Analysis of the Functionality, Value and Constraints of Using Camera Traps for Wildlife Monitoring and Ecological Research

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Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Dr Greg Falzon Date 10/11/15

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Dr Guy Ballard Date 10/11/15

Acknowledgements

My Father Douglas Meek never stopped learning and at 50 years of age he returned to school to study matriculation subjects because he was not given this opportunity as a teenager. His thirst for knowledge and desire to understand nature was the reason I entered this field of wildlife ecology. I wish he was here to witness his son's striving at being the first PhD in our family lineage. I want to offer my heart felt gratitude and love to my wife Kersten Tuckey who has encouraged me through some very tough years in pursuit of this PhD. Her support was critical to me completing this body of work and her help in the field and in editing is greatly appreciated. To my daughter Aaliyah Meek who helped me set and check camera traps when she could barely walk, and who suffered from a lack of attention at times while my mind was processing a thought - I owe you some Father-Daughter time. I would like to thank my supervisory panel Guy Ballard, Peter Fleming, Karl Vernes and Greg Falzon who have provided support and encouragement over the last 3 years. Each of them has played different roles but all are talented scientists who made my research better for their input. Each of them has also been instrumental in providing opportunities to me to undertake interesting research, visit amazing places and be a part of a cutting edge research team, I will always be grateful. Thanks to Glen Saunders for being my Masters supervisor, my Manager but importantly my friend and mentor. The advice and friendship of Caroline Gross was very much appreciated. Thank you to the Churchill Trust for providing me with a Fellowship in 2011 that ultimately facilitated this PhD. I am grateful to the NSW Dept. Primary Industries for providing me with study leave in the final year of my PhD. Many people have provided help, conversation and advice throughout this dissertation, some have been recognised as co-authors in my research and others will be acknowledged in future publications that are not included in this dissertation. I have appreciated the involvement of these people in my research and wish to thank them; Jessica Sparkes, Fran Zewe, Piers Thomas, Guy Hodgkinson, Dustin Welbourne, Geoff James, Gerhardt Koertner, Garry Gillard, Justin Thinner, Ross Meggs, Bill Power Jnr, and Damien Byrne. Research carried out in this PhD was conducted under UNE Human Ethics Approval HE12-091, UNE Animal Ethics Approval ACEC12-042 and NSW Scientific License Number SL100634.

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Abstract

Adoption of camera trapping as a survey method by wildlife practitioners is increasing at warp speed. The technique is now widely cited in the published scientific literature and it has quickly become an important and widely used method in wildlife research, wildlife monitoring, and citizen science. Camera traps have largely been developed as a tool satisfying the demands of a very large hunting industry in North America. Until recently, the needs of ecologists and wildlife enthusiasts had been second to those in pursuit of hunting trophies, and as such many camera trap models failed the litmus test for fauna surveillance. The magnitude of these limitations has not been adequately recognised by practitioners and has led to the adoption of the technique without full understanding of the constraints of the sampling tool. In this dissertation I aimed to highlight and resolve some of the pitfalls that practitioners face when sampling wildlife using camera traps. I provide a historical context summarising how methods have developed over the last decade and tried to redress some of the ongoing problems identified in the camera trap literature. To this end I provide advice and guidelines to help camera trap practitioners design studies, implement sampling and reporting on their findings. However, the main focus of my research has been to address the differences between camera trap models and brands, the biases of the equipment, the effects of placement and orientation on detection, the challenges of identification and species in photographs, and have instigated the development of computer assisted technologies that will revolutionise how wildlife researchers analyse camera trap image data. I have also used my research to provide constructive design advice to camera trap manufacturers to encourage better designs to suit the needs of wildlife practitioners. Recommendations are provided on what practitioners would consider the features of an ultimate camera trap design that have led to the development of two new models of camera traps, and modifications to existing models.

The research presented in this dissertation supports the argument that camera traps are a valuable and exciting scientific tool, but all models do not detect wildlife equally, and we need to understand how camera trap technology works and how to optimise the tool.

