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### **The Potential and Practice of Arboreal Camera Trapping**

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## 66 **Abstract**

- 67  
68 1. Arboreal camera trapping is a burgeoning method providing a novel and effective technique  
69 to answer research questions across a variety of ecosystems, and it has the capacity to  
70 improve our understanding of a wide range of taxa. However, while terrestrial camera

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

91

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

#### 94 **Resumen**

95

- 96 1. El fototrampeo arbóreo es un método emergente que brinda una técnica nueva y efectiva para  
 97 responder a preguntas de investigación en una variedad de ecosistemas, y tiene la capacidad  
 98 de mejorar nuestra comprensión de una amplia gama de taxones. Sin embargo, mientras el  
 99 fototrampeo terrestre ha recibido mucha atención, existen pocas pautas sobre cómo lidiar con  
 100 los retos únicos de trabajar con cámaras en el ámbito arbóreo.
- 101 2. Nuestra revisión se basa en la experiencia de investigadores de seis continentes y en la  
 102 literatura en general para evaluar las ventajas y desventajas del fototrampeo arbóreo y los  
 103 retos a considerar al utilizar esta tecnología. También incluimos mini-guías con información  
 104 detallada sobre la literatura actual acerca del uso de cámaras trampa en los árboles, soportes  
 105 utilizados para colocar las cámaras trampa, indicaciones y consejos para trepar árboles y  
 106 acceder al dosel de manera segura, métodos para colocar las cámaras sin trepar y consejos  
 107 para el manejo de interferencia en el funcionamiento de la cámara.

- 108 3. Nuestro estudio concluye que el fototrampeo arbóreo ha sido mayormente utilizado para el  
 109 estudio de mamíferos en bosques. Sin embargo, esta metodología tiene el potencial de ser  
 110 utilizada en un amplio rango de hábitats, incluyendo áreas urbanas, y taxones como aves,  
 111 anfibios, invertebrados y plantas. Los métodos de fototrampeo arbóreo pueden mejorarse con  
 112 una mayor comprensión de los factores que afectan la detección de especies. Los retos más  
 113 comunes en el fototrampeo arbóreo son el acceso al sitio en el dosel donde se ubicará la  
 114 cámara y la instalación de la misma. Estos retos se pueden superar entendiendo cuál es el  
 115 mejor ángulo de orientación de la cámara, el manejo de las posibles fuentes de interferencia  
 116 que se ubiquen delante de las cámaras, utilizando soportes apropiados para las cámaras y  
 117 entrenando adecuadamente a los investigadores.
- 118 4. Dados los beneficios y las oportunidades presentados por el fototrampeo arbóreo, es probable  
 119 que se convierta en un método cada vez más popular para estudiar especies y sistemas  
 120 arbóreos. La información sintetizada en esta revisión proporciona una guía que ayudará a  
 121 futuros estudios a realizar inferencias ecológicas más confiables y sólidas en base al  
 122 fototrampeo arbóreo.

### 123 **Résumé**

- 124
- 125 1. Le piégeage photographique dans la couronne des arbres est une méthode en plein essor qui  
 126 offre une technique novatrice et efficace pour répondre à des questions de recherche pour une  
 127 variété d'écosystèmes, et permet d'améliorer notre compréhension d'une large diversité de  
 128 taxons. Cependant, alors que le piégeage photographique au sol a reçu une grande attention, il  
 129 y a peu de manuel pour répondre aux défis que posent les études dans le domaine de la  
 130 canopée.
- 131 2. Notre analyse repose sur l'expertise de chercheurs provenant de six continents et sur la  
 132 littérature générale pour étudier les avantages et désavantages du piégeage photographique en  
 133 canopée, mais aussi les défis à prendre en compte quand cette technologie est utilisée. Nous  
 134 intégrons des mini-guides contenant des informations détaillées de la littérature actuelle sur  
 135 les pièges photographiques et les supports utilisés en canopée, des conseils pour grimper en  
 136 toute sécurité aux arbres, les méthodes pour déployer ces appareils sans grimper et des  
 137 conseils pour limiter les interférences lors de leur fonctionnement.
- 138 3. Nous trouvons que les pièges photographiques en canopée ont été plus souvent utilisés pour  
 139 étudier les mammifères dans les forêts, cette méthode ayant cependant un potentiel pour un  
 140 large éventail d'habitats y compris les zones urbaines, et de taxons tels que les oiseaux, les  
 141 amphibiens, les invertébrés, et les plantes. Les méthodes de piégeage photographique en  
 142 canopée pourraient être optimisées en améliorant notre compréhension des facteurs qui  
 143 affectent la détection des espèces. Les défis les plus courants du piégeage photographique  
 144 sont le placement et l'accès au site de fixation des appareils. Ces problèmes peuvent être

145 surmontés en identifiant les orientations les plus adaptées pour les appareils, en limitant les  
 146 sources potentielles d'interférences devant les objectifs, en utilisant des supports appropriés  
 147 ainsi qu'en formant correctement les chercheurs.

148 4. Compte tenu des bénéfices et des opportunités que représente l'usage du piégeage  
 149 photographique en canopée, cette méthode est de plus en plus utilisée pour étudier les espèces  
 150 dans la canopée. Les informations synthétisées dans cette revue fournissent des indications  
 151 pour les études futures afin de permettre des déductions écologiques plus fiables et plus  
 152 solides à partir du piégeage photographique dans la couronne des arbres.

### 153 **Resumo**

154 1. As armadilhas fotográficas em dossel arbóreo é um método emergente que fornece uma  
 155 técnica nova e eficaz para responder a perguntas científicas em diversos ecossistemas e tem a  
 156 capacidade de melhorar nossa compreensão de uma ampla gama de *taxa*. No entanto, embora  
 157 o uso das armadilhas fotográficas terrestres tenha recebido muita atenção, existem poucas  
 158 diretrizes sobre como lidar com os desafios exclusivos de trabalhar com câmeras em um  
 159 ambiente arbóreo.

160 2. Nossa revisão baseia-se na experiência de pesquisadores de seis continentes e na literatura  
 161 geral para avaliar as vantagens e desvantagens das armadilhas fotográficas em árvores e os  
 162 desafios a serem considerados ao usar essa tecnologia. Também incluímos mini-guias com  
 163 informações detalhadas sobre a literatura atual sobre o uso de armadilhas fotográficas,  
 164 suportes usados para sua instalação, indicações e dicas para subir em árvores e acessar o  
 165 dossel com segurança, métodos para colocar câmeras sem escalar e dicas para manejo de  
 166 interferências na operação da câmera.

167 3. Nosso estudo conclui que as armadilhas fotográficas em dosséis arbóreos têm sido utilizadas  
 168 principalmente para o estudo de mamíferos em florestas. No entanto, essa metodologia tem  
 169 potencial para ser usada em uma ampla gama de habitats, incluindo áreas urbanas, e *taxa*  
 170 como aves, anfíbios, invertebrados e plantas. Os métodos podem ser aprimorados com uma  
 171 maior compreensão dos fatores que afetam a detecção de espécies. Os desafios mais comuns  
 172 no uso das armadilhas fotográficas em árvores são o acesso ao local onde a câmera estará  
 173 localizada no dossel, e a própria instalação destas câmeras. Esses desafios podem ser  
 174 superados compreendendo o melhor ângulo de orientação da câmera, gerenciando fontes  
 175 potenciais de interferência na frente das câmeras, usando suportes de câmera apropriados e  
 176 treinando adequadamente os pesquisadores.

