Exploring the neotropical canopy: Testing the effectiveness of arboreal camera trapping methodology across varying zones of cloud forest growth

Cloudbridge Nature Reserve, Cordillera de Talamanca, Costa Rica

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I. Abstract

Despite their inherent vulnerability to forest fragmentation, tree-dwelling specimen remain understudied due to the accessibility challenges of navigating arboreal habitats. Arboreal camera trapping is a newly established technique that exhibits significant potential in canopy research, as it can collect continuous datasets of often cryptic, nocturnal species, with minimal disturbance and effort. Its novelty, however, onsets its many setup errors and limitations, impeding the accuracy of its results. By using a comparative vertebrate diversity survey at Cloudbridge Nature Reserve, located in the Talamanca region of Costa Rica, we assessed the effectiveness of arboreal camera trapping methodologies, in contrast to terrestrial methods. Findings were secondarily evaluated to determine arboreal vertebrate community structure across differing growth zones in neotropical montane cloud forest. We used a double rope climbing system to set up eight arboreal sites, four in both young and old growth forest. Terrestrial camera-trap data was provided by another Cloudbridge researcher, within the same study parameters. With a total sampling effort of 182, arboreal cameras captured 47 events, detecting 15 vertebrate species. Two t-tests for independent means concluded a significantly higher event-capture likelihood in terrestrial camera trapping, though these tests neglected the qualitative value of arboreal footage, documenting interactions inaccessible to ground-based cameras. A Mann-Whitney U test confirmed higher levels of arboreal diversity within young growth areas, which we attributed to follow outcomes of succession and age-related decline models, as well as limitations like height. Our results suggest that arboreal camera trapping methodologies are necessary in understanding the ecological plasticity of arboreal habitat, with potential of being just as effective as terrestrial methods, though further research is needed to find strategies that optimize resources and sampling effort.

Keywords: camera-trap; arboreal; cloud forest; vertebrate; fragmentation; succession; Costa Rica

Table of Contents

II. Introduction

Abundant yet understudied, nearly 75% of forest vertebrates in neotropical zones find themselves vulnerable by living either partially or fully within arboreal environments (Eisenberg & Thorington, 1973). By inhabiting or relying on forest canopies, arboreal organisms occupy limited niches, which are more susceptible to effects of climate change and disturbance (Becerra-López et al., 2022). Forest fragmentation, which is described as continuous forest habitat being "broken apart" into smaller more isolated patches (Fahrig, 1997), induces arboreal vertebrates to be primary victims of displacement. In addition, dispersal from fragmented habitat can be challenging for arboreal specimen as suitable corridors between fragments are indefinite and species-specific (Vos et al., 2002), while predator pressure, as well as risk (Mendes et al. 2020), are found to be increased in degraded habitat (Schneider, 2001). Though fragmentation has the largest impact on arboreal mammals (Whitworth et al., 2019), its threat equally persists in forest bird populations (Malt & Lank, 2007), some even succumbing to extinction such as the po'uli (*Melamprosops phaeosoma)* and alagoas foliage-gleaner *(Philydor novaesi) (*Butchart et al., 2018).

Due to the complexity of ecological systems, landscape changes invoking habitat loss and fragmentation can largely contribute to extinction and globally declining biodiversity (Groombridge, 1992). Keystone species, endemism and interspecific relationships constitute toward the complexity of these systems and can heavily influence the damage onset by habitat and species loss. Keystone species, classified into five general categories, predators, prey, hosts, modifiers, and mutualists (Mills et al., 1993), are so heavily involved in ecosystem function that their extinction almost guarantees secondary extinction (Christianou, 2005). In the neotropics, many keystone species are arboreal living, such as the green-backed firecrown hummingbird *(Sephanoides sephaniode),* a migratory keystone species endemic to Argentina and Chile (Villasenor & Escobar, 2022). Endemism also exacerbates the fragility of ecosystem dynamics as it instigates habitat limitations and low population sizes within a species (Frankham, 1996). Endemic specimen therefore face additional challenges such as lower genetic variability, random genetic drift and reduced adaptive potential (Frankham, 1996), further sensitizing them to disturbance and fragmentation threats.

Costa Rica, located within the neotropical isthmus of Central America, is home to 4.5% of the planet's biological wealth, out of which 1.3%, 1170 species, are endemic (Kohlmann, 2011). Costa Rica not only establishes global recognition for its ecological threshold, but also underscores a reputation as a leading pillar in environmental governance. Since the 1990's, the country has made commendable efforts to preserve their wildlife by increasing conservation legislation and funding environmental initiatives (National Forest Financing Fund, 2018). An exemplary policy renowned as FONAFIFO, in article 46 of Forest Law No. 7575, dedicates financial payment towards small to medium producers for reforesting private land and leaving it untouched (National Forest Financing Fund, 2018). Not only does this law endorse and reward an eco-conscious mindset that contributes to habitat persistence, the law also imparts a socially sustainable agenda by supporting financially vulnerable families and communities. Currently, near 32% of the land accounts for protected areas spanning various habitat domains and climatic gradients (Sáenz-Bolaños et al., 2020).