My assessments of several camera trap models show that all camera traps emit sounds and light that can be detected by most animals, thus debunking claims that camera traps, in particular infra-red flash models, are non-intrusive. Subsequent analysis involving animals detected by camera traps showed negative and positive behavioural responses by a suite of species to camera traps. These responses were recorded in day and night hours, therefore

suggesting that a range of stimuli may be causing animals to detect the devices. The implications of these behavioural responses are discussed in the context of measuring animal populations. In addition, evidence is presented confirming that height, orientation and the animal's passage of travel affects detection probability. Moreover, irrespective of the best placed camera trap, species identification in some habitats is problematic and requires additional analysis, for example using pattern (texture) algorithms. Using the Hastings River Mouse as a case study species, I report that identifying several species from camera trap images without computer assisted technology is unreliable. This finding is further validated through an evaluation of mammalogists who were invited to identify a range of small-medium sized mammals using camera trap images. That survey confirmed that for some species that are similar in appearance, camera trap images could not be used to accurately identify to species.

Throughout this dissertation it has been my goal to resolve some of the constraints of these devices, not to de-value their role and benefits, but to help generate robust ecological data. Camera trap data is now being used to formulate management strategies for the protection of the world's biodiversity, for evaluating effectiveness of important interventions for the protection and recovery of impacts, and to measure ecological health in global ecosystems. Fine tuning how we use this method to improve wildlife population data collection and help inform management of global biodiversity is imperative.

The applications for camera traps in wildlife research and management are profound and they offer a new dimension to understanding the biology and ecology of wildlife throughout the world. In my studies of small mammals I was able to utilise the unique circadian data provided by camera trap images, allowing me to map the activity patterns of rodents. This investigation showed how rodents partition time to avoid contact with congeners, research otherwise restricted to laboratory studies, and an example of how valuable these tools are to wildlife science.

As camera traps replace traditional survey methods into the future, researchers must ensure that the "tools are fit for the trade". If camera traps and the methods used are not accurate, robust and consistent, then the data we gather and analyse will be compromised. Poor data results in poor decision making and bad outcomes for ecological management and conservation. I provide recommendations on design elements for future camera trap models based on the needs of wildlife practitioners and science. I also outline a gold standard approach for reporting camera trap research methods in scientific publications with the expectation that greater detail will be provided in future manuscripts. Finally, I outline a range of future research directions for improving the use of camera traps in wildlife research and monitoring. Accordingly, all of the papers that comprise this dissertation, and other related works listed in the Appendices, have a common inter-woven thread; optimising a scientific method to amplify ecological outcomes.

Preamble

In 2009-10 my interest in camera traps as a survey tool was stirred by the decreasing financial resources in the government sector, despite the growing acceptance of monitoring and evaluation as policy mantra. In the ensuing years, together with my colleagues, I began to assess camera trapping as a methodology, and more importantly camera traps to assess their effectiveness as an ecological sampling tool. During 2010-15 our Invasive Animals Cooperative Research Centre (IACRC) Wild Canid Demonstration Site team initiated research projects aimed at evaluating the strengths and weaknesses of the devices and how they are being used. Primarily to assess the potential value of, and ecological consequences of, a substandard, inaccurate or un-calibrated sampling tool in research and management. The body of work presented in this dissertation forms a part of a larger program evaluating camera traps for a suite of species and purposes.

Camera trapping has been adopted with vigour in Australian wildlife research and management and this practice has preceded appropriate testing: for the most part, our team has been more tentative in adopting camera traps. I pose the following questions to reconcile in this dissertation:

> *"When conducting a scientific investigation using equipment, you need to calibrate measuring devices and set up the equipment accurately to obtain reliable values. Why, then, buy camera traps and place them in the field without considering the right settings, the correct placement or without understanding bias and potentially generating a calibration factor?"*

