Chapter 1

A Review of Camera Trapping: an Australian and International Perspective

Chapter 1 – A Review of Camera Trapping: an Australian and International Perspective

Précis

Camera trapping is a relatively new tool in the repertoire of ecological surveys in Australia. However in typical fashion, Australians have adopted this technology with vigour and camera traps are replacing some conventional survey methods at an astounding rate. In this chapter I highlight the history of use and adoption of camera traps in Australian wildlife research and management. I also discuss the advantages and disadvantages of these devices and review the Australian literature to emphasise some of the issues with camera trapping methods, and identify areas that must be considered when designing surveys using camera traps.

This chapter summarises the considerable body of work undertaken in Australia given our relatively short exposure to this method compared to the northern hemisphere. Moreover, I will highlight the progress we have made towards optimising the efficiency of camera trapping as a method, particularly in the recent few years. Further, I will provide an international context in a review paper outlining the strength and weaknesses of camera trapping. The papers presented in this chapter will affirm that considerable research and evaluation is still required to improve the methods used in camera trapping. The information discussed identifies some of the issues that are common to all camera trap practitioners, and provides some guidance and suggestions to help pave a way forward. Detailed discussion on some of the information outlined in these papers will be further explored throughout the dissertation with specific recommendations for future research and solutions that are outlined in the final chapter.

Conclusions

Nationally and internationally, the use of camera trapping in ecological research and management has changed dramatically although there is still a need to improve the methods used. It is important that we understand how the use of camera traps has developed in the Australian context. Moreover, that we understand how camera traps may affect ecological investigations and how we can refine the application of this method. This chapter presents two papers, first a historical account of the role Australian practitioners and manufacturers have had in the field of camera trapping, and a critical review of current camera trap methods that provides guidance for improving the technical application and deployment of camera traps in ecological investigations. Finally the information presented in this chapter will assert that despite the wide adoption of camera trapping globally, we must continue to unravel the pitfalls and constraints of these devices to the highest scientific level possible, while we celebrate the achievements.

Supporting manuscripts

1. Meek, PD, Ballard, G-A, Vernes, K, Fleming, PJS (2015). The history of wildlife camera trapping as a survey tool in Australia. *Australian Mammalogy* **37**, 1-12.

2. Meek, PD, Ballard, G-A, Fleming, PJS (2015). The pitfalls of wildlife camera trapping as a survey tool in Australia. *Australian Mammalogy* **37**, 13-22.

Supervenience Chapter 1

This manuscript includes sections based on aspects of the research conducted by the candidate. The manuscript providing international advice and guidance on how to optimise camera trap use in ecological research. In particular, how specific attributes of camera traps may influence different study designs. The advice provided is central to many of the issues raised in Chapter 1 and that are addressed in subsequent chapters.

1. Rovero, F, Zimmerman, F, Berzi, D, Meek , PD (2013) Which camera trap type and how many do I need? A review of camera features and study designs for a range of wildlife research applications. *Hystrix The Italian Journal of Mammalogy* **24,** 148-156.

Chapter 2

Application of Camera traps for studying small mammals

Chapter 2 – Application of Camera traps for Studying Small Mammals

Précis

Camera traps were primarily designed to detect large northern hemisphere mammals with large heat signatures. Similarly, the methods of camera trap deployment recommended by manufacturers, and reported in much of the literature, until fairly recently, have focussed on larger animals. The methods required for detecting smaller heat signatures in animals, that also move faster than larger animals, necessitates methodological modifications to maximise detection. Simply applying survey principles for large mammals is not practical for small mammals such as rodents and weasels. There are other variables that will also constrain the accurate detection and identification of small mammals in camera trap surveys such as the camera trap model, the placement in relation to the detection zone and background temperature, and the coexistence of other similar species. I investigated whether camera traps could be considered a suitable and efficient alternative trapping tool to conventional Elliot (Sherman) trapping of Australian mammals. I provide evidence that camera traps can be used to detect small Australian mammals, moreover they provide scientists with the ability to better understand animal interactions i.e. activity patterns. However, my research shows that there are limitations and where similar looking species co-exist, camera trap images are not always perfect. I will provide evidence that experienced mammalogists find accurate identification of some species using camera trap images very difficult and as such I issue a warning; camera traps are an imperfect tool that must be carefully evaluated against the objectives of the study and the species targeted.

