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The Potential and Practice of Arboreal Camera Trapping

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	received much attention, there is little guidance for dealing with the unique challenges of working in the arboreal realm. 2. Our review draws on the expertise of researchers from six continents and the broader literature to investigate the advantages and disadvantages of arboreal camera trapping, and challenges to consider when using this technology. We also include mini-guides with detailed information on the current arboreal camera trap literature, mounts used to install arboreal cameras, tree climbing pointers and safety tips, methods for deploying cameras without climbing, and tips for managing interference with camera function. 3. We find that arboreal camera traps have been most commonly used in the study of mammals in forests, however there is potential for this method to be applied to a broad range of habitats including urban areas, and taxa such as birds, amphibians, invertebrates, and plants. Methods in arboreal camera trapping could be improved by developing a greater understanding of the factors affecting detection of species. The most common challenges of arboreal camera trapping are camera placement and camera site access. These can be overcome by understanding correct camera orientation, managing potential sources of interference in front of cameras, utilizing appropriate cameras mounts, and training researchers properly. 4. Given the benefits and opportunities presented by arboreal camera trapping, it is likely to become an ever-more popular method of studying arboreal species and systems. The information synthesized in this review provides guidance for future studies to help direct more reliable and robust ecological inferences from arboreal camera trapping.

The Potential and Practice of Arboreal Camera Trapping

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Abstract

1. Arboreal camera trapping is a burgeoning method providing a novel and effective technique to answer research questions across a variety of ecosystems, and it has the capacity to improve our understanding of a wide range of taxa. However, while terrestrial camera trapping has received much attention, there is little guidance for dealing with the unique challenges of working in the arboreal realm.
2. Our review draws on the expertise of researchers from six continents and the broader literature to investigate the advantages and disadvantages of arboreal camera trapping, and challenges to consider when using this technology. We also include mini-guides with detailed information on the current arboreal camera trap literature, mounts used to install arboreal cameras, tree climbing pointers and safety tips, methods for deploying cameras without climbing, and tips for managing interference with camera function.
3. We find that arboreal camera traps have been most commonly used in the study of mammals in forests, however there is potential for this method to be applied to a broad range of habitats including urban areas, and taxa such as birds, amphibians, invertebrates, and plants. Methods in arboreal camera trapping could be improved by developing a greater understanding of the factors affecting detection of species. The most common challenges of arboreal camera trapping are camera placement and camera site access. These can be overcome by understanding correct camera orientation, managing potential sources of interference in front of cameras, utilizing appropriate cameras mounts, and training researchers properly.
4. Given the benefits and opportunities presented by arboreal camera trapping, it is likely to become an ever-more popular method of studying arboreal species and systems. The information synthesized in this review provides guidance for future studies to help direct more reliable and robust ecological inferences from arboreal camera trapping.

Keywords: camera traps, canopy ecology, conservation, detectability, forest ecology, mammals, urban wildlife, wildlife monitoring

1. Introduction

Camera traps have rapidly become a popular technique in wildlife research (e.g., Burton et al., 2015; Fleming et al., 2014; O'Connell et al., 2010; Trolliet et al., 2014). Terrestrial camera trap studies have demonstrated the enormous capacity and potential of this method to provide ecological insights and inform conservation and management. For example camera traps have been used to document species richness and occupancy (e.g., Ahumada et al., 2011; Tobler et al., 2015), revealed species new to science (e.g., Rovero et al., 2008), recorded species' range expansions (e.g., Cove et al., 2011; Noss et al., 2004), and documented new species interactions and behaviours (e.g., Rowcliffe et al., 2014). However, this powerful technique has only just begun to be applied to the study of arboreal species and systems. Arboreal taxa are disproportionately impacted by habitat loss, forest fragmentation, and other anthropogenic activities (Whitworth et al., 2019). An increased uptake of methods that provide greater insight into the interactions between arboreal species and their environments will therefore contribute to better conservation outcomes.

There are several potential advantages of using camera traps to study arboreal species and systems. While many approaches for the study of arboreal species exist (e.g., line transects, radiotelemetry, mark-recapture, spotlighting), camera trapping methods have the potential to collect more data with less effort. Camera traps allow near-continuous data collection with relatively little human interference and effort, and thus can be cost-effective, even over large spatial and temporal scales. This is invaluable for the detection of rare and elusive arboreal species that are often overlooked by 'snapshot' monitoring approaches, as well as nocturnal species, which can be exceedingly difficult to observe from the ground at night. Cameras can also provide insights into species behaviour, the effectiveness of novel conservation efforts (e.g., nest boxes, artificial and natural canopy bridges), or responses to anthropogenic disturbances that would be incredibly difficult and time-consuming to document using direct observation methods. However, there are also unique challenges to using camera traps to study arboreal species. In contrast to the ground, the arboreal sampling space is more complex due to the third dimension of height, making camera placement more difficult. In addition, safety precautions must be taken when working at heights, requiring specialized skills or equipment, and may therefore be more costly. Understanding the potential benefits and challenges of this method will help researchers decide how to make the most of its use.