In 2011, it became apparent that there was considerable propensity for researchers to be duplicating their camera trap research and/or limiting their findings because the literature could not keep up with their studies. I was motivated to take a proactive role in changing the trajectory of this emerging field. That same year, I was awarded a Churchill Fellowship visiting some of the world leaders in camera trapping in Europe and the USA to help advance the field. The fellowship facilitated many benefits (Appendix - Meek 2012) to camera trap use that ultimately resulted in a proposal to the Australasian Wildlife Management Society (AWMS) and NSW Royal Zoological Society to host the world's first camera trapping conference in Sydney, 2012. This provided a means of fast-tracking the sharing of new developments. The concept of the Colloquium was simple; "*camera traps are amazing tools providing new insights into the ecology of animals and creating new opportunities for scientific endeavour, however they are imperfect wildlife sampling tools*". This forum brought together international and Australia camera trap researchers. The main objective was to fast track the dissemination of ideas, information and findings so that camera trap based research advanced quickly and collegially. The first Camera Trapping Colloquium was heralded a huge success with over 230 participants from 13 Countries. Thirty-three spoken papers and forum deliberations were peer-reviewed and published as an edited volume (Appendix - Meek *et al*. 2014a). The papers presented in that book identified many areas where camera traps were valuable in replacing historical survey methods whilst also outlining some of the pitfalls.

In 2012, the IACRC supported the preparation of Australia's first camera trapping manual that provided guidance to practitioners on how to use camera traps for ecological investigations (Appendix - Meek *et al*. 2012a). This manual was the first publication aimed at informing Australian practitioners of the complexities of using camera traps in wildlife management and research. The manual was well received and acknowledged internationally as well as in Australia (Fig 1) with 2477 page views from 2032 users and 310 downloads since it was uploaded to the internet. Several methodological issues highlighted in the manual form the backbone of research that underpins this dissertation.

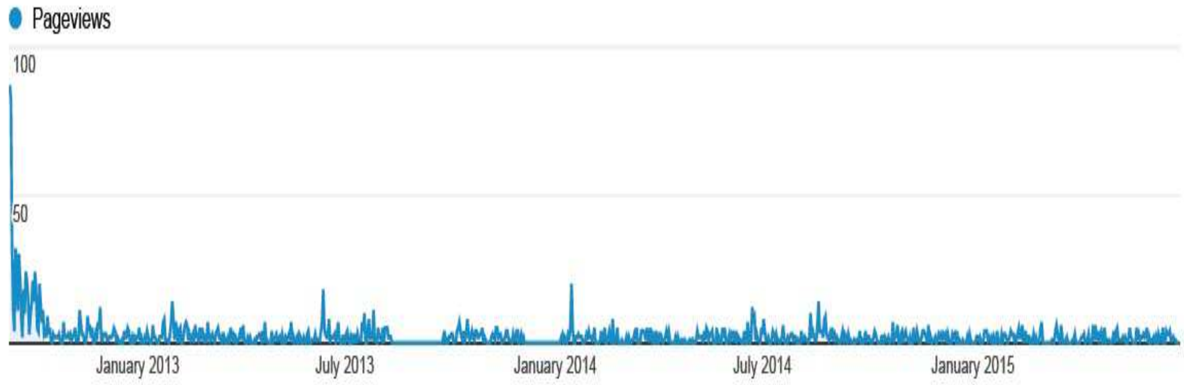

Figure 1. Camera trap manual (Meek *et al*. 2012) page view data from 2012-2015.

While the subject matter of most of my camera trap research has focussed on understanding constraints, I am not advocating that camera trapping is unsuitable for use in ecological investigations. Recognition and improved understanding of camera trapping limitations are necessary for refinement of this method and imperative to maximize research and monitoring opportunities, while minimising spurious data that can lead to poor ecological decision making. Camera trapping provides wildlife researchers, managers and citizen scientists with opportunities to study animals in new ways, to monitor over larger spatial and temporal scales, and to make new discoveries.

Introduction to Chapters

In the first decade of the 21st Century, the adoption of camera traps as an ecological sampling tool was in its infancy in Australia and the extent of its use in scientific research was not fully realised. To date we have made rapid progress and camera trapping has permitted practitioners to study the ecology and biology of animals in ways never before possible with conventional survey methods (Swann *et al.* 2004; O'Connell *et al.* 2011). Using the time and date stamping on images, practitioners are now able to attribute previously hidden behaviours to specific times of day and night thereby making it possible to study animal behaviour at all hours, and un-ravelling ecological mysteries about species and their interactions (Bolton *et al.* 2007; Borchard and Wright 2010; Meek *et al.* 2012; Diete *et al.* 2014; Vernes and Jarman 2014; Diete *et al.* 2015; Fancourt 2015).