I will advocate throughout, that it is imperative we constantly review whether camera trapping does provide ecological and resource advantages over conventional methods. Although recognising that camera trap provide us with the opportunity to investigate new areas of ecology that until recently were not tackled, or at least not without sophisticated technology and a considerable budget.

Undoubtedly, camera trapping can provide new insight into species occurrence, behaviour and ecological interactions. However, I question whether camera trapping is a suitable surrogate (economic and ecological) that can usurp conventional methods without appropriate assessment. In particular, the challenges of accurate species identification using camera trap imagery (ID-parallax) can be problematic. In this chapter I present some possible technical solutions to redress this challenge; the development of computer assisted technologies to process and analyse camera trap image data is evolving quickly and studies using texture and facial recognition algorithms to identify species and individuals are leading the way.

Conclusions

Camera traps provide new opportunities for improving ecological understanding and enhancing decision making but we must understand their limitation so we can account for them in analysis and interpretation. This chapter emphasises the benefits of research using camera trap image data whilst highlighting the variability in detection of small mammals differences between camera trap models, poses some challenges in accurately identifying species and provides some solutions using computer assisted technology to aid data processing and analysis.

Supporting manuscripts

1. Meek, PD, Zewe, F, Falzon, G (2012) Temporal activity patterns of the swamp rat (*Rattus lutreolus*) and other rodents in north-eastern New South Wales, Australia. *Australian Mammalogy* **34**, 223-233
2. Meek, PD and Vernes, K. (2015). Are camera traps effective at surveying for the Hastings River mouse and rodent congeners? *Australian Mammalogy* **37**, in press
3. Meek, P.D., Falzon, G. and Vernes, K. (2013). On the Reliability of Expert Identification of Small-Medium Sized Mammals from Camera Trap Photos. *Wildlife Biology in Practice* **9**, 1-19.

Supervenience Chapter 2

The inclusion of this manuscript in the dissertation provides evidence that the candidate has pursued expert computer science input to resolve a major issue identified in the research presented in Chapter 2. This manuscript confirms that the recommendations made by the candidate, that rodent identification cannot be accurately done using camera trap images and requires the development of computer assisted technology. The manuscript provides a description of the algorithm generated by the authors to overcome this limitation.

1. Falzon, G, Meek, PD, Vernes, K (2014) Computer-Assisted Identification of Australian Rodents in Camera Trap Imagery. In 'Camera Trapping in Wildlife Research and Management.' (Eds PD Meek, AG Ballard, PB Banks, AW Claridge, PJS Fleming, JG Sanderson, DE Swann.) (CSIRO Publishing: Melbourne, Australia).

Chapter 3 – Application of camera trapping for studying medium sized mammals

Chapter 3 – Application of Camera Trapping for studying Medium Sized Mammals

Précis

Camera trapping has been widely adopted throughout the world as a surrogate for intensive ecological survey methods. Adoption was swift by ecological practitioners with little understanding of how the devices work, in particular how they detect fox and dog sized animals or what level of variability is introduced by different models, environmental conditions or placement. In this chapter I provide experimental evidence to support our recommendations that height and orientation of camera traps when surveying medium sized mammals is critical. That in turn, failure to understand how camera traps detect animals could result in biased, inaccurate and spurious results that misrepresent population data. Inappropriate placement and orientation of camera traps in relation to animal size, the importance of temperature in PIR detection, the direction of travel by the animal and camera trap settings, all influence the results of camera trap surveys.