177 4. Dados os benefícios e oportunidades apresentados pelo uso das armadilhas fotográficas em  
 178 árvores, é provável que se torne um método cada vez mais popular de estudar espécies e  
 179 sistemas arbóreos. As informações sintetizadas nesta revisão fornecem orientações que  
 180 ajudarão estudos futuros a fazer inferências ecológicas mais confiáveis e robustas com base  
 181 no uso desta técnica.

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## 摘要

1. 作为一种新兴的技术方法，树栖红外相机为我们探究多种生态系统中的科学问题提供了有效的技术支持，可以进一步加深我们对广大生物类群的理解。然而，相比广泛应用的地面相机监测技术，我们依旧缺乏对于解决树栖红外相机应用相关问题的指导方针。
2. 通过综述来自六大洲研究人员的专业技术知识和广泛的文献，我们分析了树栖红外相机的优缺点及其实际应用中面临的问题和挑战。同时基于现有文献信息，我们撰写了树栖红外相机使用的迷你指南，包括安装和固定相机的装置、爬树技巧和安全提示、无需攀爬部署相机的方法和解决干扰使相机正常工作的技巧。
3. 结果发现树栖红外相机经常用于森林哺乳动物的研究，但这种方法仍有其他潜在的应用，如可应用于城市地区等的各种动物栖息地，可应用于包括鸟类、两栖动物、无脊椎动物和植物等多种生物类群。通过进一步了解影响物种检测率的因素，可以改进关于树栖红外相机的研究方法。树栖红外相机应用中最常见的挑战是相机的布置和相机位点的访问。这些问题可以通过确定正确的相机方向、处理相机镜头前的潜在干扰因素、使用合适的安装和固定装置及培训当地的研究人员来解决。
4. 鉴于树栖红外相机的优点和所带来的机遇，它很可能会成为研究树栖物种和生态系统更流行的技术方法。这篇综述提供的各种信息为未来相关研究提供了指导，将有助于从树栖红外相机研究中获得更可靠和稳健的生态推论。

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## 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; Trollet 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

210 al., 2011; Noss et al., 2004), and documented new species interactions and behaviours (e.g., Rowcliffe  
211 et al., 2014). However, this powerful technique has only just begun to be applied to the study of  
212 arboreal species and systems. Arboreal taxa are disproportionately impacted by habitat loss, forest  
213 fragmentation, and other anthropogenic activities (Whitworth et al., 2019). An increased uptake of  
214 methods that provide greater insight into the interactions between arboreal species and their  
215 environments will therefore contribute to better conservation outcomes.

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

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

238

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

240 Arboreal camera trapping is the use of camera traps placed above the ground to study arboreal  
241 or semi-arboreal species or systems. It often involves the placement of cameras at heights, requiring  
242 the ascent of a tree or structure (e.g., buildings). For this review, we searched the peer-reviewed  
243 literature to develop a database of studies that have used arboreal camera trapping. Because the goal  
244 was to identify the breadth of the relevant literature, our search methods were purposive, rather than  
245 systematic. We used the following search terms: “arboreal”, “canopy”, “wildlife”, “camera”, “camera  
246 trap” in databases such as Scopus, Google Scholar, and ResearchGate to identify relevant studies. We

247 also examined the reference section of these studies and review papers to identify any further  
 248 literature. For each study, we extracted information on the primary research focus, focal taxa, habitat  
 249 type, height of camera placement, country of study, and year of publication.

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

263 Much like terrestrial camera trapping, arboreal cameras trapping studies have spanned a  
 264 broad range of research foci: species behaviour, species richness and presence, movement and  
 265 corridor use, nesting, methods testing, and the impacts of human activity (Table 1). This diversity of  
 266 research foci, focal taxa, and habitat type illustrates the capacity of arboreal camera trap studies to  
 267 provide valuable ecological insights into a wide variety of systems (Figure 2). Arboreal camera traps  
 268 have proven particularly valuable in recording the presence of rare or elusive species (e.g., Fang et al.,  
 269 2020; Geyle et al., 2020; Moore & Niyigaba, 2018), little-known behaviours (e.g., Dalloz et al., 2012;  
 270 Laughlin et al., 2017; Mella et al., 2018), and inter-specific interactions (e.g., Saeki et al., 2020;  
 271 Schruhl et al., 2012; Zhu et al., 2021) that would otherwise be difficult to observe in the canopy. For  
 272 example, cameras placed in the Ankeniheny–Zahamena rainforest corridor in eastern Madagascar  
 273 validated the presence of the critically endangered greater bamboo lemur *Prolemur simus* (Olson et  
 274 al., 2012), and the first documentation of the pollinator community of the endangered and epiphytic  
 275 ghost orchid (*Dendrophylax lindenii*) in Florida’s Everglades Basin was made by cameras (Houlihan  
 276 et al., 2019). Additionally, this method has been used to evaluate the effectiveness of crossing  
 277 structures intended to mitigate the barriers of linear infrastructure (e.g., Goldingay et al., 2013; Linden  
 278 et al., 2020; Teixeira et al., 2013) and for monitoring nests and nest boxes (e.g., Aguiar-Silva et al.,  
 279 2017; Kettel et al., 2016; Stojanovic et al., 2014). Studies evaluating the effectiveness of arboreal  
 280 camera traps show that they are an effective tool for: 1) inventorying arboreal communities, 2)  
 281 providing accurate estimates of species richness in the canopy, and 3) detecting species not identified  
 282 by other survey methods (Bowler et al., 2017; Moore et al., 2020; Whitworth et al., 2016). However,  
 283 only three studies (Bowler et al., 2017; Moore et al., 2020; Whitworth et al., 2019) measured

284 occupancy of species to investigate trends and distributions over time, a common application of  
 285 terrestrial camera trap studies.

286

### 287 **3. Setting up an arboreal camera study**

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

#### 295 **3.1 Ecological considerations**

##### 296 *3.1.1 Camera placement: trade-offs between systematic approaches and maximising detection*

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

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

321 attract species to positions where they can be more easily observed (Boulerice & Fleet, 2016; Harley  
322 et al., 2014; Kierulff et al., 2004).

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

### 334 *3.1.2 Camera settings for arboreal studies*

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

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

### 357 **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

394 al. 2015). Therefore, it is important to consider additional costs and equipment necessary to complete  
 395 an arboreal study during the planning and budgeting phases of the project.