In early 2000, only a few camera trap models were used in Australia and because it was a fledgling but 'emerging market', only cheap models from the USA such as Moultrie® and Cuddeback® and Pixcontroller DigitalEye® devices were used (Chapter 1 - Meek *et al*. 2015a). One Australian model (Faunafocus®) was being developed and several efforts at retrofitting cheap film cameras had been attempted (see Meek *et al.* 2015a). Some of the early camera trap research used equipment that was available to practitioners and in true Australian fashion, technology uptake was rapid. By 2013, camera traps were being used widely (Meek *et al.* 2014) but often the users were unaware of the nuances and limitations of the device (Chapter 1 - Meek *et al*. 2015b).

The research I present here are the findings from several years of mapped-out and targeted investigation (Fig 2). The goal was to unravel the technical limitations of the different types of camera traps, and how they can be deployed to optimise detection and scientific rigour. The *line of enquiry* (Fig 2) is focussed on the recognition that practitioners need to understand how research tools work so that we can optimise device placement, quantify calibration factors and appropriately analyse data (Meek *et al*. 2015b). Moreover, as practitioners we need to ensure that the tools used do not compromise research outcomes and lead to misinterpretation of ecological data in management. It is crucial therefore, that camera trap practitioners clearly understand the benefits and constraints of camera traps as a wildlife data collection tool. When practitioners are using traditional methods to calculate a population estimate for fauna, a consistent approach is required including calibration factors to account for detection probabilities where necessary. The same principles apply to camera trapping and in order to determine which factors influence detection, we need to understand and measure those variables and derive calibration factors to account for the variability.

It is my aim to highlight, through the research presented in this dissertation, some of the fundamental constraints of using camera traps in ecological investigations so they may be considered in the design, analysis and interpretation of image data (Chapter 1 – Meek *et al*. 2015b; Rovero *et al*. 2013). In addition, to assess the value and role that camera traps can play in unravelling some of the gaps in our ecological knowledge of Australia mammals, and species world-wide.

