability of detection than did hair tunnels. For

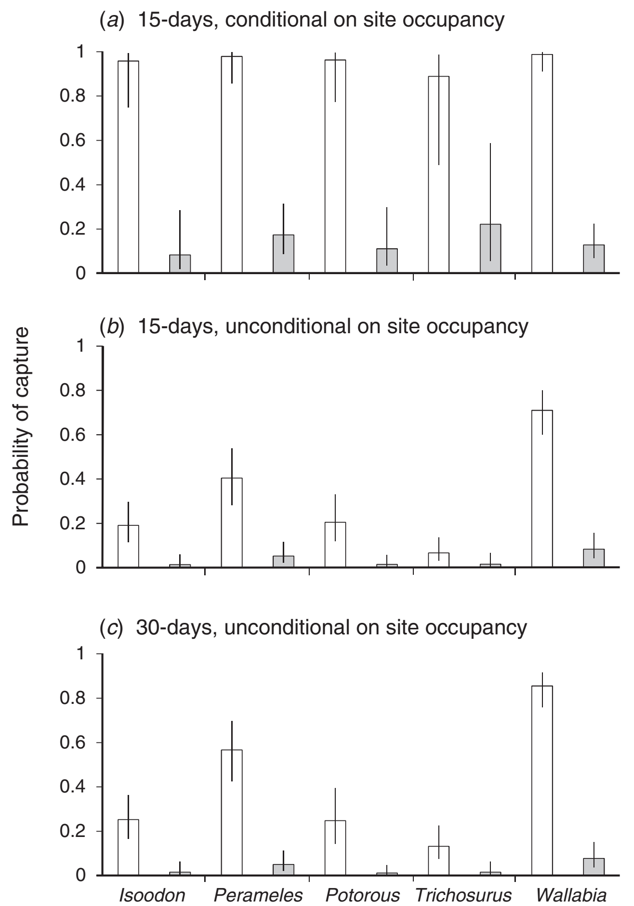

Fig. 4. Comparison of detection probabilities for five mammal species by cameras (white bars) and hair-tunnels (grey bars) after (*a*) 15 days, conditional on site occupancy, (*b*) 15-days, unconditional on site occupancy, and (*c*) 30 days, unconditional on site occupancy. Vertical bars represent 95% confidence intervals about mean.

camera detections, doubling the duration of camera deployment from 15 to 30 days increased the detection probabilities for the five taxa of interest 1.2–1.9 (1.4 ± 0.1) times (Fig. 4*b*, *c*).

Discussion

Our research offers significant benefits for wildlife conservation programs by contributing to the development of optimal methods to locate and monitor difficult-to-detect threatened fauna, particularly small to medium-sized, ground-dwelling Australian mammals. We have demonstrated that under the conditions reported here, infrared cameras are considerably more effective than are hair tunnels at detecting a wide range of species, particularly those of conservation-management significance such as bandicoots and potoroos. The question arises, why were hair tunnels so poor at detecting ground-dwelling mammals relative to cameras? For some taxa, the answer may lie in hair-tunnel design limitations. For many of the small bodyweight species, the entrance diameter of the tunnel was probably sufficiently wide enough to allow them to move freely within the device, without touching the adhesive tape surface. This is not surprising because the hair devices we used were specifically designed for detecting medium-sized mammal species (Murray 2005). Modified hair-tunnel designs with narrower entrances may improve the success rate at recording small-bodyweight taxa such as *Antechinus* and *Rattus* (Lindenmayer *et al*. 1999; Mills *et al*. 2002). For similar design limitations, hair tunnels were also less effective than cameras at detecting large body-sized mammals such as wallabies and wombats. Clearly, for these species, the entrance diameter and overall dimensions of hair tunnels were insufficient to allow for easy access and subsequent deposition of hair.

For our target species of bandicoot and potoroo, the poor performance of hair tunnels is less easy to explain. Part of the discrepancy may be accounted for by the way in which each type of device records a species as being present. The design of the hair tunnel is such that an animal must enter the device to gain close contact with the bait holder, thereby leaving hair behind on the adhesive tape. In contrast, with an infrared camera, animals move freely into and out of frame and can be detected without necessarily being attracted to the bait holder. This is certainly the case for bandicoots, such as *P. nasuta*, which are otherwise known to be trap shy (Claridge and Barry 2000). Many of the images obtained of this species in the present study were of animals foraging naturally in-frame, rather than being attracted to the bait holder *per se*. Further understanding the behaviour of these target species about hair tunnels would be useful, as would trialling different attractants to maximise the rate at which animals interact with them (Paull *et al*. 2011). Doing this might lead to design improvements to increase the rate at which hairs are captured.