In this paper, we draw on global expertise and the existing literature to review the advantages and disadvantages of arboreal camera trapping, and we highlight issues to consider when using this technology for the first time. We explore the variety of ways in which cameras have been used to study arboreal species and systems, present important factors to consider in the design of arboreal camera trap studies, detail how common pitfalls can be avoided and where important gaps lie, and identify future opportunities and research directions for this field.

2. The what, where, and why of arboreal camera trapping

Arboreal camera trapping is the use of camera traps placed above the ground to study arboreal or semi-arboreal species or systems. It often involves the placement of cameras at heights, requiring the ascent of a tree or structure (e.g., buildings). For this review, we searched the peer-reviewed literature to develop a database of studies that have used arboreal camera trapping. Because the goal was to identify the breadth of the relevant literature, our search methods were purposive, rather than systematic. We used the following search terms: "arboreal", "canopy", "wildlife", "camera", "camera trap" in databases such as Scopus, Google Scholar, and ResearchGate to identify relevant studies. We also examined the reference section of these studies and review papers to identify any further literature. For each study, we extracted information on the primary research focus, focal taxa, habitat type, height of camera placement, country of study, and year of publication.

Our search identified 90 studies published between 1991 and April 2021 (Table 1; see Appendix 1 "Annotated bibliography of published arboreal camera trap studies" for a full list and summary of each study). Studies represent research across 24 countries (Figure 1A). The earliest published use of arboreal camera traps was in 1991 (Carthew & Slater, 1991) in which a custom-made film camera trap was used to monitor pollination of shrubs by arboreal wildlife. The method remained relatively rare until 2013 and has become more common since, with 17 studies published in 2020 (Figure 1B). Mammals were the most common focal taxa (n=78), followed by birds (n=16), with very few studies on other taxa (Figure 1C). Arboreal camera traps have been predominantly used to study tropical forests (n=39), temperate forests (n=34), and roads (n=13), with fewer than five studies each reported for agricultural, urban, and other habitat types (Figure 1D). Cameras are placed at a wide variety of heights, ranging from just 1–2 m to study activity on shrubs or low tree trunks (e.g., Debruille et al., 2020; Kierulff et al., 2004; Mella et al., 2018), to more than 30 m high in the forest canopy (e.g., Gregory et al., 2014; Whitworth et al., 2016).

Much like terrestrial camera trapping, arboreal cameras trapping studies have spanned a broad range of research foci: species behaviour, species richness and presence, movement and corridor use, nesting, methods testing, and the impacts of human activity (Table 1). This diversity of research foci, focal taxa, and habitat type illustrates the capacity of arboreal camera trap studies to provide valuable ecological insights into a wide variety of systems (Figure 2). Arboreal camera traps have proven particularly valuable in recording the presence of rare or elusive species (e.g., Fang et al., 2020; Geyle et al., 2020; Moore & Niyigaba, 2018), little-known behaviours (e.g., Dalloz et al., 2012; Laughlin et al., 2017; Mella et al., 2018), and inter-specific interactions (e.g., Saeki et al., 2020; Schruhl et al., 2012; Zhu et al., 2021) that would otherwise be difficult to observe in the canopy. For example, cameras placed in the Ankeniheny–Zahamena rainforest corridor in eastern Madagascar validated the presence of the critically endangered greater bamboo lemur *Prolemur simus* (Olson et al., 2012), and the first documentation of the pollinator community of the endangered and epiphytic ghost orchid (*Dendrophylax lindenii*) in Florida's Everglades Basin was made by cameras (Houlihan et al., 2019). Additionally, this method has been used to evaluate the effectiveness of crossing structures intended to mitigate the barriers of linear infrastructure (e.g., Goldingay et al., 2013; Linden et al., 2020; Teixeira et al., 2013) and for monitoring nests and nest boxes (e.g., Aguiar-Silva et al., 2017; Kettel et al., 2016; Stojanovic et al., 2014). Studies evaluating the effectiveness of arboreal camera traps show that they are an effective tool for: 1) inventorying arboreal communities, 2) providing accurate estimates of species richness in the canopy, and 3) detecting species not identified by other survey methods (Bowler et al., 2017; Moore et al., 2020; Whitworth et al., 2016). However, only three studies (Bowler et al., 2017; Moore et al., 2020; Whitworth et al., 2019) measured occupancy of species to investigate trends and distributions over time, a common application of terrestrial camera trap studies.