### 396 *3.2.2 Difficulties placing cameras*

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

### 414 *3.2.3 Greater interference, reduced maintenance access*

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

## 430 **3.3 Managing the challenges**

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

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

455 There are also several technological advances that are not yet widely used but may help  
456 address common challenges of arboreal camera trap studies. Cameras that have the capacity for  
457 wireless data transfer allow data access without the need to access cameras directly (e.g., Soanes et  
458 al., 2015). The status and function of cameras can also be remotely assessed, either through an online  
459 diagnostic or by programming the cameras to record regular “test” images (i.e., daily or twice daily  
460 time lapse images)—the absence of an image recorded at the designated time suggests the camera  
461 stopped functioning, allowing the researcher to determine survey effort and identify sites for repair or  
462 replacement. Depending on the location and power use requirements, these systems can be supported  
463 by larger batteries or solar panels to enable long-term deployment (Figure 4). While these approaches  
464 may not be practical in all contexts (e.g., insufficient light, lack of safe places to mount heavy  
465 equipment), they represent an opportunity for long-term data collection while reducing costs and  
466 safety risk of accessing sites regularly, and they will likely become more widespread as the  
467 technology develops. Automation of species identification can help deal with the excessive number of

468 frames triggered by interference. For example, software such as Animal Scanner (Beery et al., 2019;  
 469 Yousif et al., 2019) separates “empty” frames (i.e., those with no animals) from animal events, which  
 470 can be helpful to process arboreal camera trap photographs more efficiently. If these AI tools are  
 471 appropriately trained using arboreal camera trapping data, they could help reduce the time and cost  
 472 required to process images.

473

#### 474 **4. The future of arboreal camera trapping**

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

- 478 • *Behavioural studies*: A key strength of camera traps is their capacity to document behaviours  
 479 and interactions that would be missed by other field methods. Our review identified many  
 480 studies on behaviour, however there is still enormous untapped potential for this method  
 481 (particularly video recording) to shed light on little known aspects of species ecology, such as  
 482 their responses to disturbance, use of novel and artificial habitat structures, and general  
 483 natural history knowledge.
- 484 • *Urban ecosystems*: Little is known about how arboreal species persist within urban  
 485 environments. A better understanding of how species interact with novel structures and  
 486 habitats, the potential threats that these interactions present to those species, and changes in  
 487 behaviour that allow animals to adapt to urban living would dramatically improve  
 488 conservation management.
- 489 • *Plants, ectotherms and invertebrates*: The bias towards the study of mammals in part reflects  
 490 issues relating to detectability—animals that are very fast, small, or ectothermic are  
 491 traditionally more difficult to detect using camera traps. However, recent advances in  
 492 technology are widening the possibilities for such species, including the use of time-lapse,  
 493 near-infrared light, and advanced camera settings, which allow variability in focal distance  
 494 and frame rate, among others (Droissart et al., 2021; Laughlin et al., 2017).
- 495 • *New technologies*: Recent studies have explored the use of drone-mounted cameras and  
 496 thermal imaging to inventory mammal species across large areas that would otherwise be  
 497 difficult to access (Kays et al., 2019; McCarthy et al., 2021). Some research teams have also  
 498 developed arboreal cameras for specific uses, such as recording pollination activity (Droissart  
 499 et al., 2021). This system can record sharp images just 5 cm from the lens.
- 500 • *Community engagement*: Cameras are an opportunity to engage the public with a world that is  
 501 otherwise out of reach. Researchers can take advantage of opportunity for public engagement  
 502 in science and conservation through live-streamed webcams (e.g., The Cornell Lab Live  
 503 Cams (<https://www.allaboutbirds.org/cams/savannah-ospreys/>)), making images and videos

504 publicly available, or inviting participation in data analysis through citizen-science platforms  
 505 (e.g., Zooniverse (<https://www.zooniverse.org/>), eMammal (<https://emammal.si.edu/>),  
 506 Wildlife Spotter (<https://scistarter.org/wildlife-spotter>)).

## 507 **5. Conclusion**

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

519

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526

## 527 **Author Contributions**

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

530

## 531 **Conflict of Interest**

532 We have no conflict of interest to declare.

533

## 534 **Data Availability**

535 Data used to create Figure 1 were gathered from literature summarized in Appendix 1.

## 536 **References**

537 Aguiar-Silva, F. H., Jaudoin, O., Sanaiotti, T. M., Seixas, G. H. F., Duleba, S., & Martins, F.  
 538 D. (2017). Camera Trapping at Harpy Eagle Nests: Interspecies Interactions Under

- 539 Predation Risk. *Journal of Raptor Research*, 51(1), 72–78.  
 540 <https://doi.org/10.3356/JRR-15-58.1>
- 541 Ahumada, J. A., Silva, C. E. F., Gajapersad, K., Hallam, C., Hurtado, J., Martin, E.,  
 542 McWilliam, A., Mugerwa, B., O'Brien, T., Rovero, F., Sheil, D., Spironello, W. R.,  
 543 Winarni, N., & Andelman, S. J. (2011). Community structure and diversity of tropical  
 544 forest mammals: Data from a global camera trap network. *Philosophical Transactions*  
 545 *of the Royal Society B: Biological Sciences*, 366(1578), 2703–2711.  
 546 <https://doi.org/10.1098/rstb.2011.0115>
- 547 Aziz, S. A., Clements, G. R., McConkey, K. R., Sritongchuay, T., Pathil, S., Yazid, M. N. H.  
 548 A., Campos-Arceiz, A., Forget, P.-M., & Bumrungsri, S. (2017). Pollination by the  
 549 locally endangered island flying fox (*Pteropus hypomelanus*) enhances fruit  
 550 production of the economically important durian (*Durio zibethinus*). *Ecology and*  
 551 *Evolution*, 7(21), 8670–8684. <https://doi.org/10.1002/ece3.3213>
- 552 Basset, Y., Horlyck, V., & Wright, S. J. (2003). *Studying forest canopies from above: The*  
 553 *international canopy crane network*. (p. 196). Smithsonian Tropical Research Institute  
 554 and UNEP.
- 555 Beery, S., Morris, D., Yang, S., Simon, M., Norouzzadeh, A., & Joshi, N. (2019). Efficient  
 556 Pipeline for Automating Species ID in new Camera Trap Projects. *Biodiversity*  
 557 *Information Science and Standards*, 3, e37222. <https://doi.org/10.3897/biss.3.37222>
- 558 Boulterice, J. T., & Fleet, L. A. V. (2016). A novel technique for detecting northern flying  
 559 squirrels. *Wildlife Society Bulletin*, 40(4), 786–791. <https://doi.org/10.1002/wsb.701>
- 560 Bowler, M. T., Tobler, M. W., Endress, B. A., Gilmore, M. P., & Anderson, M. J. (2017).  
 561 Estimating mammalian species richness and occupancy in tropical forest canopies  
 562 with arboreal camera traps. *Remote Sensing in Ecology and Conservation*, 3(3), 146–  
 563 157. <https://doi.org/10.1002/rse2.35>
- 564 Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Bayne, E., &  
 565 Boutin, S. (2015). REVIEW: Wildlife camera trapping: a review and  
 566 recommendations for linking surveys to ecological processes. *Journal of Applied*  
 567 *Ecology*, 52(3), 675–685. <https://doi.org/10.1111/1365-2664.12432>
- 568 Carthew, S. M., & Slater, E. (1991). Monitoring Animal Activity with Automated  
 569 Photography. *The Journal of Wildlife Management*, 55(4), 689–692.  
 570 <https://doi.org/10.2307/3809519>
- 571 Cove, M. V., Pardo, V., Spínola, R. M., Jackson, V. L., & Sáenz, J. C. (2011). Coyote *Canis*  
 572 *latrans* (Carnivora: Canidae) range extension in northeastern Costa Rica: possible