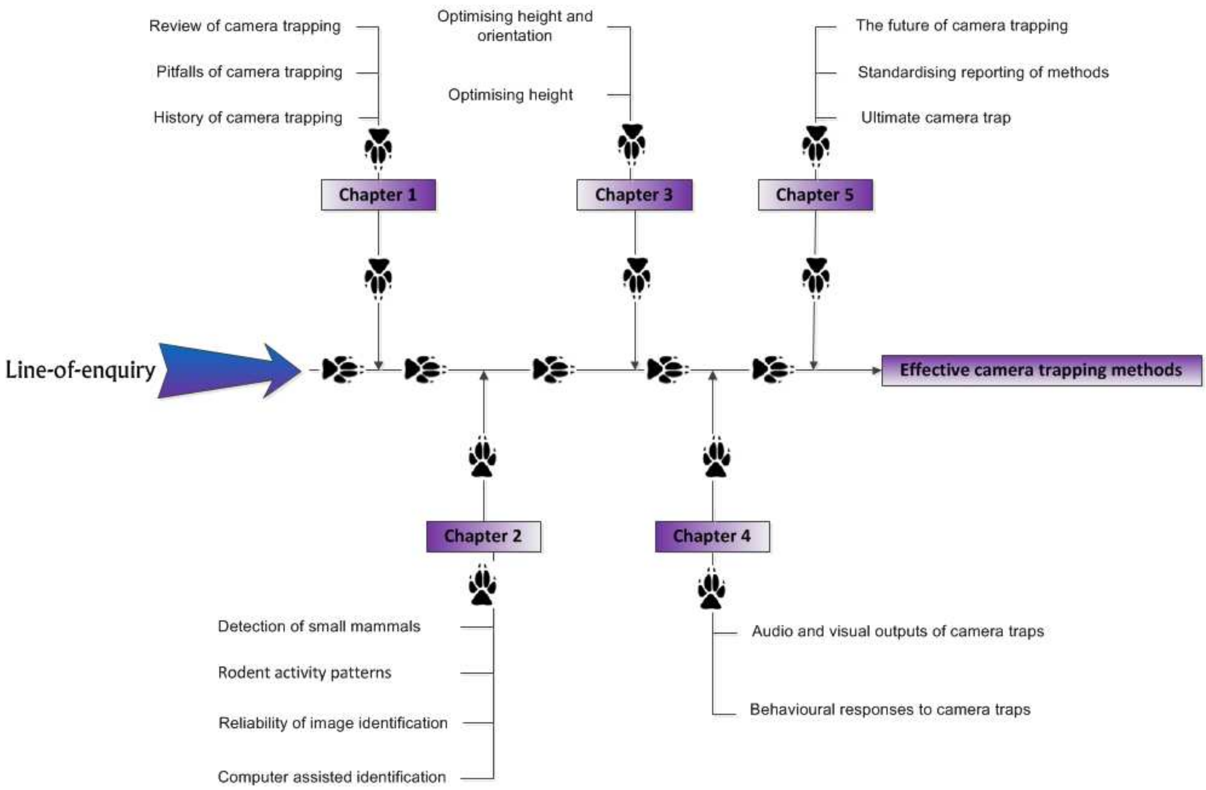

Figure 2. The line-of-enquiry and associated publications used in this dissertation to address issues related to camera trap constraints and the effects on ecological interpretation and decision making in wildlife research and management.

The aim of this dissertation was to assess the value and role that camera traps can play in improving our ecological knowledge of Australia mammals, and species world-wide. Therefore, the specific objectives were to;

1. review the development and use of camera traps for wildlife research and monitoring, and highlight some of the fundamental constraints of using camera traps in ecological

investigations so they may be considered in the design, analysis and interpretation of image data (Chapter 1)

2. investigate the applicability of camera trapping to surveys of and ecological questions about some small Australian mammals (Chapter 2)
3. investigate the applicability of camera trapping to surveys of and ecological questions about medium sized Australian mammals (Chapter 3)
4. investigate whether animals can detect camera traps, and if so what effects might that have on animal behaviour (Chapter 4)
5. make recommendations to improve the use and reporting of camera trapping studies and to map out important areas of future research and camera trap design.

Whether animals can detect camera traps, and whether any observed detection influences animal behaviour, are important questions because such issues may affect repeat visit surveys and subsequent population estimations. I tested the audio and infra-red illumination outputs of a number of camera trap models and compared the outputs to the hearing and vision of animals (Chapter 4 - Meek *et al*. 2014b). Secondly, my colleagues and I assessed the behavioural responses of predators in Australia to evaluate if disturbances from camera traps affect behaviour, and as such influence their detection (Meek *et al*. 2015b). I was also interested to evaluate how the model, components and operation of a camera trap may affect detection probability of smaller mammals like those found in Australia.

Despite the first Reconyx brand camera traps being designed for small mammal surveys (Meek 2012b), the majority of contemporary devices were built to detect medium to large sized mammals such as deer (Chapter 5 - Meek and Pittet 2012). As a result, the detection zones can potentially influence how the devices are deployed and which models can be used for small-medium sized mammals. In 2010, I pioneered surveys for the Hastings River Mouse (*Pseudomys oralis)* using camera traps, where different models were contrasted and species detections compared with Elliot trapping (Meek 2010; Meek and Vernes in prep). I raised important issues related to using camera traps for rodents and this led to an expansion of the earlier pilot studies on Hastings River Mouse (Chapter 2 - Meek and Vernes 2015). Pitfalls were identified using camera traps for sympatric rodents where differentiation between species normally requires hand-eye observations and morphological measurements. Importantly, the variability in detection between different camera trap models has led to some new technical innovations.

The use of computer-assisted technology has facilitated significant break-throughs in camera trap image processing, including the individual recognition of wild dogs-dingoes from camera trap images (Appendix - Falzon *et al*. submitted). Despite innovation in camera trap research; I continue to grapple with basic methodological issues such as optimising detection through camera trap placement and orientation, in particular camera trap height. There are two reasons for this approach, reducing theft of cameras and optimising detection of target animals.