3. Setting up an arboreal camera study

Many of the fundamental aspects of camera trap studies have been discussed extensively in the terrestrial literature and apply equally to the canopy (e.g., Burton et al., 2015; Rovero et al., 2013). However, arboreal camera trapping introduces two unique challenges: the third dimension of height and a potentially more complex sampling space. These factors can have ecological and practical implications for the study design and implementation, which, if not properly accounted for can lead to such consequences as increased costs, data loss, bias in the interpretation of the results, and/or a limited ability for the study to achieve its intended goals (Figure 3).

3.1 Ecological considerations

3.1.1 Camera placement: trade-offs between systematic approaches and maximising detection

Camera placement is critical in arboreal camera trap studies. Animal activity is often restricted to a particular movement pathway (e.g., a favoured branch or nesting site), to the extent that even placing the camera on the 'wrong' side of a tree trunk can result in missed observations. Important resources, such as food and shelter, may also be stratified across different heights. Consequently, cameras placed at one height may detect a different suite of species than cameras placed at another (Bowler et al., 2017; Laughlin et al., 2020; Whitworth et al., 2019). Similarly, different tree species provide different architecture for travel or differing availability of feeding resources that may influence wildlife detections. For example, preliminary work in northern Wisconsin, USA, comparing wildlife detections between two species of pine tree (*Pinus* spp.) that were immediately adjacent to one another and of similar height, showed much greater vertebrate diversity in one pine species over the other (E.R. Olson, pers. comm.). This means that arboreal camera trap studies may require a larger number of cameras than a terrestrial study in the same habitat, particularly if multiple cameras are required per tree. This may also explain why we found so few studies that investigated occupancy using arboreal camera traps, as these would require a larger number of cameras to collect sufficient data (Kays et al., 2020).

To maximise detection, cameras can be placed at identified "hotspots" of activity where detection probability will likely be higher. These may include important feeding resources, shelter sites, or movement pathways used by the target. For example, cameras placed in flowering trees improved detection of flying foxes in Malaysia (Aziz et al., 2017). Thinking about how an animal accesses the tree or resource can also help guide camera placement. For example, medium-large bodied rainforest mammals were more likely to be detected in trees with greater canopy connectivity (Whitworth et al., 2019) or branched bottlenecks over clearings (Gregory et al., 2017), while gliding species had higher detection rates when cameras were placed above the landing zone facing downward (e.g., Goldingay et al., 2019; Laughlin et al., 2020). Alternatively, bait may be used to attract species to positions where they can be more easily observed (Boulerice & Fleet, 2016; Harley et al., 2014; Kierulff et al., 2004).

However, sampling of hotspots introduces a challenge for all camera trapping studies; when detection probability is maximised, maintaining a standardized approach across sites, surveys, and even species can be difficult. Studies that aim to record a particular species or behaviour can adjust camera placement to optimise detection of that species. However, optimising placement at hotspots can inadvertently introduce bias into studies that aim to estimate species richness, occupancy, or habitat preferences. Ultimately, the most appropriate placement of cameras depends on the study question and must address the influence of height and habitat complexity on the detection of species. Heterogeneity in the positioning of cameras along, under, or perpendicular to branches and on branches of different diameter, length, and shape, as well as the placement of cameras at different heights, will introduce considerable variation in detection probabilities which need to be accounted for in statistical analyses (Bowler et al., 2017).

3.1.2 Camera settings for arboreal studies

The choice of camera model and settings can be critical to detecting species and identifying them from the resulting images. Many detection issues are not unique to arboreal studies and common camera recommendations apply here also, including: opting for low- and no-glow infrared flash rather than white flash so as not to cause fear and/or temporary blindness (particularly dangerous for arboreal species); opting for 'quiet' camera models that minimise disturbance; adjusting the sensitivity of the passive infrared (PIR) sensor to high or very-high to improve detection of fast-moving animals; enabling video recording for easier species and behaviour identification; and the use of time-lapse modes to improve detection of species that are often missed by PIR sensors, such as ectotherms (e.g., Droissart et al., 2021; Laughlin et al., 2017; Schipper, 2007).

Perhaps the most important consideration when trying to maximise detections in arboreal camera trap studies is placing the area of expected activity within the camera's PIR motion detection band. Camera traps are typically designed for terrestrial use, and therefore, the motion detection band(s) often lie in the lower portion of the field of view (Debruille et al., 2020). This means that cameras placed in arboreal settings risk inadvertently misaligning the detection band with the trunk, branch, or pathway of interest. For example, installing the camera pivoted 90° to one side (portrait position) can cause the PIR motion detection band to align with a branch, trunk, or timber pole, maximizing the time an animal spends in the detection band and thus maximizing detection (Harley et al., 2014). Camera technology is constantly evolving, and providing a detailed analysis of the specifications and settings pertinent to arboreal camera trapping is beyond the scope of this paper. We recommend that researchers familiarize themselves with camera specifications, PIR motion detection band locations, and setting options of their chosen camera model considering the issues discussed here and the needs of the study.