- 573 explanations and consequences. *Revista Latinoamericana de Conservación*, 2(2), 82–  
574 86.
- 575 Dalloz, M. F., Loretto, D., Papi, B., Cobra, P., & Vieira, M. V. (2012). Positional behaviour  
576 and tail use by the bare-tailed woolly opossum *Caluromys philander*  
577 (*Didelphimorphia*, *Didelphidae*). *Mammalian Biology*, 77(5), 307–313.  
578 <https://doi.org/10.1016/j.mambio.2012.03.001>
- 579 Debrulle, A., Kayser, P., Veron, G., Vergniol, M., & Perrigon, M. (2020). Improving the  
580 detection rate of binturongs (*Arctictis binturong*) in Palawan Island, Philippines,  
581 through the use of arboreal camera-trapping. *Mammalia*, 1(ahead-of-print).  
582 <https://doi.org/10.1515/mammalia-2019-0113>
- 583 Droissart, V., Azandi, L., Onguene, E. R., Savignac, M., Smith, T. B., & Deblauwe, V.  
584 (2021). PICT: A low cost, modular, open-source camera trap system to study plant-  
585 insect interactions. *Methods in Ecology and Evolution*. [https://doi.org/10.1111/2041-](https://doi.org/10.1111/2041-210X.13618)  
586 [210X.13618](https://doi.org/10.1111/2041-210X.13618)
- 587 Fang, Y., Li, Y., Ren, G., Huang, Z., Cui, L., Zhang, L., Garber, P. A., Pan, R., & Xiao, W.  
588 (2020). The effective use of camera traps to document the northernmost distribution  
589 of the western black crested gibbon in China. *Primates*, 61(2), 151–158.  
590 <https://doi.org/10.1007/s10329-019-00774-5>
- 591 Fleming, P., Meek, P., Banks, P., Ballard, G., Claridge, A., Sanderson, J., & Swann, D.  
592 (2014). *Camera Trapping: Wildlife Management and Research*. Csiro Publishing.
- 593 Geyle, H. M., Woolley, L., Davies, H. F., Woinarski, J. C. Z., Murphy, B. P., Geyle, H. M.,  
594 Woolley, L., Davies, H. F., Woinarski, J. C. Z., & Murphy, B. P. (2020). Targeted  
595 sampling successfully detects the cryptic and declining arboreal marsupial  
596 (*Phascogale pirata*) in northern Australia. *Pacific Conservation Biology*, 26(4), 395–  
597 403. <https://doi.org/10.1071/PC20008>
- 598 Goldingay, R. L., Rohweder, D., & Taylor, B. D. (2013). Will arboreal mammals use rope-  
599 bridges across a highway in eastern Australia? *Australian Mammalogy*, 35(1), 30–38.  
600 <https://doi.org/10.1071/AM12006>
- 601 Goldingay, R. L., Taylor, B. D., Parkyn, J. L., Goldingay, R. L., Taylor, B. D., & Parkyn, J.  
602 L. (2019). Use of tall wooden poles by four species of gliding mammal provides  
603 further proof of concept for habitat restoration. *Australian Mammalogy*, 41(2), 255–  
604 261. <https://doi.org/10.1071/AM18008>

- 605 Gottsberger, G. (2017). Canopy Operation Permanent Access System: A novel tool for  
 606 working in the canopy of tropical forests: history, development, technology and  
 607 perspectives. *Trees*, 31(3), 791–812. <https://doi.org/10.1007/s00468-016-1515-1>
- 608 Gregory, T., Carrasco-Rueda, F., Alonso, A., Kolowski, J., & Deichmann, J. L. (2017).  
 609 Natural canopy bridges effectively mitigate tropical forest fragmentation for arboreal  
 610 mammals. *Scientific Reports*, 7(1), 3892. <https://doi.org/10.1038/s41598-017-04112-x>
- 611 Gregory, T., Lunde, D., Zamora-Meza, H. T., & Carrasco-Rueda, F. (2015). Records of  
 612 *Coendou ichillus* (Rodentia, Erethizontidae) from the lower urubamba region of Peru.  
 613 *ZooKeys*, 509, 109.
- 614 Gregory, T., Rueda, F. C., Deichmann, J., Kolowski, J., & Alonso, A. (2014). Arboreal  
 615 camera trapping: Taking a proven method to new heights. *Methods in Ecology and*  
 616 *Evolution*, 5(5), 443–451. <https://doi.org/10.1111/2041-210X.12177>
- 617 Harley, D. K., Holland, G. J., Hradsky, B. A. K., & Antrobus, J. S. (2014). The use of camera  
 618 traps to detect arboreal mammals: Lessons from targeted surveys for the cryptic  
 619 Leadbeater's Possum *Gymnobelideus leadbeateri*. *Camera Trapping: Wildlife*  
 620 *Management and Research*, 233–243.
- 621 Houlihan, P. R., Stone, M., Clem, S. E., Owen, M., & Emmel, T. C. (2019). Pollination  
 622 ecology of the ghost orchid (*Dendrophylax lindenii*): A first description with new  
 623 hypotheses for Darwin's orchids. *Scientific Reports*, 9(1), 1–10.
- 624 Kays, R., Arbogast, B. S., Baker-Whatton, M., Beirne, C., Boone, H. M., Bowler, M.,  
 625 Burneo, S. F., Cove, M. V., Ding, P., & Espinosa, S. (2020). An empirical evaluation  
 626 of camera trap study design: How many, how long and when? *Methods in Ecology*  
 627 *and Evolution*, 11(6), 700–713.
- 628 Kays, R., Sheppard, J., Mclean, K., Welch, C., Paunescu, C., Wang, V., Kravit, G., &  
 629 Crofoot, M. (2019). Hot monkey, cold reality: Surveying rainforest canopy mammals  
 630 using drone-mounted thermal infrared sensors. *International Journal of Remote*  
 631 *Sensing*, 40(2), 407–419. <https://doi.org/10.1080/01431161.2018.1523580>
- 632 Kettel, E. F., Gentle, L. K., & Yarnell, R. W. (2016). Evidence of an Urban Peregrine Falcon  
 633 (*Falco peregrinus*) Feeding Young at Night. *Journal of Raptor Research*, 50(3), 321–  
 634 323. <https://doi.org/10.3356/JRR-16-13.1>
- 635 Kierulff, M. C. M., Canale, G., Guidorizzi, C. E., & Cassano, C. (2004). The use of camera-  
 636 traps in a survey of the Buff-headed capuchin monkey, *Cebus xanthosternos*.  
 637 *Neotropical Primates*, 4.