As camera trapping continues to be used as an ecological sampling tool, it is imperative that practitioners understand ways to improve their efficacy, including developing methods and solutions to analytical effects on data collection and interpretation. A failure to understand "how to place the device" may have significant implications for species and ecosystem management and have dire consequences for nature conservation and natural resource management.

Conclusions

The height and orientation of camera traps in relation to the direction of travel by the target animal does influence detection. Optimising the height of a camera trap's passive infrared sensor (PIR) in relation to the target animal requires the camera trap height to be proportional to the heat signature of the animal (Fig 3.1). There is still a lot to learn and understand about how PIR sensors detect animals under natural conditions and these two papers provide valuable advice on how to set camera traps to optimise animal detection.

Figure 3.1. The heat signature of a dog measured using a thermal imaging camera, note the variability in radiant heat outputs between the dog, human and the background (Meek and Falzon unpub. data).

Supporting manuscripts

1. Meek, PD, Ballard, G and Falzon, G. (in press)**.** The higher you go the less you will know: placing camera traps high to avoid theft will effect detection. *Remote Sensing in Ecology and Conservation*. ??-??

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Supervenience Chapter 3

1. Ballard, G., Fleming, P. J.S., Melville, G. and Meek P. D. (in prep). Estimating detection probability in mammal surveys. *Australian Wildlife Research*

Chapter 4

Effect of Camera Traps on Mammals and Their Behaviours

Chapter 4 – Effects of Camera Traps on Mammals and Their Behaviours

Précis

Claims are often made that camera trapping is a valuable substitute for traditional surveys, especially because it is non-intrusive to animals (Cutler and Swan 1999; Sollmann *et al.* 2013; Gregory *et al.* 2014). Furthermore, users believe that the technological evolution from incandescent to infra-red illumination has overcome the behavioural effects of white flash on animals (Rowcliffe *et al.* 2008; Trolliet *et al.* 2014). Modern day infra-red camera traps are promoted by scientists and manufacturers as tools that are undetectable to animals. It is therefore considered to be a non-intrusive survey method, providing better animal welfare options to ecologists whilst maintaining the same level of data as historical survey methods i.e. trapping. However, these observations from the northern hemisphere and Asia were not consistent with the behavioural responses of wild dogs, foxes and feral cats we were observing in our Australian surveys.

In this chapter I investigate whether animals can detect infra-red camera traps through vision and hearing. Whether or not the detection of camera traps by animals is problematic will depend on the objectives of the studies being undertaken. As such, some research projects may discount the importance of whether animals respond to the camera trap or not, as long as their subject species are detected and identified. However, there are many analytical methods e.g. mark resight/recapture, where practitioners do not want to influence the behaviour or movements of animals, nor do they wish to create "camera-trap shy" study animals. In these studies minimising disturbance to study animals is a priority, or at least being able to calibrate for the bias introduced by the response.

In this chapter, I provide evidence of the sound and illumination outputs of camera traps and where they overlap with the hearing and vision ranges of most animals, proving that under most circumstances, animals can hear and see camera traps. I will also provide evidence of the considerable variability in behaviours between wildlife species and individuals in response to camera traps in the field. Confirming that the detection and response by animals to camera traps is capricious, with little certainty that one species or individual will consistently behave the same around camera traps throughout its life-exposure to the devices.

Conclusions

Most animals can hear and see camera traps and the effect on their behaviour and detection probability is not fully understood and rarely acknowledged. The significance of this finding will be dependent on the purpose of the study and the analytical approach being used. For example, presence/ absence surveys will be unaffected by animals detecting camera traps at time of their being photographed but behavioural and activity studies will be affected by unknown biases. None the less, it is a fallacy that camera trapping is a non-intrusive survey method and that animals cannot detect camera traps.