3.2 Practical challenges

3.2.1 Specialized skills and equipment are required

Placing and accessing arboreal camera traps usually requires specialized skills, equipment, and safety planning (Figure 4). Tree climbing is the most common method and can include expert free-climbing, rope climbing, use of tree stands, tree climbing spikes, pole climbing irons, or ladders. The first priority in selecting a location for placing an arboreal camera trap is evaluating the suitability and safety of the tree for access. For example, some tree species may be too small or brittle to support the weight of a climber, or they may be dangerous to climb because of insects that inhabit them. Local community members can often provide knowledge of dangers unique to a study area or tree species and should be consulted when possible. Tree climbing can be *extremely* dangerous and should only be conducted by trained, experience personnel using tested, updated equipment, and a well-designed safety protocol should be developed and implemented for any study (see Appendix 3 "Climbing protocols and safety").

There are a variety of other options for deploying arboreal cameras. In some cases, machinery such as elevated work platforms or bucket lifts can be used to access a site, particularly when cameras are placed at lower heights or in urban and roadside environments. It is also possible to deploy cameras without leaving the ground, using approaches such as the Orion Camera System (OCS; Méndez-Carvajal, 2014), in which a series of tubes and cables are used to manipulate a camera into place (Figure 4). Other systems such as the COPAS (Canopy Operating Permanent Access System; Gottsberger, 2017) or the Canopy Access Crane (Basset et al., 2003) involve installing fixed structures, such as towers, scaffolding, or cranes, in the forest to allow researchers access to the canopy (see Appendix 4 "Non-climbing methods").

The need for specialized climbing and access equipment (and maintenance of that equipment) means that arboreal camera trap studies may be more expensive than other survey approaches (Whitworth et al., 2016). For example, tree climbing to place arboreal cameras should always be done with multiple people with specialized skills, both for safety and logistical reasons (see Appendix 3 "Climbing protocols and safety"), and this necessarily results in an increased cost (~$950/person for a basic canopy access course, e.g., https://canopyaccess.co.uk/training/bcap/). It can also take more time to install arboreal camera traps than terrestrial cameras, particularly if access to the site is difficult, meaning that fewer cameras may be set per day. For example, placing a camera high (e.g., 30 m) in a dense canopy, on angled branches with lots of epiphytes, could take well over four hours, due to the time necessary to 1) traverse trails through dense vegetation carrying heavy climbing equipment to access the sampling location, 2) shoot and set a safe climbing line (typically with a slingshot), and 3) climb the tree, select a placement location, and place the camera on a branch while suspended from a rope (T. Gregory, pers. comm.). In studies of road-crossing structures where access is less complex, it took a full day to install four camera systems due to the need for traffic control, specialist plant operators, and strict road engineering safety guidelines (K. Soanes pers. comm., regarding Soanes et al. 2015). Therefore, it is important to consider additional costs and equipment necessary to complete an arboreal study during the planning and budgeting phases of the project.

3.2.2 Difficulties placing cameras

Having identified the best study design and camera placement method for the target species and research questions, researchers are likely to encounter practical limitations regarding their ability to achieve the desired set up. Suitable positions for cameras may not be available at the different heights required to investigate stratification, or the trees most likely to support the target species may be unsafe to climb or unsuitable for placement. Trees with complicated or angled branching architecture may force camera placement at unusual angles and orientations, potentially increasing interference and reducing detection rates. For example, upward-orientated cameras may produce over-exposed images due to glare from the sun or accumulated debris, snow, or water on the lens. Cameras orientated down or toward the tree trunk reduce over-exposure and unwanted triggers associated with wind movement in the branches, but they miss activity that occurs mainly on branches and are prone to condensation. Selecting for trees that allow easy placement (i.e., larger trunks, with regular, horizontal branching) can introduce biases into the study design that limit the ecological inference possible. Further, placing cameras in trees (or other structures) is typically difficult to do using straps or bungees provided with the camera at purchase (e.g., Bowler et al., 2017; Houlihan et al., 2019). A range of versatile, specialised mounting structures can be purchased or homemade to provide more secure placement that better aligns the camera with the focal point, thus maximizing detection (see Appendix 2, “A guide to camera mounts”).