- 638 Laughlin, M. M., Martin, J. G., & Olson, E. R. (2020). Arboreal Camera Trapping Reveals  
 639 Seasonal Behaviors of *Peromyscus* spp. in *Pinus strobus* Canopies. *The American*  
 640 *Midland Naturalist*, 183(2), 210–222. <https://doi.org/10.1637/0003-0031-183.2.210>
- 641 Laughlin, M. M., Olson, E. R., & Martin, J. G. (2017). Arboreal camera trapping expands  
 642 *Hyla versicolor complex* (Hylidae) canopy use to new heights. *Ecology*, 98(8), 2221–  
 643 2223.
- 644 Linden, B., Foord, S., Horta-Lacueva, Q. J. B., & Taylor, P. J. (2020). Bridging the gap: How  
 645 to design canopy bridges for arboreal guenons to mitigate road collisions. *Biological*  
 646 *Conservation*, 246, 108560. <https://doi.org/10.1016/j.biocon.2020.108560>
- 647 McCarthy, E. D., Martin, J. M., Boer, M. M., & Welbergen, J. A. (2021). Drone-based  
 648 thermal remote sensing provides an effective new tool for monitoring the abundance  
 649 of roosting fruit bats. *Remote Sensing in Ecology and Conservation*.  
 650 <https://doi.org/10.1002/rse2.202>
- 651 Mella, V. S. A., McArthur, C., Friend, R., & Crowther, M. S. (2018). Foxes in trees: A threat  
 652 for Australian arboreal fauna? *Australian Mammalogy*, 40(1), 103–105.  
 653 <https://doi.org/10.1071/AM16049>
- 654 Méndez-Carvajal, P. G. (2014). The orion camera system, a new method for deploying  
 655 camera traps in tree canopy to study arboreal primates and others mammals: A case  
 656 study in Panama. *Mesoamericana*, 18(1), 9–23.
- 657 Moore, J. F., & Niyigaba, P. (2018). First records of the Central African oyan (*Poiana*  
 658 *richardsonii*) in Rwanda. *African Journal of Ecology*, 56(4), 828–830.  
 659 <https://doi.org/10.1111/aje.12576>
- 660 Moore, J. F., Pine, W. E., Mulindahabi, F., Niyigaba, P., Gatorano, G., Masozera, M. K., &  
 661 Beaudrot, L. (2020). Comparison of species richness and detection between line  
 662 transects, ground camera traps, and arboreal camera traps. *Animal Conservation*,  
 663 23(5). <https://doi.org/10.1111/acv.12569>
- 664 Noss, A. J., Pena, R., & Rumiz, D. I. (2004). Camera trapping *Priodontes maximus* in the dry  
 665 forests of Santa Cruz, Bolivia. *Endangered Species Update*, 21(2), 43–53.
- 666 O'Connell, A. F., Nichols, J. D., & Karanth, K. U. (2010). *Camera Traps in Animal Ecology:*  
 667 *Methods and Analyses*. Springer Science & Business Media.
- 668 Olson, E. R., Marsh, R. A., Bovard, B. N., Randrianarimanana, H. L. L., Ravaloharimanitra,  
 669 M., Ratsimbazafy, J. H., & King, T. (2012). Arboreal camera trapping for the  
 670 Critically Endangered greater bamboo lemur *Prolemur simus*. *Oryx*, 46(04), 593–597.  
 671 <https://doi.org/10.1017/S0030605312000488>

- 672 Rovero, F., Rathbun, G. B., Perkin, A., Jones, T., Ribble, D. O., Leonard, C., Mwakisoma, R.  
 673 R., & Doggart, N. (2008). A new species of giant sengi or elephant-shrew (genus  
 674 Rhynchocyon) highlights the exceptional biodiversity of the Udzungwa Mountains of  
 675 Tanzania. *Journal of Zoology*, 274(2), 126–133. <https://doi.org/10.1111/j.1469-7998.2007.00363.x>
- 677 Rovero, F., Zimmermann, F., Berzi, D., & Meek, P. (2013). “Which camera trap type and  
 678 how many do I need?” A review of camera features and study designs for a range of  
 679 wildlife research applications. *Hystrix, the Italian Journal of Mammalogy*, 24(2),  
 680 148–156. <https://doi.org/10.4404/hystrix-24.2-8789>
- 681 Rowcliffe, J. M., Kays, R., Kranstauber, B., Carbone, C., & Jansen, P. A. (2014). Quantifying  
 682 levels of animal activity using camera trap data. *Methods in Ecology and Evolution*,  
 683 5(11), 1170–1179. <https://doi.org/10.1111/2041-210X.12278>
- 684 Saeki, I., Niwa, S., Osada, N., Azuma, W., & Hiura, T. (2020). Contrasting effects of  
 685 urbanization on arboreal and ground-dwelling land snails: Role of trophic interactions  
 686 and habitat fragmentation. *Urban Ecosystems*, 1–12.
- 687 Schipper, J. (2007). Camera-trap avoidance by Kinkajous *Potos flavus*: Rethinking the “non-  
 688 invasive” paradigm. *Small Carnivore Conservation*, 36, 38–41.
- 689 Schruhl, D., Beus, T., Abel, T., Medler, M., Arce, A., & Mork, K. (2012). Macaw Cam:  
 690 Exploratory Camera Trap Techniques for Monitoring and Conservation of Scarlet  
 691 Macaw (*Ara macao*) Nests. *Huxley Spatial Institute, Working Paper 01-2012*.  
 692 [https://cedar.wvu.edu/hcop\\_facpubs/16](https://cedar.wvu.edu/hcop_facpubs/16)
- 693 Soanes, K., Vesk, P. A., & Ree, R. van der. (2015). Monitoring the use of road-crossing  
 694 structures by arboreal marsupials: Insights gained from motion-triggered cameras and  
 695 passive integrated transponder (PIT) tags. *Wildlife Research*, 42(3), 241–256.  
 696 <https://doi.org/10.1071/WR14067>
- 697 Stojanovic, D., Webb, M. H., Alderman, R., Porfirio, L. L., & Heinsohn, R. (2014).  
 698 Discovery of a novel predator reveals extreme but highly variable mortality for an  
 699 endangered migratory bird. *Diversity and Distributions*, 20(10), 1200–1207.  
 700 <https://doi.org/10.1111/ddi.12214>
- 701 Teixeira, F. Z., Printes, R. C., Fagundes, J. C. G., Alonso, A. C., & Kindel, A. (2013).  
 702 Canopy bridges as road overpasses for wildlife in urban fragmented landscapes. *Biota*  
 703 *Neotropica*, 13(1), 117–123. <https://doi.org/10.1590/S1676-06032013000100013>
- 704 Tobler, M. W., Hartley, A. Z., Carrillo-Percestequi, S. E., & Powell, G. V. N. (2015).  
 705 Spatiotemporal hierarchical modelling of species richness and occupancy using