Throughout the world, camera trap practitioners face the risk of loss of data either directly through theft/damage of the camera trap or through a stolen or damaged SD card (Appendix - Meek & Butler 2014) during their studies. The financial loss from stolen camera traps and equipment can greatly impact upon a research budget. Following a series of camera trap thefts during the surveys undertaken during this PhD, I proposed a hypothesis that placing camera traps above the level of human eye may overcome detection by humans without compromising animal detection. However, raising the height of the camera trap above the core body zone of the target species could interfere with detection of target species. If such a dramatic change to placement is necessary to avoid theft, the implications for detection probability of the target species must be evaluated (Chapter 3). To understand how the animal, camera trap placement and the ecosystem interacted, I needed to investigate how detection zones and passive infra-red sensors functioned. However, resolving the theft of camera traps by humans needed a non-scientific solution. A means of protecting the device by enclosing the camera trap in a lockable steel box on a concrete filled steel post permanently located in the field was subsequently designed (Appendix - Meek *et al*. 2012c).

In these investigations, it became apparent how important temperature was in the camera traps capacity to detect species. This was particularly so in a hot-tropical environment where rodent body temperature can be close to background temperature during some parts of the day (Meek *et al*. unpub data). I used thermal imagery technology to identify potential detection problems on track based surveys for wild dogs. To unravel the complexity of how PIR's detected the heat-in-motion of dogs in a forest, I needed to determine where the dogs' hottest and coolest regions were on the body. I also sought to understand the differential between the animal and the background heat signatures, and how the temperature 'mosaic' of a forest background might influence animal detection. Using dogs from a training school and a thermal camera, I conducted a pilot study to record the heat signatures of a range of dog sizes/breeds providing some valuable insights into how camera traps detect animal presence

(Meek and Falzon in prep). Despite the small scale of this investigation and the constraints on collecting empirical data, the knowledge gleaned has further refined the way our research team place camera traps. For example, I revealed that the background temperature signature contains pockets of heat that would not enable the PIR in camera traps to register a difference when an animal passed the device. To minimise the effect of this fault in detection, our team now place camera traps in sites where the background has the most homogenous contrast. It appears that there are serious limitations in contemporary camera traps and methods, and these need careful consideration before deployment. Some of the technical ways of overcoming camera trap detection problems is provided in Meek and Pittet (2012, 2014) and Meek *et al*. (2015b).

The immense volume of data being collected in camera trap studies throughout the world is daunting, a large component of which contains superfluous images, often consisting of humans and vehicles. Managing images of people is problematic and during surveys along roads where human activity can be high, it occurred to me that there might be legal risks of detecting and recording humans in wildlife surveys. This ominous side to camera trapping is rarely considered. When we take a person's photo in camera trap surveys it is considered their private datum and misuse of images may lead to prosecution; a cost few have fully realised. Under privacy laws throughout the world, capturing images of people and distributing them without permission can be illegal. I recognised this potential litigation issue following a prank in New South Wales, Australia following the misuse of indecent images of a colleague. I sought counsel from a privacy expert and in an unprecedented review we explored the issue from a legal position (Appendix - Butler and Meek 2013) and from an ecological viewpoint (Appendix - Meek and Butler 2014). In these papers, we described the legal responsibilities of camera trap practitioners in handling images of people and provide legal guidance on how to minimise the potential for prosecution under Australian privacy laws. Despite these threats, the future of camera trapping as an ecological survey tool is bright, especially where new models are being designed to facilitate research objectives.

Such changes to the technology are possible, although practitioners collectively need to influence the camera trap market to ensure that new models cater for the needs of wildlife researchers as well as the hunting fraternity (Chapter 5 - Meek and Pittet 2012). Through my consultation with one camera trap manufacturer, a camera trap was especially built using white LED illuminators specifically for researchers (after Meek 2012). This has ensured that high quality equipment remains available to researchers studying species that need night time colour photos to aid identification (Chapter 2 - Meek and Vernes submitted). The same manufacturer has also built another new model specifically for those researchers using video footage. The power of the practitioner is substantial and can be used to impart new ideas for camera trap designs that are more aligned with wildlife research than game detection.