Because attractants are not necessarily as important when using cameras, leaving them in the field for longer durations of time may further increase the detection rate of mammal species. This was most certainly the case in our study, where doubling the deployment length for cameras from 15 to 30 days resulted in further detections of all target species and higher estimates of mammal species richness at sites. Indeed, by doubling the deployment length, the mammal richness increased on average by one species per site (Fig. 3). Ultimately, however, the length of time cameras are left field-deployed will be a trade-off, influenced at least in part by the number of sites planned to be surveyed within a given timeframe. Optimising deployment lengths to maximise return for effort is a key research question for future studies.

Both cameras and hair tunnels are low impact in terms of the level of interference with the animals and therefore offer substantial ethical benefits over direct detection approaches such as cage trapping. Other indirect approaches, such as sand-plot tracking, cause no harm to animals but they ordinarily require daily field presence to identify species and can be affected by poor weather (Catling and Burt 1994, 1997; Catling *et al*. 1997; Engeman *et al*. 2002). Camera traps and hair tunnels, by contrast, can be set and left *in situ* for weeks, or indeed months, without frequent checking, irrespective of weather (Lindenmayer *et al*. 1999; Mills *et al*. 2002; Claridge *et al*. 2004). Although both cameras and hair tunnels are low impact, the latter are arguably more obtrusive because they collect a physical sample of the fur of mammals. There is also a potential for hair tunnels to lethally trap very small animals on the sticky medium, which has been observed for birds, insects, reptiles and mammals (Mills *et al*. 2002). This is not the case with digital infrared surveillance cameras where animals can move freely. Another advantage of cameras over hair tunnels is that somewhat less specialised interpretation of the raw data is necessary; in the case of hair tunnels, the identification of hair samples is highly specialised and must be conducted by a highly trained practitioner (Lobert *et al*. 2001). In contrast, the identification of species from digital images on cameras is less of a specialised skill and requires less training.

Comparison of wildlife-detection methods has recently been considered by De Bondi *et al*. (2010) who found camera trapping to be more cost-effective than live trapping for small terrestrial mammals. In the present study, no attempt was made to calculate the cost-effectiveness of cameras relative to hair tunnels; however, we make the following observations. Although camera units are considerably more expensive to purchase than are hair tunnels, they do offer the means to acquire more and different types of information than simple detection of species presence, which is all that hair tunnels are usually capable of. With an average of ~700 images being captured by each camera of ~20 visitation events each month in our study, the utility of data captured by cameras *v*. that captured by hair tunnels is really incomparable. The two methods are incomparable in other ways too because cameras collect additional metadata, which has been exploited in the present paper in a most basic way by calculating detections at two discrete time steps (i.e. 15 and 30 days). Such data can be used retrospectively to determine optimal deployment lengths for detecting species (De Bondi *et al*. 2010). Time and date stamps on each image also mean that more detailed temporal analysis can potentially be made by cameras, along with other opportunistic observations such as inter-specific and intra-specific interactions. This offers scope to explore various aspects of behaviour of different species, such as at what time of the daily cycle they are more or less active (see Claridge *et al*. 2010). Furthermore, the frequency with which a species is detected at a site during a deployment may provide other clues about patterns of habitat use (Borchard and Wright 2010). In some cases, individual animals can be identified on images from their unique markings, scars, damaged ears or general body size (Claridge *et al*. 2004). For some species, population enumeration from individuals identified in images is possible (Bengsen *et al*. 2011; Bluff *et al*. 2011). Information can also be gleaned about reproductive status of some species by observing pouch young and young at foot in images, none of which is available via hair samples from hair tunnels. Finally, local ambient air temperature and moon phase are also recorded on each image captured by the Reconyx RapidFire PC90 cameras we used, offering scope to look at the effect of these environmental variables on detection rates of different mammal species. This may allow for further refinements to be made about the timing and duration of deployments, maximising opportunities for interactions with target taxa during survey or monitoring programs.

Despite their relative inefficiency, hair tunnels should not necessarily be discounted entirely for targeted mammal surveys. Other studies have shown that they can successfully detect rare and cryptic species, including the endangered long-footed potoroo (*Potorous longipes*) (Scotts and Craig 1988; Elsner *et al*. 2011) and the spotted-tailed quoll (Murray 2005). Also, hair obtained from tunnels can be processed forensically, with subsequent extraction of DNA potentially used to identify individual animals and enumerate populations (Ruibal *et al*. 2010). The key is that to counteract their relative inefficiency, more devices must be deployed in the field. Undoubtedly, this will increase the labour costs associated with surveys because more time will be needed to deploy devices at any given site.

The camera technology and hair-tunnel methods we used are both well developed, so the innovation of our study lies in systematically testing the two methods against each another. This particular comparison has never been undertaken before. Given the rate at which remote cameras and hair tunnels are variously being applied in wildlife survey and monitoring studies in Australia (see Garden *et al*. 2007; Towerton *et al*. 2008, 2011; Claridge *et al*. 2010; De Bondi *et al*. 2010; Borchard and Wright 2010; Bluff *et al*. 2011; Paull *et al*. 2011), our trial is timely.

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