Supporting manuscripts

1. Meek, PD, Ballard, G-A, Fleming, PJS, Schaefer, M, Williams, W, Falzon, G (2014) Camera traps can be heard and seen by animals. *PLoS ONE* 9, e110832.
2. Meek, PD Ballard, G, Fleming, PF. and Falzon, G. (2016). Are we getting the full picture? Animal responses to camera traps and implications for predator studies. *Ecology and Evolution* **6**, 3216-3225.

Chapter 5

Future Directions for Camera traps as a Survey Tool

Chapter 5 – Future Directions for Camera traps as a Survey Tool

Précis

The ultimate camera trap for wildlife research does not exist. Every model has limitations although in the last decade there have been vast improvements in camera trap features and functionality. We have progressed from Active sensors (infrared beam) to PIR (heat-in-motion) sensors and at a camera trapping colloquium in 2012, it was formally proposed and endorsed by participants that we should reconsider the Active sensor system for reliability. We have also seen the end of negative film camera traps, replaced by digital technology. Illumination has progressed from Xenon gas flash to no-glow infra-red technology and more recently white flash LED flash. Trigger speeds, data storage, video and sound capabilities and all manner of quirky features have been added to the camera trap toolkit. Yet we still have not resolved some of the basic issues of using this technology and managing the data. The search for data federation solutions for international camera trap research projects has been successful in some areas, but unilateral solutions in many other areas are yet to be resolved.

Despite having several software programs for managing image data from camera traps, there is no consensus on the best way to manage and analyse camera trap data. Some of the analytical tools available for camera trap data are highly sophisticated and some espouse the capacity to counter the detection issues of camera traps. However, we have not resolved the basic methodological recipe for deploying these devices effectively, despite the increasing number of camera trap papers published each year. Neither have we refined the reporting requirements for publishing camera trap data to a standard commensurate with other survey methods.

In this chapter, I present the design features required for the ultimate camera trap for wildlife research, I identify some of challenges for the future and make recommendations for research and innovations based on my research and involvement in this field of science since 2009. I also provide guiding principles for publishing camera trap research data based on the agreed recommendations of eleven international camera trap experts. These guidelines will help encourage and facilitate a higher level of reporting on the fine-scale methodological approaches used in research. That in-turn will help elucidate new and innovative approaches whilst highlighting where techniques are potentially weakened by poor camera trap use.

Conclusions

The future of camera trapping is dependent on; quality equipment that is customised to suit the needs of all wildlife researchers, methods based on evidence, practitioner training, data federation systems, including "image-museums" that are accessible and steadfast, accessible one-stop shop analysis software, computer-assisted automated data management systems, science focussed methods and standards, and promoting the opportunity for information sharing through networks and forums. The manuscripts presented in this chapter provide well founded arguments and recommendations for advancing camera trap use throughout the world, some of which have already come to fruition as a result of the publishing process (Glen *et al.* 2013; Taylor *et al.* 2013; Burton *et al.* 2015; Doherty *et al.* 2015; Moseby *et al.* 2015).

Supporting manuscripts

1. Meek, PD, Pittet, A (2012) User-based design specifications for the ultimate camera trap for wildlife research. *Wildlife Research* **39**, 649-660.
2. Meek, PD, Ballard, G, Claridge, A, Kays, R, Moseby, K, O'Brien, T, O'Connell, A, Sanderson, J, Swann, DE, Tobler, M, Townsend, S (2014). Recommended guiding principles for reporting on camera trapping research. *Biodiversity and Conservation* **23**, 1-23.

Chapter 6

Dissertation Summary and Conclusions

Chapter 6 – Dissertation Summary and Conclusions

In this dissertation and the supporting manuscript for this conclusion (Meek *et al.* 2014b), I have identified some of the strengths and weaknesses of camera trapping, with a focus on optimising the detection of small and medium sized mammals, and providing identification solutions using computer assisted technologies. I further evaluated the influence of camera traps on animal behaviour, isolating the range of factors that are likely driving animal recognition of these devices. I have presented a detailed list of recommendations to improve camera traps, their use and how we report our research results. I have proposed a range of research directions to improve the applicability of camera trapping for wildlife research and management.