3.2.3 Greater interference, reduced maintenance access

Arboreal cameras are more susceptible to interference and maintenance requirements than those placed on the ground. For example, tree leaves and branches moving in the wind can block the field of view or cause unwanted triggers, leading to missed observations and full memory cards (Gregory et al., 2014). Cameras placed at heights are also much more exposed to the sun, which can create detection problems where there is insufficient difference between the background temperature and the body temperature of passing vertebrates. Arboreal species are often agile, dexterous and curious, and may be more likely to interfere with and damage arboreally placed cameras. Some animals may find the cameras to be a convenient nesting substrate or a place to lay their eggs or sharpen their teeth (Gregory et al., 2015). Such manipulation can cause camera failure, structural damage, unwanted triggers, or changes in position, which can lead to data loss (see Appendix 5, "Managing animal interference with arboreal camera traps"). These factors are compounded by the fact that arboreally placed cameras are difficult to access, and therefore often left in the field for long periods of time (Figure 3). Unscheduled maintenance to deal with failures or damage can be beyond a budget's scope, meaning that researchers are simply unable to replace or repair the cameras during the life of the study.

3.3 Managing the challenges

The challenges of arboreal camera trap studies can introduce negative consequences and undesirable trade-offs, resulting in either an increased cost, compromised study design, reduced spatial extent, or data loss (Figure 3). However, these risks can be managed by being aware of the various decisions that need to be made and their potential consequences. We present a framework for thinking through the design of arboreal camera trap studies, including the key questions to ask, the potential trade-offs of different choices, and suggestions for each step of the process (Table 2). The overarching principle of this framework is that all decisions regarding the design and placement of cameras should be made with the study question firmly in mind. Careful placement of cameras and calculation of sampling sites needed, selecting settings that maximise detection of target species while minimizing unwanted triggers, and use of the optimal battery and memory card type, will all contribute to increased study success (Table 2). We also suggest research teams carry ample replacement equipment including cameras, mounts, batteries, memory cards, and placement (e.g., climbing) equipment into the field during each maintenance visit to allow issues to be resolved on the spot and to avoid expensive return trips or lost data.

Small-scale pilot tests are an invaluable way of exploring some of these issues. They allow researchers to become familiar with the performance of the camera system in a controlled environment. We encourage researchers to use pilot tests to experiment with the camera settings and sensitivity, orientations, and mounts, and to identify the limits of the battery life and storage capacity. For example, some authors of this paper have created prototype mounting structures in the office, used pets or cardboard cut-outs to explore the sensitivity settings and image quality, or left cameras in the yard for extended periods to time to determine how often field visits might be required to replace batteries and memory cards. Being familiar with the equipment and functions in this way will enable better decision-making when it comes to widespread deployment and prevent the expensive consequences of learning lessons “the hard way” in the field.

There are also several technological advances that are not yet widely used but may help address common challenges of arboreal camera trap studies. Cameras that have the capacity for wireless data transfer allow data access without the need to access cameras directly (e.g., Soanes et al., 2015). The status and function of cameras can also be remotely assessed, either through an online diagnostic or by programming the cameras to record regular “test” images (i.e., daily or twice daily time lapse images)—the absence of an image recorded at the designated time suggests the camera stopped functioning, allowing the researcher to determine survey effort and identify sites for repair or replacement. Depending on the location and power use requirements, these systems can be supported by larger batteries or solar panels to enable long-term deployment (Figure 4). While these approaches may not be practical in all contexts (e.g., insufficient light, lack of safe places to mount heavy equipment), they represent an opportunity for long-term data collection while reducing costs and safety risk of accessing sites regularly, and they will likely become more widespread as the technology develops. Automation of species identification can help deal with the excessive number of frames triggered by interference. For example, software such as Animal Scanner (Beery et al., 2019; Yousif et al., 2019) separates “empty” frames (i.e., those with no animals) from animal events, which can be helpful to process arboreal camera trap photographs more efficiently. If these AI tools are appropriately trained using arboreal camera trapping data, they could help reduce the time and cost required to process images.

4. The future of arboreal camera trapping

Arboreal camera trapping is a growing field and there are many opportunities to expand the method to further increase our knowledge of the species within the arboreal realm. Five key areas for future research include:

- *Behavioural studies:* A key strength of camera traps is their capacity to document behaviours and interactions that would be missed by other field methods. Our review identified many studies on behaviour, however there is still enormous untapped potential for this method (particularly video recording) to shed light on little known aspects of species ecology, such as their responses to disturbance, use of novel and artificial habitat structures, and general natural history knowledge.