- 706 camera trap data. *Journal of Applied Ecology*, 52(2), 413–421.  
707 <https://doi.org/10.1111/1365-2664.12399>
- 708 Trolliet, F., Huynen, M.-C., Vermeulen, C., & Hambuckers, A. (2014). Use of camera traps  
709 for wildlife studies. A review. *Biotechnol. Agron. Soc. Environ.*, 9.
- 710 Whitworth, A., Beirne, C., Pillco Huarcaya, R., Whittaker, L., Serrano Rojas, S. J., Tobler,  
711 M. W., & MacLeod, R. (2019). Human disturbance impacts on rainforest mammals  
712 are most notable in the canopy, especially for larger-bodied species. *Diversity and*  
713 *Distributions*. <https://doi.org/10.1111/ddi.12930>
- 714 Whitworth, A., Braunholtz, L. D., Huarcaya, R. P., MacLeod, R., & Beirne, C. (2016). Out  
715 on a Limb: Arboreal Camera Traps as an Emerging Methodology for Inventorying  
716 Elusive Rainforest Mammals. *Tropical Conservation Science*, 9(2), 675–698.  
717 <https://doi.org/10.1177/194008291600900208>
- 718 Wilson, E. O., & Moffett, M. W. (1991). Rain forest canopy: The high frontier. El dosel del  
719 bosque lluvioso: la frontera alta. *Natl. Geogr*, 180, 79–107.
- 720 Yousif, H., Yuan, J., Kays, R., & He, Z. (2019). Animal Scanner: Software for classifying  
721 humans, animals, and empty frames in camera trap images. *Ecology and Evolution*,  
722 9(4), 1578–1589.
- 723 Zhu, C., Li, W., Wang, D., Ding, P., & Si, X. (2021). Plant–frugivore interactions revealed by  
724 arboreal camera trapping. *Frontiers in Ecology and the Environment*, 19(3), 149–151.  
725 <https://doi.org/10.1002/fee.2321>

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

Research Focus	Number of Studies	Taxa represented	Habitat types	Types of questions
<b>Species behaviour</b>	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?
<b>Species presence/richness/occupancy</b>	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?
<b>Movement/Corridor use</b>	18	Mammals	Roadway Forest Agriculture	Are natural and artificial canopy bridges, glider poles, vegetated medians used by arboreal wildlife? Which designs best promote movement?
<b>Nesting</b>	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?

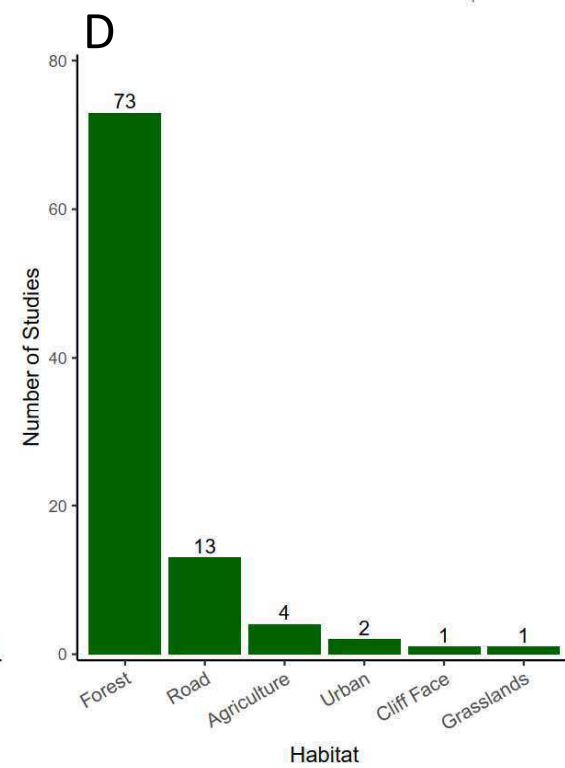
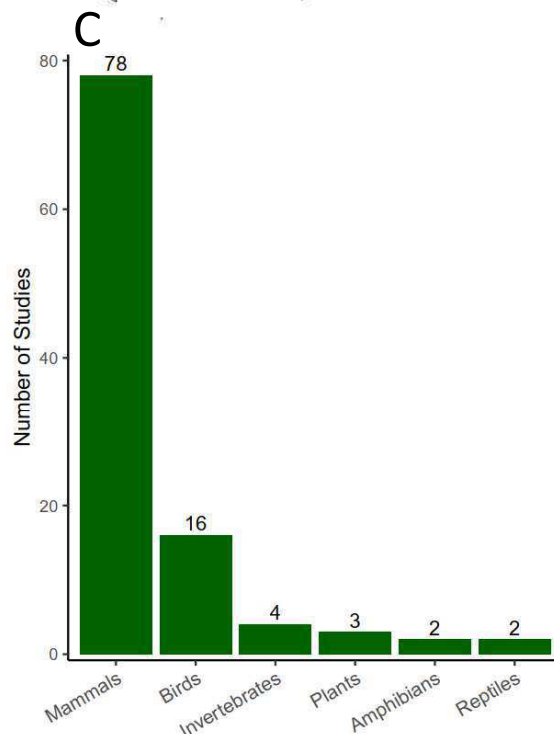
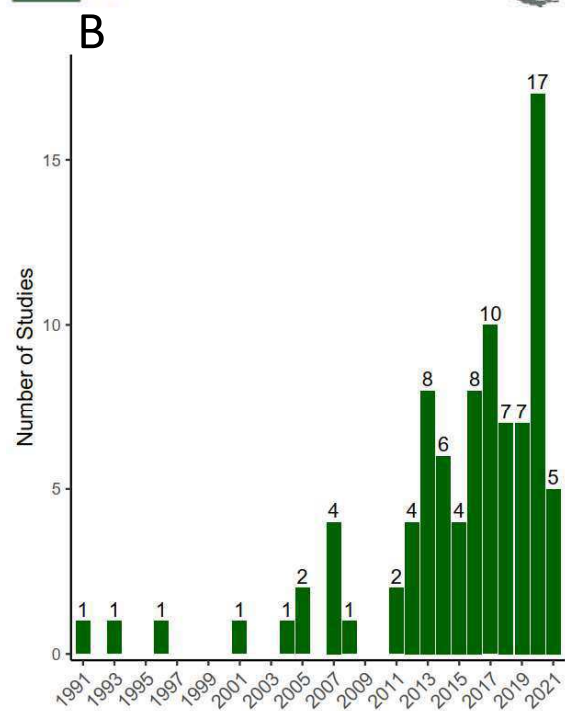
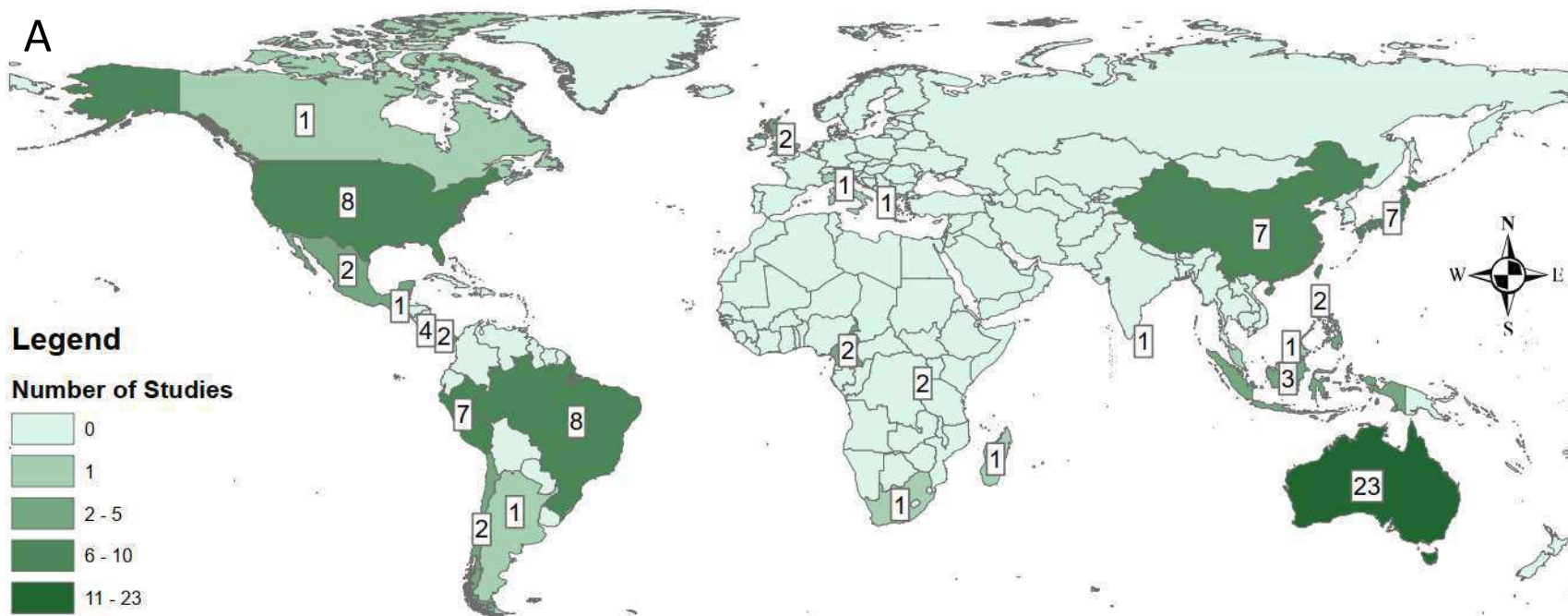
<b>Methods testing</b>	15	Mammals	Forest	Which camera type is most effective?
		Birds	Grasslands	How should cameras be oriented?
		Insects		Does camera flash affect the species?
		Plants		How can we modify the camera use or setup to improve the detection rate? How can bait be used to increase detection rate?
<b>Human activity</b>	2	Mammals	Forest	Are species affected by forest fragmentation, degradation, or human disturbance?