Camera trapping is "here to stay" and scientific understanding and progress towards efficient use of this tool is now being recognised internationally as a priority. The information produced in this dissertation tackles some of the issues that, until now, had not been fully realised or studied; namely the use and misuse of camera traps used and misused, the technical pitfalls of these devices, optimising deployment, identification challenges and producing technological solutions. There have been other spin-offs from my research including furthering scientific investigations of and with camera traps, development of new technologies and improvements to systems and policies, and the development of the first Australian camera trapping manual and training course. I formulated the concept of the First International Camera Trapping Colloquium, which was held in Sydney during October 2012 and there are plans afoot for a second Colloquium in Bhutan in 2016.

The research in this dissertation represents a significant contribution towards improving wildlife survey methods using camera traps in ecological science. Additionally, it has facilitated the development of innovations using computer assisted technology to manage and filter camera trap data that will ultimately lead to new software, the production of algorithms for identifying species and individuals in camera trap images, e.g. Wild Dog Alert http://www.pestsmart.org.au/wild-dog-alert.

The consequences of failing to address the current methodological gaps in our knowledge about camera trap use are significant, especially where the data are being used to inform management and conserve species. In the 1980-2000s leading Australian scientists recognised the importance of a refined method when aerial surveys were first introduced to Australia. In assessing the inherent bias in aerial surveys, (Caughley 1974) identified that strip width, altitude and speed of the aircraft all influenced the population estimate. He recognised this potential bias, measured its magnitude and produced correction factors to overcome the problem. In later years, Hone (2008) and Tracey *et al.* (2008) further redefined and measured the sources of biases in aerial surveys of wildlife and urged against ignoring the effects that variability in detection has on analyses. These same issues are relevant to camera trapping and it with the same impetus that I have tackled some of the limitations of camera trapping in ecological research and management. To ignore such variation and biases in camera trapping is blind disregard for the scientific process and a potential risk to the conservation of wildlife species, populations and communities.

There are still some important issues in using camera traps for wildlife research and management requiring resolution. Some authors propose that the failings of camera traps as a device can be resolved using complex statistical methods and have developed solutions (Carbone *et al.* 2001; MacKenzie *et al.* 2002; MacKenzie *et al.* 2003; Rowcliffe *et al.* 2008; Gopalaswamy *et al.* 2015; Tobler *et al.* 2015), but I have an alternative position; we should firstly account for what we fail to observe in sampling and not rely on statistical analyses as a surrogate or first-point-of-call for understanding biological processes. Understanding the equipment we use in science is fundamental to generating robust knowledge; using data that have been derived from un-calibrated equipment and unreliable methods is not good practice. However, the future of camera trapping is exciting, especially as we discover new species occurrences, start to resolve camera trap constraints and develop computer assisted technologies to improve data processing and analysis (Meek *et al*. 2014b).

Supporting Manuscript

1. Meek, PD, Fleming, PJS, Ballard, AG, Banks, PB, Claridge, AW, McMahon, S, Sanderson, JG, Swann, DE, (2014). Putting contemporary camera trapping in focus. Camera Trapping: Wildlife Management and Research. CSIRO Publishing, Melbourne, Australia. 349-356.

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Carbone, C, Christie, S, Conforti, K, Coulson, T, Franklin, N, Ginsberg, JR, Griffiths, M, Holden, J, Kawanishi, K, Kinnaird, M, Laidlaw, R, Lynam, A, Macdonald, DW, Martyr, D, McDougal, C, Nath, L, O'Brien, T, Seidensticker, J, Smith, DJL, Sunquist, M, Tilson, R, Wan Shahruddin, WN (2001) The use of photographic rates to estimate densities of tigers and other cryptic mammals. *Animal Conservation* **4**, 75-79.

Caughley, G (1974) Bias in aerial survey. *Journal of Wildlife Management* **38**, 921-933.