- *Urban ecosystems*: Little is known about how arboreal species persist within urban environments. A better understanding of how species interact with novel structures and habitats, the potential threats that these interactions present to those species, and changes in behaviour that allow animals to adapt to urban living would dramatically improve conservation management.
- *Plants, ectotherms and invertebrates*: The bias towards the study of mammals in part reflects issues relating to detectability—animals that are very fast, small, or ectothermic are traditionally more difficult to detect using camera traps. However, recent advances in technology are widening the possibilities for such species, including the use of time-lapse, near-infrared light, and advanced camera settings, which allow variability in focal distance and frame rate, among others (Droissart et al., 2021; Laughlin et al., 2017).
- *New technologies*: Recent studies have explored the use of drone-mounted cameras and thermal imaging to inventory mammal species across large areas that would otherwise be difficult to access (Kays et al., 2019; McCarthy et al., 2021). Some research teams have also developed arboreal cameras for specific uses, such as recording pollination activity (Droissart et al., 2021). This system can record sharp images just 5 cm from the lens.
- *Community engagement*: Cameras are an opportunity to engage the public with a world that is otherwise out of reach. Researchers can take advantage of opportunity for public engagement in science and conservation through live-streamed webcams (e.g., The Cornell Lab Live Cams (https://www.allaboutbirds.org/cams/savannah-ospreys/)), making images and videos publicly available, or inviting participation in data analysis through citizen-science platforms (e.g., Zooniverse (https://www.zooniverse.org/), eMammal (https://emammal.si.edu/), Wildlife Spotter (https://scistarter.org/wildlife-spotter)).

5. Conclusion

With so much still to be learned about what Wilson & Moffett (1991) called "the last [biological] frontier" 30 years ago, arboreal camera traps have the potential to reveal many of the canopy's secrets. We have documented 90 studies using this method, but there is still much to be learned regarding the application of this ever-evolving method. This is the first attempt to provide evidenced-based recommendations for arboreal camera trap studies, review the challenges to consider and manage when planning a study, and identify future directions for this emerging method. Our synthesis provides a necessary foundation upon which future studies can build and works towards the development of standardized best practice approaches. In the terrestrial realm, standardization has permitted the synthesis of data across many projects, thus elucidating large scale (global) patterns and processes of interest (e.g., Kays et al., 2020). We hope that this will one day also be possible for arboreal camera trapping.

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Author Contributions

All authors conceived the ideas. JFM, KS, and TG led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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599 **Table 1.** Arboreal camera trap studies summarised by research focus.

Research Focus	Number of Studies	Taxa represented	Habitat types	Types of questions
Species behaviour	21	Mammals Birds Invertebrates Reptiles Amphibians Plants	Forest	How does the species use the canopy/habitat? What is the species' activity patterns? What are the species' postural behaviours? What is the species' feeding behaviour? What is used as a sleeping site? What are the predators of this species, and how are inter and intra-specific interactions characterized? What pollinates this species?
Species presence/richness/occupancy	19	Mammals Birds	Forest Agriculture Urban	Are the species(s) present in an area? How many species are there? What are the habitat preferences or environmental factors that influence presence? What is the occupancy or distribution of the species?
Movement/Corridor use	18	Mammals	Roadway Forest Agriculture	Are natural and artificial canopy bridges, glider poles, vegetated medians used by arboreal wildlife? Which designs best promote movement?
Nesting	15	Mammals Birds Reptiles Amphibians	Forest Cliff Face Urban	Was the nest successful? Which species are nest predators? What are the nesting species feeding upon? Are natural or artificial hollows used by this species?
Methods testing	15	Mammals Birds Insects Plants	Forest Grasslands	Which camera type is most effective? How should cameras be oriented? Does camera flash affect the species? How can we modify the camera use or setup to improve the detection rate? How can bait be used to increase detection rate?
Human activity	2	Mammals	Forest	Are species affected by forest fragmentation, degradation, or human disturbance?

Table 2. Arboreal species camera trapping study design process, with suggested considerations or necessary decisions under each main step.

Step	Questions to ask	Key trade-offs to consider	Suggestion
1. Study question	Do I need to detect multiple species (diversity) or a focal species? Estimating presence or relative abundance?	Systematic, homogenous sampling scheme improves estimates of abundance, but may miss important microhabitats. A focus on 'hotspots' of activity may improve detection but introduces bias.	Camera placement should maximise detection without compromising the study question.
2. Monitoring & maintenance plan	Number of locations to sample? Length of monitoring period? Frequency of maintenance?	The longer cameras are present in the field, the greater the need for maintenance to prevent data loss.	Budget for repeat visits and emergency maintenance.
3. Camera placement	On the ground, branches, trunk, or artificial structure? Height(s) of cameras? How should cameras be oriented? Where is the camera detection zone? Are there important resources or movement paths that may be hotspots? Could bait be used to attract animals to more easily accessible camera trapping locations? What are the sources of interference (leaves, sunlight, etc.) and how can they be managed?	Reducing sources of interference can inadvertently lead to reduced detections or introduce a detection bias (e.g. trimming leaves may disturb species). However, not managing them properly can result in a larger number of non-target stimulus frames, rapidly filling memory cards, and data loss.	Consider resources present, the potential for interspecific interactions, movement pathways, and the diversity of habitats and how they will affect detection.
4. Equipment & personnel needs	Camera type and number? Are camera mounts required and what type? Which access technique and is equipment required?	Certain study questions require more cameras (e.g. at various heights) and may result in fewer sites being surveyed due to budget constraints. The more difficult a site is to access, the greater the cost.	Consider the length of time, safety requirements, and need for additional specialized equipment when budgeting.
5. Camera settings & accessories	Photo, video, or both? Sensitivity camera setting? Battery type (lithium, alkaline, NiMH rechargeable)? Solar battery charging source? Memory card size?	Photos are easier to review, but videos help identify species and behaviours. Higher sensitivity results in more detections, but potentially more false triggers and processing time. Lithium batteries tend to last the longest, but they are more expensive and cannot be recharged.	Maximise battery life and memory storage when access will be infrequent.