One of the primary objectives of this dissertation is to evaluate the accuracy and suitability of camera traps as a survey tool to mitigate adverse effects on ecological interpretation and management practice and outcomes. Camera traps have allowed us to investigate the nocturnal behaviours of rodents with renewed vigour (Appendix - Meek *et al*. 2012b; Diete *et al*. 2014 and Diete *et al*. 2015) and to allow more robust testing of other management tools (Appendix - Zewe *et al*. 2013). It has allowed us to fill in some of the knowledge gaps with this technology but also provides us with a clearer understanding of what information, tests and experiments are still required (Chapter 5 - Meek *et al*. 2014c) to ensure that we use these devices with more understanding of their constraints and pitfalls (Meek *et al*. 2015a).

In this dissertation I review the historical development and adoption of this new technology in wildlife research and monitoring. It is incumbent on scientists to clearly describe the methods used in their research in sufficient detail to enable repetition by others. Australian camera trap papers are often inconsistent in describing the methods used (Meek *et al*. 2015b). Failure to provide such methodological information makes a thorough evaluation of their techniques and findings very difficult. The development of a gold standard approach to reporting camera trap research is required to ensure greater consistency in methods used (Chapter 5 - Meek *et al*. 2014b). Many camera trap methodological issues have not been tested or resolved leaving practitioners with many questions regarding camera trap models, variability in detection, optimising settings and the enormous problem of data management and analysis. In Chapter 6, a summary of issues that need to be tackled are presented that should help to progress the refinement of camera trap methods, to ensure that ecological decision making is not compromised by poor or invalid evidence.

Dissertation structure

The dissertation comprises a sequential series of manuscripts either published or submitted for publication in a range of journals and a book, as such the published manuscripts hold their journal formatting and page numbers confirming their authenticity. Where a manuscript has been submitted but review has not been completed at the time of dissertation submission, it is provided in word format pending the editorial process. A supervenience chapter has been included after some of the main chapters (1-3) where important manuscripts co-authored by the candidate are presented. It is important that these manuscripts are included as a part of the body of research presented, because the research is integral to the objectives of this dissertation. However, these manuscripts fall outside of the dissertation proper (and need not, therefore, be assessed) because I was not senior author, despite contributing to the conceptualisation of the studies, assisting in the field work, interpreting the results and contributing to writing the manuscript. Also, I have included the first page of other related manuscripts in the Appendix to support my claim and supplement the research *line-of-enquiry* outlined in the Introduction.

Dissertation Publications

Peer Reviewed Journal Manuscripts

Meek, PD., Ballard, GA. 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*, ??-??.

Meek, PD., Ballard, GA., 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.

Meek, PD. and Vernes, K. (2016) Can camera trapping be used to accurately survey and monitoring the Hastings River mouse (*Pseudomys oralis*)? *Australian Mammalogy* **38**, 44-51.

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.

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.

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.

Meek, PD., Ballard, G., Claridge, A., Kays, R., Moseby, K., O'Brien, T., O'Connell, A., Sanderson, J., Swann, D.E., Tobler, M. & Townsend, S. (2014) Recommended guiding principles for reporting on camera trapping research. *Biodiversity and Conservation***, 23**, 2321-2343.

Meek , P.D., Vernes, K. & Falzon, G. (2013) On the Reliability of Expert Identification of Small-Medium Sized Mammals from Camera Trap Photos. *Wildlife Biology in Practice,* **9,** 1-19.

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.

Meek, P.D. & Pittet, A. (2012) User-based design specifications for the ultimate camera trap for wildlife research. *Wildlife Research,* **39,** 649-660.

Meek, P.D., 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.

Submitted Manuscripts

Ballard, G, Meek, PD., Melville, G. and Fleming, PF. (in prep). Estimating detection probability in camera trapping surveys. *Australian Wildlife Research* (publication was submitted in 2015 and is being edited for re-submission)

Books

Meek, PD, Fleming, PJS, Ballard, AG, Banks, PB, Claridge, AW, McMahon, S, Sanderson, JG, Swann, DE (2014) Camera Trapping: Wildlife Management and Research. CSIRO Publishing, Australia.