Cutler, T, Swan, D (1999) Using remote photography in wildlife ecology: a review. Wildlife Society Bulletin **27**, 571-581.

Diete, RL, Adamczyk, SM, Meek, PD, Dickman, CR, Leung, LK-P (2015) Burrowing behaviour of the delicate mouse (*Pseudomys delicatulus*) and the management implications for a threatened sympatric rodent (*Notomys aquilo*). *Australian Mammalogy* in press.

Diete, RL, Meek, PD, Dickman, CR, Leung, LK-P (2014) Burrowing behaviour of the northern hopping-mouse (Notomys aquilo): field observations. *Australian Mammalogy* **36**, 242-246.

Doherty, TS, Bengsen, AJ, Davis, RA (2015) A critical review of habitat use by feral cats and key directions for future research and management. *Wildlife Research* **41**, 435-446.

Fancourt, BA (2015) Making a killing: photographic evidence of predation of a Tasmanian pademelon (Thylogale billardierii) by a feral cat (Felis catus). *Australian Mammalogy* **37**, 120-124.

Glen, AS, Cockburn, S, Nichols, M, Ekanayake, J, Warburton, B (2013) Optimising Camera Traps for Monitoring Small Mammals. *PLoS ONE* **8**, e67940.

Gopalaswamy, AM, Delampady, M, Karanth, KU, Kumar, NS, Macdonald, DW (2015) An examination of index-calibration experiments: counting tigers at macroecological scales. *Methods in Ecology and Evolution* in press.

Gregory, T, Carrasco Rueda, F, Deichmann, J, Kolowski, J, Alonso, A (2014) Arboreal camera trapping: taking a proven method to new heights. *Methods in Ecology and Evolution* **5**, 443-451.

Hone, J (2008) On bias, precision and accuracy in wildlife aerial surveys. *Wildlife Research* **35**, 253-257.

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Meek, PD, Zewe, F, Falzon, G (2012) Temporal activity patterns of the swamp rat (Rattus lutreolus) and other rodents in north-eastern New South Wales, Australia. *Australian Mammalogy* **34**, 223-233.

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Taylor, BD, Goldingay, RL, Lindsay, JM (2013) Horizontal or vertical? Camera trap orientations and recording modes for detecting potoroos, bandicoots and pademelons. *Australian Mammalogy* **36**, 60-66.

Tobler, MW, Zúñiga Hartley, A, Carrillo-Percastegui, SE, Powell, GVN (2015) Spatiotemporal hierarchical modelling of species richness and occupancy using camera trap data. *Journal of Applied Ecology* **52**, 413-421.

Tracey, JP, Fleming, PJS, Melville, GJ (2008) Accuracy of some aerial survey estimators: contrasts with known numbers. *Wildlife Research* **35**, 377-384.

Trolliet, F, Vermeulen, C, Huynen, M, Hambuckers, A (2014) Use of camera traps for wildlife studies: a review. *Biotechnology, Agronomy, Society and Environment* **18**, 446-454.

Vernes, K, Jarman, P (2014) Long-nosed potoroo (Potorous tridactylus) behaviour and handling times when foraging for buried truffles. *Australian Mammalogy* **36**, 128-130.

Appendices

The attached camera trap papers (published title pages only) are included in this dissertation as both an addendum to the body of work presented in the thesis chapters, but also to provide evidence of the application of my research in other publications, and in support of the common line of enquiry that I have adopted in this field. Each of these manuscripts bears direct relationships to the papers presented for this dissertation and have been a product of my camera trap research portfolio.

THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by PAUL D MEEK – 2011 Churchill Fellow

REFINING AND IMPROVING THE USE OF CAMERA TRAP TECHNOLOGY FOR WILDLIFE MANAGEMENT AND RESEARCH IN AUSTRALIA AND NEW ZEALAND.