728 **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
<b>1. Study question</b>	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.
<b>2. Monitoring &amp; maintenance plan</b>	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.
<b>3. Camera placement</b>	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.
<b>4. Equipment &amp; personnel needs</b>	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.

<b>5. Camera settings &amp; accessories</b>	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.
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Plant-frugivore interactions  
(Zhu et al. 2021)



Detection of previously unobserved species  
(Moore & Niyigaba 2018)



Movement paths through high canopy  
(Gregory et al. 2017)



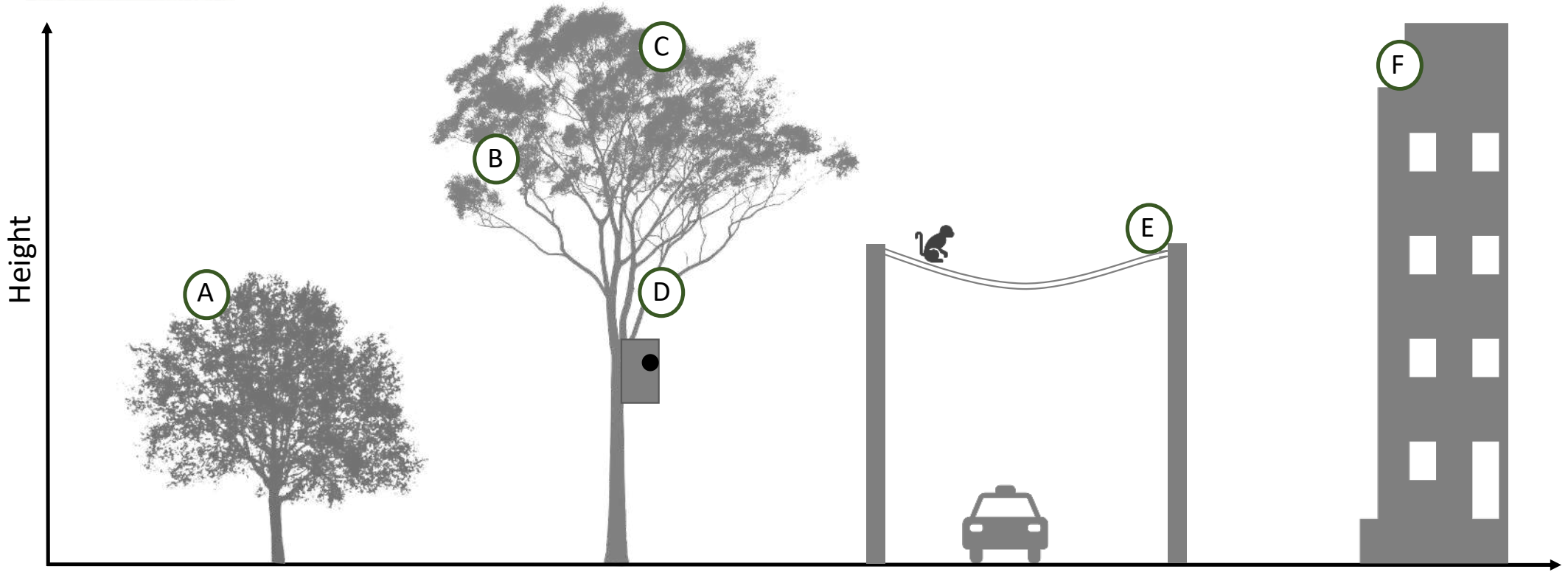
Novel predators at nesting hollows  
(Stojanovic et al. 2014)