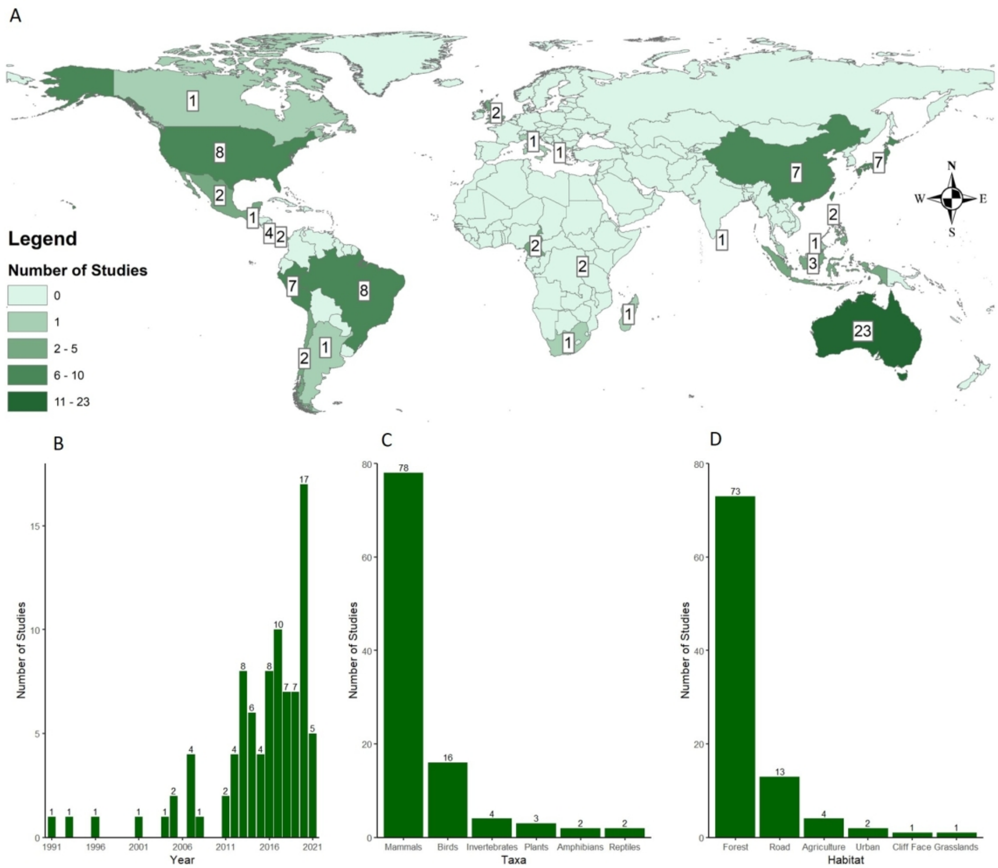

Figure 1: Studies using arboreal camera trapping method summarised by country (A), year of publication (B), focal taxa (C), and habitat type (D) based on data extracted from 90 peer-reviewed articles (Appendix 1).

340x301mm (150 x 150 DPI)