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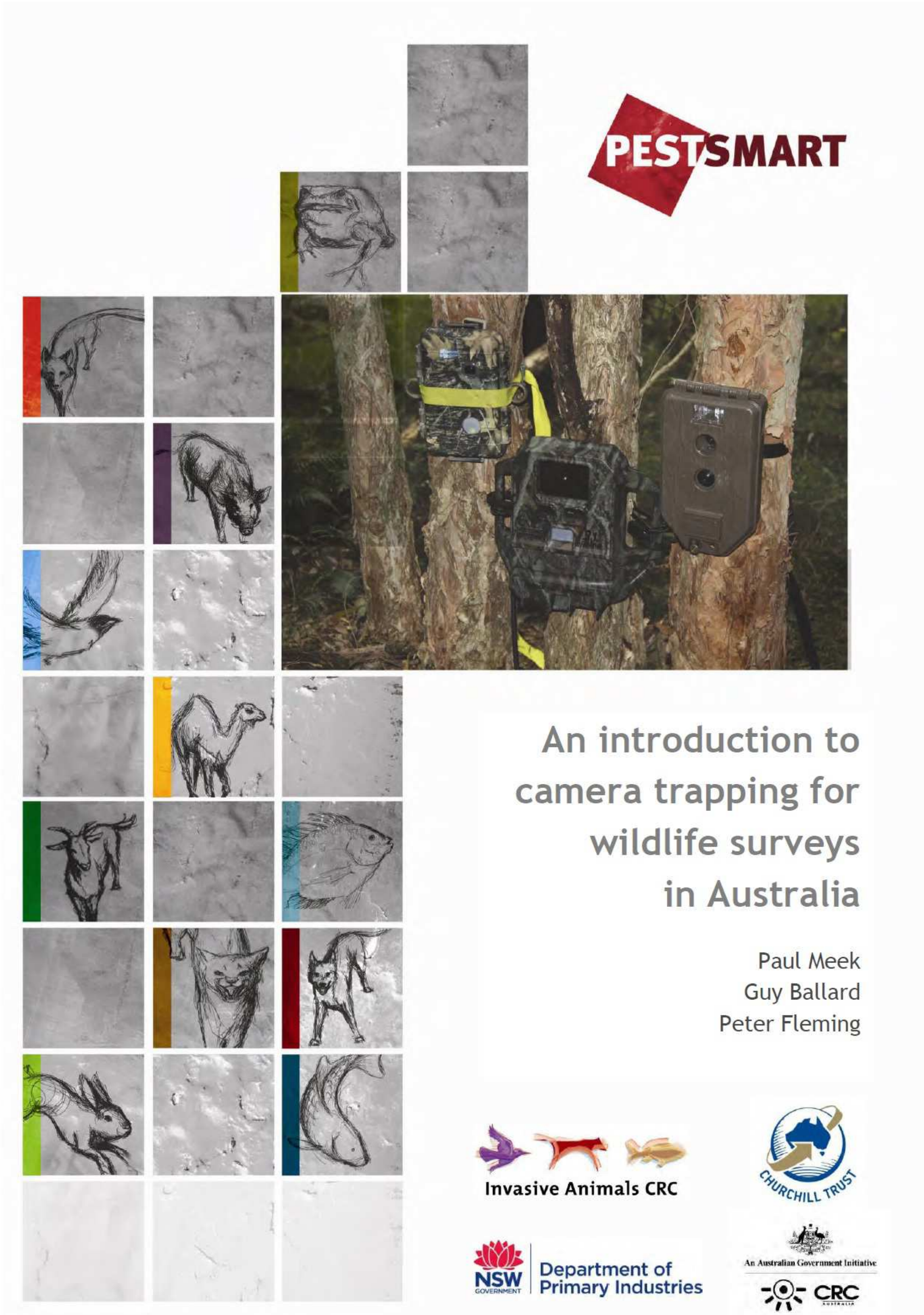

PESTSMART

An introduction to camera trapping for wildlife surveys in Australia

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Invasive Animals CRC

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