However, as humanity further encroaches upon natural spaces, conservation is but the first step. To fully assess habitat fragmentation, its effects and solutions, research is indispensable as we must first deduce how different taxa interact with the landscape (Forman, 1995). Though there has been significant biological work done within the country, arboreal vertebrates; primary victims of fragmentation (Whitworth et al., 2019), have been and continue to be highly neglected. Between 1991 and April 2021, only 90 studies investigating arboreal specimen and methodologies were published globally, out of which only 4 were conducted within Costa Rica (Moore et al., 2021). In addition to the notably high costs of biodiversity research in tropical forests (Lawton et al., 1998), research efforts within arboreal environments are even more limited due to lack of accessibility (Kays & Allison, 2001). The challenge of height, unseen in terrestrial studies, presents an array of hurdles that complicate arboreal research. The added complexity of this third dimension, especially within dense forest canopy, inhibits study visibility and access, imposing higher initial costs and planning (Moore et al., 2021). For instance, being able to reach targeted heights requires arborist-specific climbing equipment and experienced personnel with knowledge of safety, rigging, and climbing within arboreal environments, which can be expensive (Moore et al., 2021). High costs often impose compromises to the study outline, influencing a smaller study area or shorter research term (Moore et al., 2021). Avoidance of these study changes can otherwise lead to potentially indeterminate findings.

To efficiently investigate arboreal environments, camera trapping methods are preferred to traditional ground surveying methods (Moore et al., 2021). Though ground surveying methodologies have constituted towards most of our current understanding of arboreal specimen, they present inherent challenges, including non-continuous and unreliable data acquisition, particularly for fast, nocturnal, or cryptic species (Kays & Allison, 2001). Camera trapping surpasses conventional methods by addressing their limitations and enabling extended research efforts with minimal disturbance (Moore et al., 2021). Although they have higher initial costs (Silveira et al., 2003), cameras are widely applicable and can offer unparalleled insight into behavioural uses of habitat as well as adaptations to anthropogenic change (Moore et al., 2021).

Despite the many benefits ensuing the use of camera trapping methodologies, arboreal environments pose limitations that make study setup complicated. Random branch angling can cause ideal placements to fail, as many branches can be awkward or unsuitable for effective camera positioning (Moore et al., 2021). This challenge is amplified when camera placements are made in the upper canopy, as branch visibility is lower, but effort is higher. Undesirable angles can lead to forced poorly framed shots, overexposure if directly facing east or west, or weather damage if disproportionately oriented laterally (Moore et al., 2021). In addition, branches that are highly vegetated present issues in framing, and the removal of such can be equated to some degree of disturbance (Kays & Allison, 2001). While frames that are over-vegetated can cause false triggers, limit visibility and fill up SD card memory, studies that avoid highly epiphytic branches introduce bias and/or limit results (Moore et al., 2021).