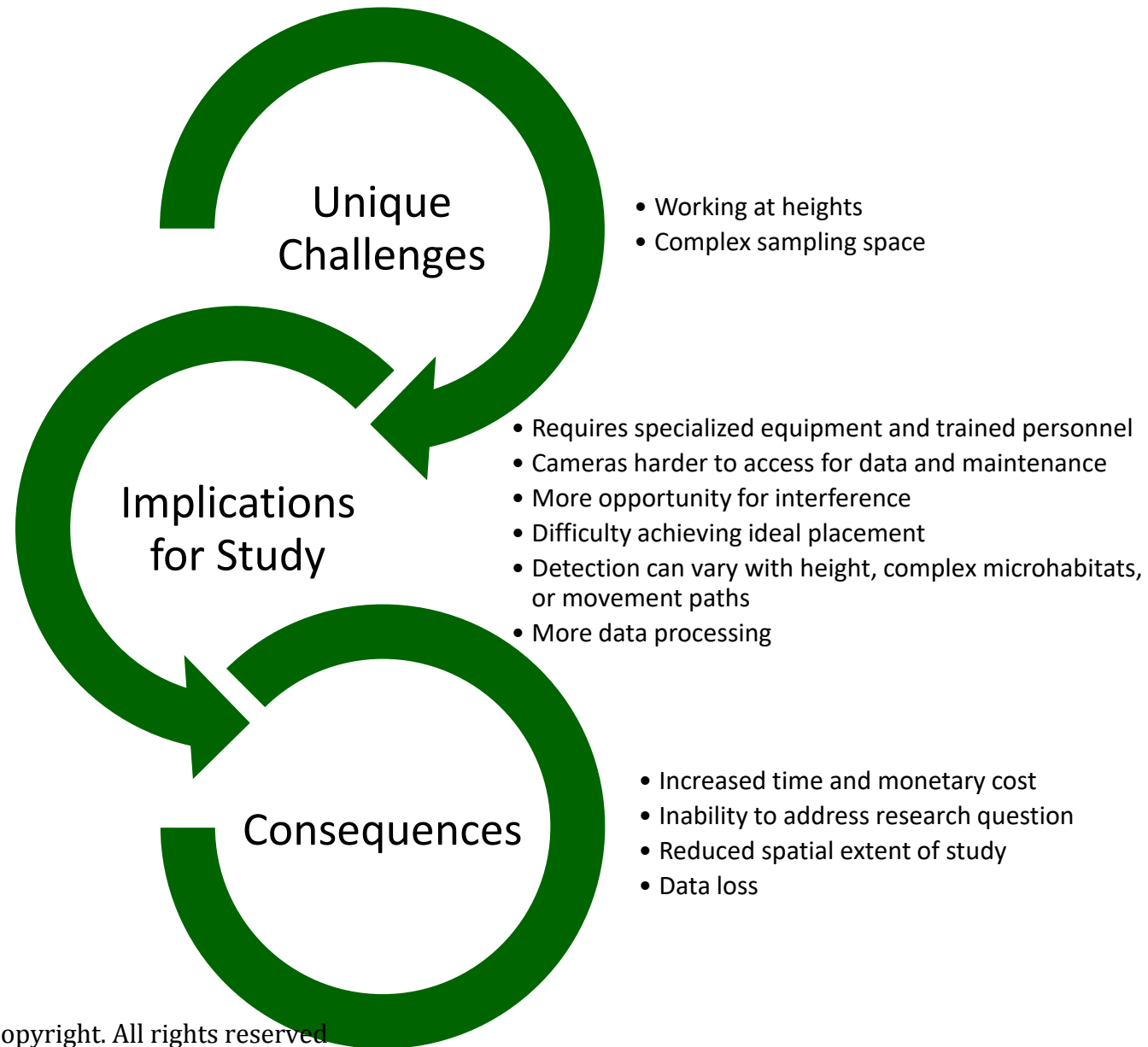
Evaluation of road-crossing structures  
(Soanes et al. 2015)

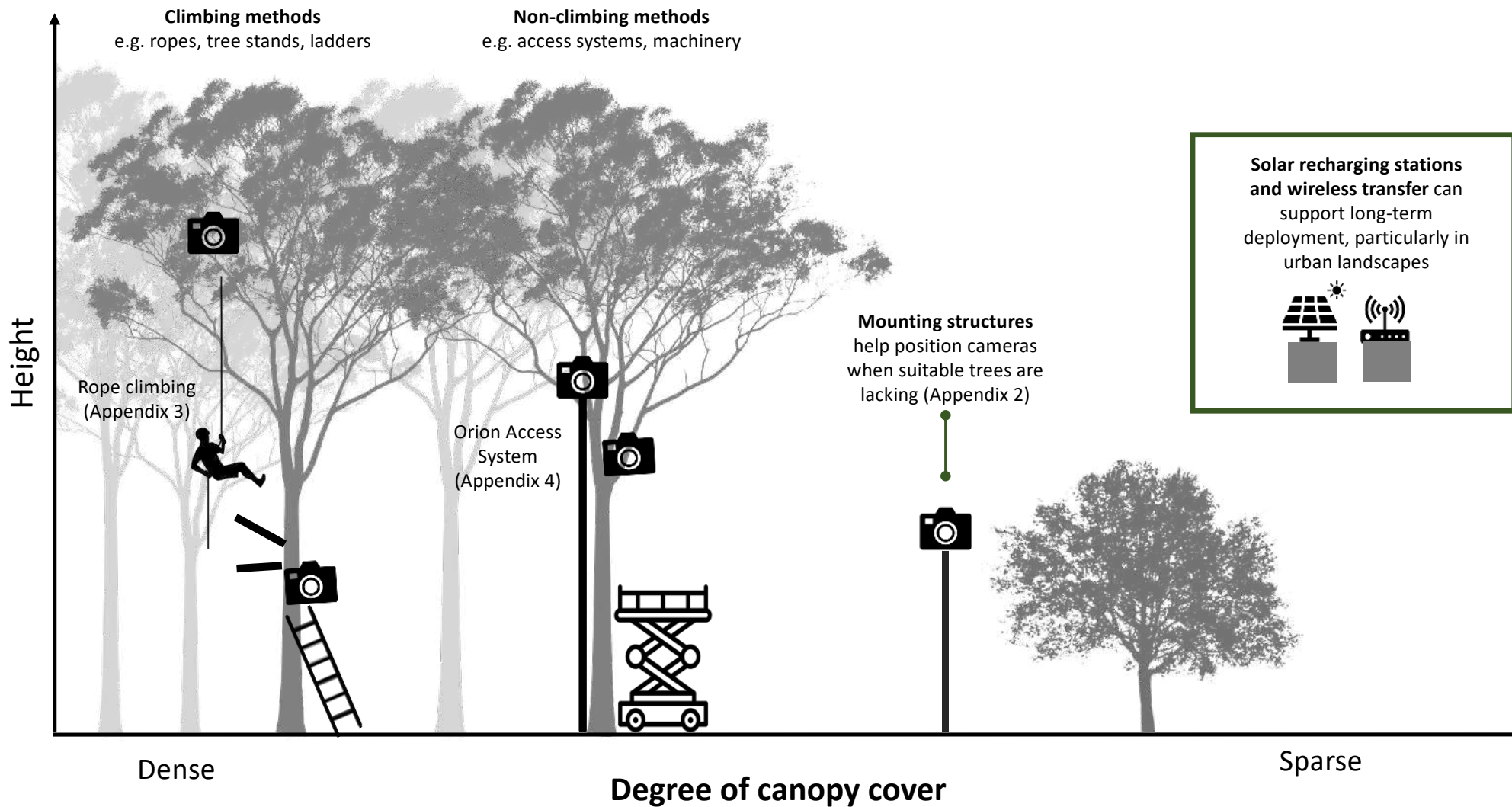


Nesting behaviour of urban raptors  
(Kettel et al. 2016)



Common applications of arboreal camera trapping





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