Book Chapters

Meek, PD, and Butler, D (2014) Now we can 'see the forest and the trees too' but there are risks: camera trapping and privacy law in Australia. In 'Camera Trapping: Wildlife

Management and Research.'Eds PD Meek, AG Ballard, PB Banks, AW Claridge, PJS Fleming, JG Sanderson, DE Swann. pp. 331-345. CSIRO Publishing: Melbourne, Victoria, Australia.

Meek, PD, and Pittett, A, (2014). A review of the ultimate camera trap for wildlife research and management. 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. CSIRO Publishing, Melbourne, Victoria, Australia.

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: 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 CSIRO Publishing, Melbourne, Australia.

Meek, PD, Butler, D (2014) Now we can 'see the forest and the trees too' but there are risks: camera trapping and privacy law in Australia. In 'Camera Trapping: Wildlife Management and Research.'Eds PD Meek, AG Ballard, PB Banks, AW Claridge, PJS Fleming, JG Sanderson, DE Swann. pp. 331-345. CSIRO Publishing: Melbourne, Victoria, Australia.

Ballard, G, Meek, PD, Doak, S, Fleming, PJS, Sparkes, J (2014) Camera traps, sand plots and known events: what do camera traps miss? 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.

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.

Publications Intrinsic to the Dissertation

Cover pages of these publications are in the Appendix.

Butler, D, Meek, PD (2013) Camera trapping and invasions of privacy: An Australian legal perspective. *Torts Law Journal* **20**, 234-264.

Meek, PD, Ballard, G-A, Fleming, PJS (2013) A permanent security post for camera trapping. *Australian Mammalogy* **35**, 123-127

Meek, PD, Ballard, AG, Fleming, PJS (2012) An Introduction to Camera Trapping for Wildlife Surveys in Australia. Invasive Animals CRC, Canberra, Australia.

Meek, PD (2012) Refining and Improving the Use of Camera Trap Technology for Wildlife Management and Research in Australia and New Zealand. Fellowship Report to The Winston Churchill Memorial Trust of Australia.

Meek, PD, 2010. Remote Camera Monitoring of The Hastings River Mouse (*Pseudomys oralis*): Trial of a Novel Technique for Monitoring Populations. Unpublished Report for Gondwana Rainforests of Australia.

Related Camera Trap Ecological Research

Diete, RL, Meek, PD, Dickman, CR, Dixon, K, and Leung, LK-P. (2016). Best bait for your buck: bait preference for camera trapping north Australian mammals. *Australian Journal of Zoology* **63,** 376-382.

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* **37**, 260-263.

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.

Zewe, F, Meek, P, Ford, H, Vernes, K (2014) A vertical bait station for black rats (*Rattus rattus*) that reduces bait take by a sympatric native rodent. *Australian Mammalogy* **36**, 67-73.

Author roles, authenticity and contributions

- **Paul D Meek** was primary researcher in the main chapter manuscripts, conceptualised research topics and ideas, designed studies, conducted field and laboratory research, analysed and interpreted data and wrote manuscripts as senior author, including journal submission and review, and contributed to writing three papers presented in this Dissertation as co-author. He co-edited a CSIRO book in 2014 on camera trapping in wildlife management and research.
- **Guy Ballard** was primary researcher in one study and contributed to study design and implementation of most investigations, analysed and interpreted data and contributed to the writing and editing of several manuscripts. (Chapter 1, 2, 3, 4, 5). Dr Ballard was a panel supervisor.
- **Peter Fleming** contributed to research concepts and ideas, planning and data collection, also contributed to the writing and editing of several manuscripts. (Chapter 1, 2, 3, 4, 5). Dr Fleming was a panel supervisor.
- **Greg Falzon** contributed to research concepts and ideas, analysis, development of models and contributed to the writing and editing of several manuscripts. (Chapter 1, 2, 3, 4, 5). Dr Falzon was a panel supervisor.
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