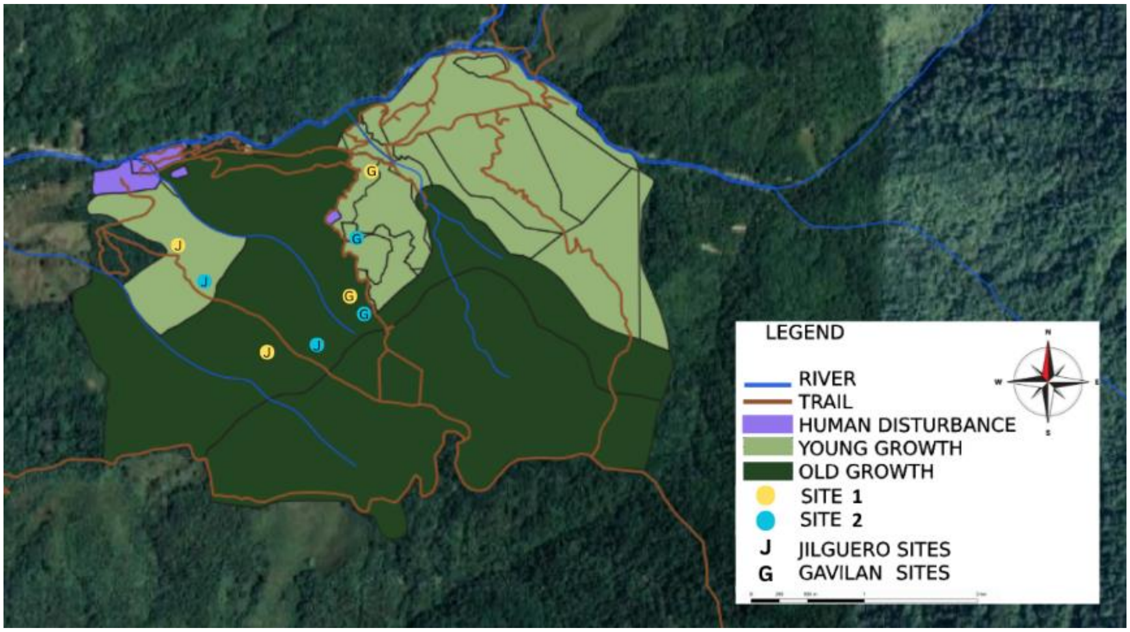
The numerous challenges present in the burgeoning field of canopy research must be endured as arboreal camera trapping holds great potential, filling a unique role that cannot be replicated by any other method. The main objective of this study therefore was to assess the efficiency of arboreal camera trapping methodologies and discern any differences in outcomes when compared to terrestrial camera trapping methods. We tested this basis using a comparative biodiversity survey spanning across the differing succession zones of a neotropical montane cloud forest. Secondary analysis of arboreal camera-trap data was tested to determine differences in vertebrate composition between young and old growth forest types. It was hypothesized that there would be significant differences in vertebrate diversity structure across zones of growth. As this study was the first arboreal survey to be conducted within the reserve, resulting species counts were employed to the Cloudbridge database, thereby striving to uphold their ongoing conservation efforts.

III. Methods

a) Study area

Cloudbridge Nature Reserve is located in the southern edge of San Jose Province, Costa Rica, and is nestled within the Cordillera de Talamanca (9.4722° N, 83.5776° W). The cordillera is included as one of the four great areas of endemism identified within Costa Rica (Kohlmann, 2011). Cloudbridge borders Cerro Chirripó National Park, which at 3820 meters, holds the highest point of elevation within the country (Quesada-Román et al., 2020). The reserve itself ranges between altitudes of 1675m and 2600m (Cloudbridge, n.d). At high elevation, neotropical temperatures, and an averaged daily precipitation rate of 6.6mm (Romp, 2019), the climate yields near 100% humidity and consistent cloud cover during the rainy season, enabling the persistence of a cloud forest (Cloudbridge, n.d). Working alongside the water cycle, the abundant presence of epiphytic and bryophytic plant cover reduces runoff and erosion within cloud forests, allowing them to retain their moisture (Cloudbridge, n.d). As water is a critical component of their survival, and a limiting resource, tropical montane cloud forests are some of the most threatened ecosystems in the world (Wheelwright & Nadkarni, 2000). Despite their fragility, cloud forests are largely diverse and are globally recognized as pillar ecosystems for endemic specimen (Kohlmann, 2011; Obando, 2002). Cloudbridge Nature Reserve has undergone extensive reforestation efforts, following its purchase as a pastureland in 2002, with omission of the property’s 70-acre old growth forest that has been left untouched. The reserve currently reflects a vast range of forest structures, ranging between old growth, young growth and naturally regenerated forest zones (Cloudbridge, nd).

Figure 1 Arboreal camera-trap site map



Camera trap locations on trails El Jilguero and Gavilan within the southern region of Cloudbridge Nature Reserve, Talamanca Cordillera, Costa Rica. Colours of sites, turquoise or yellow, indicate their collection period as camera locations were swapped bi-weekly - the first period beginning with yellow placements. This map generalizes young growth, naturally regenerated and planted zones of the reserve, though sites were exclusively placed in young growth forest. Map made by author in December 2023, using Garmin and QGIS 3.28.10.

b) Process overview

Eight study sites were split and positioned between two trails, El Jilguero and Gavilan, allowing four camera trap placements per trail. These trails were chosen for two primary reasons, the first being their privacy. Though the reserve has both public and private trails, research initiatives conducted on the public trails are often factored by human presence, leading to a reduction in animal activity and consequently, a potential distortion of findings. El Jilguero and Gavilan trails can only be accessed by Cloudbridge Staff and therefore encounter a higher volume of animal exposure. The second reason in the selection of these trails follows their vast range in forest growth structure, as they both extend across the different stages of the cloud forest's succession. Among the various stages of the forest's succession, old growth and naturally regenerated young growth were compared in this study. This was a choice that ensured consistency between trail sites as well as arboreal trap placement feasibility.