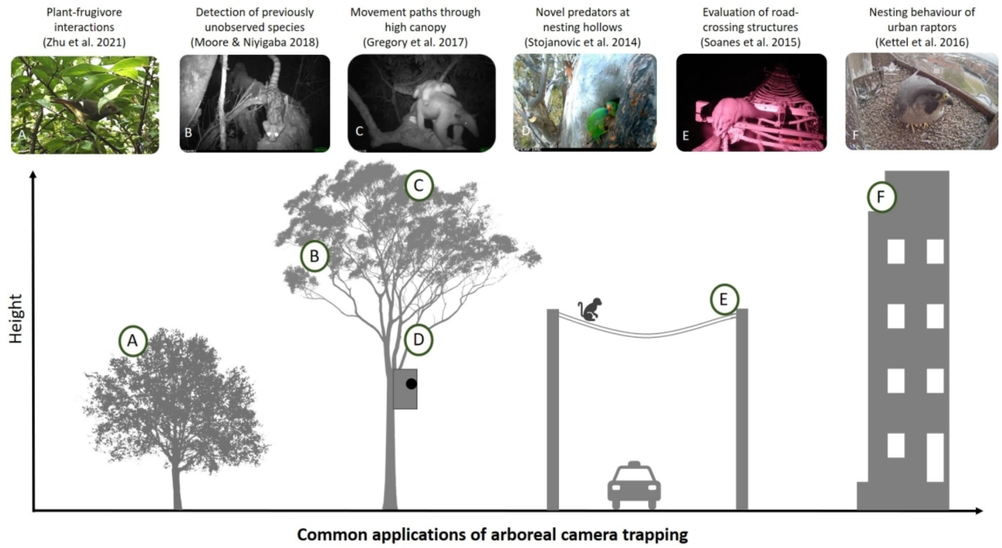

Figure 2. Examples of arboreal camera trap studies that illustrate the diversity of species, systems, and research questions to which the method can be successful applied. Photo credit: A – Chen Zhu, B – Wildlife Conservation Society, Rwanda Program, C – Smithsonian Conservation Biology Institute, D – Dejan Stojanovic, E – Kylie Soanes, F – Nick Moyes (Wikimedia commons CC 4.0).

337x187mm (150 x 150 DPI)

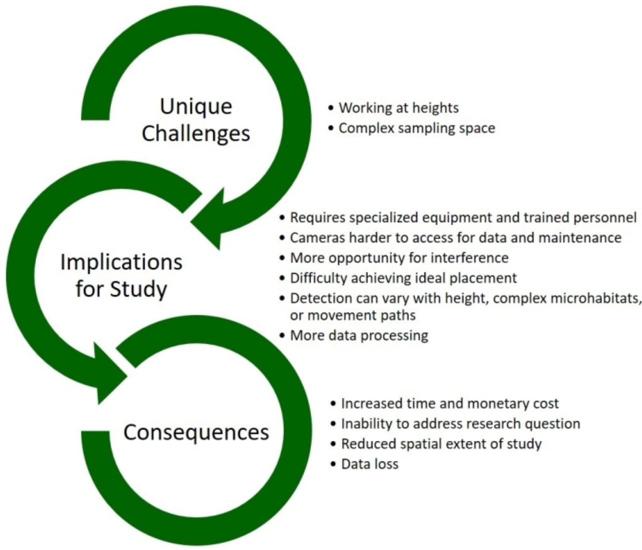

Figure 3. The two unique challenges of arboreal camera trapping, the implications for study design, and the consequences of mismanagement of these challenges.

268x150mm (150 x 150 DPI)

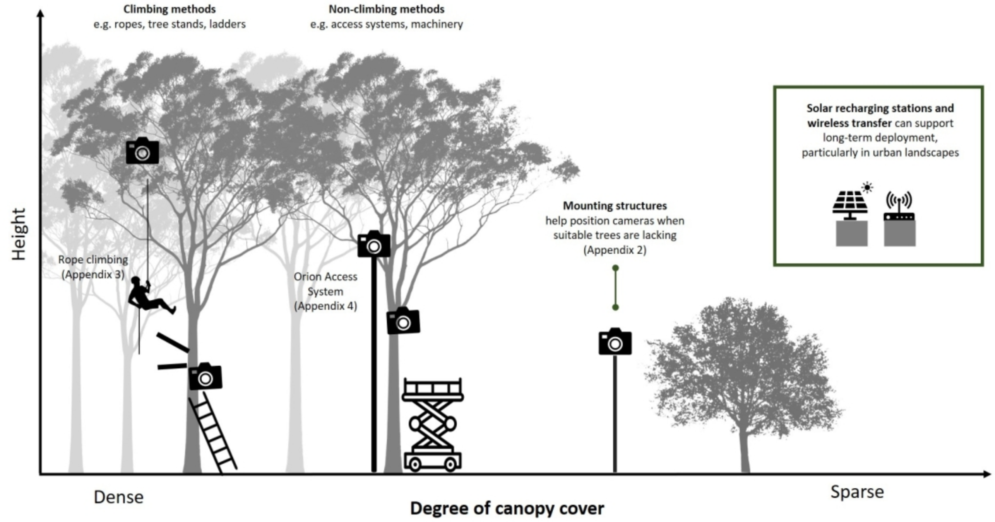

Figure 4. Arboreal camera traps may be placed using climbing or non-climbing methods. The choice of best method is usually determined by the height at which cameras need to be placed and the ease of access. Photo credit: the Noun Project (scissor lift icon)

317x169mm (150 x 150 DPI)