Four arboreal camera placements were positioned on each trail and divided between zones of growth: two locations in old growth forest and two in naturally regenerated young forest. Cameras used in this study included Bushnell119932C, GamekeeperCo5625 and WosodaLY-1234. With eight study sites and only four cameras, each camera was rotated between two consistent sites twice monthly. Rotations were grouped by assignments of “Site 1” or “Site 2”. Site 1 and 2 groupings never overlapped and regulated the congruous placement of cameras in the young and old growth regions of each trail. During the first two-week period, cameras were placed in their Site 1 locations: JilgueroYoung1, JilgueroOld1, GavilanYoung1, GavilanOld1. By the start of the second two-week period, Site 1 cameras were taken down, renewed of batteries and SD cards, and repositioned at Site 2 locations. Site 2 locations were independent of Site 1’s but followed the same format. In an eight-week research period, this cycle was repeated twice, allowing four weeks of data collection at each site location (see Appendix A, table A1).

Individual arboreal camera-trap locations were strategically selected following criteria relative to animal activity. Ideal trap locations were identified in regions characterized by complex treetop highways; areas in the canopy where denser branches intersected, facilitating potential passage for canopy-dwelling vertebrates (Schipper, 2007). Other placement considerations included sites in proximity to fruit-bearing trees, terrestrial animal-made pathways or fallen trees with accessible climbing opportunities. These criteria were devised to span a larger number of traverse zones and ecological regions within the study area.

Additional criteria included physical limitations of the climb, like access to the canopy and rope placement feasibility. Fixed lines were set at heights of 10 meters using a 16-ounce throw weight and a

2-millimetre lightweight nylon throwline. To ensure minimum disturbance to arboreal flora, a double rope system was used to ascend and descend the trees. Selected trees were required to be at an acceptable condition of health, free from any visible indications of wilting, water damage or detrimental fungal infestation. Tree crotches were deemed suitable for rope placement if they exhibited a minimum diameter of 10 centimeters and were accessible by throw weight. Some camera placements were limited due to restrictions like sunlight overexposure, rain exposure at certain angles, irregular branching or tree architecture, or excessive crowding of vegetation within the frame.

IV. Results

Table 1 Likelihood of event capture (%) on an average sampling day between terrestrial and arboreal camera trapping methodologies

	Terrestrial camera trapping				Arboreal camera trapping			
Trail	Days	Sampling Effort	Events	%	Days	Sampling Effort	Events	%
Jilguero	56	112	205	183	42	84	19	22.6
Gavilan	47	47	134	285	49	98	28	28.5

A one-tailed, t-test for independent means at $\alpha = 0.05$ was used to determine whether event capture probability significantly differed between terrestrial and arboreal camera trapping methods. The results concluded that between the two trails, El Jilguero and Gavilan, the terrestrial camera trap sites ($M = 234$, $SD = 51$) compared to the arboreal camera trap sites ($M = 25.6$, $SD = 2.95$) demonstrated a significantly higher likelihood of event capture, $t(1) = 4.08043 = 0.02757$.

Table 2 Likelihood of event capture (%) on an average sampling day between terrestrial and arboreal camera trapping methodologies excluding the collared peccary (*Pecari tajacu)* from species data

	Terrestrial camera trapping				Arboreal camera trapping			
Trail	Days	Sampling Effort	Events	%	Days	Sampling Effort	Events	%
Jilguero	56	112	68	60.7	42	84	19	22.6
Gavilan	47	47	33	70.2	49	98	28	28.5

A one-tailed, t-test for independent means at $\alpha = 0.05$ was used to determine whether event capture probability significantly differed between terrestrial and arboreal camera trapping methods when *P. tajacu* were not included within the data sets. The results concluded that between the two trails, El Jilguero and Gavilan, the terrestrial camera trap sites (*M* = 65.5, *SD* = 6.72) compared to the arboreal camera trap sites (*M* = 25.6, *SD* = 2.95) demonstrated a significantly higher likelihood of event capture, *t*(1) = 7.13582 = 0.009539.

Table 3 Total capture frequency, species richness and calculated diversity between zones of forest growth, across all arboreal camera-trap sites

	Capture Abundance	Species Richness	Shannon-Weaver Diversity Index
Young Growth	36	12	2.151
Old Growth	8	8	1.667

A Mann-Whitney U test was performed to evaluate the significance of diversity structure between young growth and old growth forest. The results indicated that young growth forest demonstrated a significantly higher diversity index than old growth forest, $U = [10]$, $p = [0.00842]$.

V. Discussion

a) Preliminary findings

Across all arboreal sites, 47 events were captured, spanning across 15 different species (see Appendix A, table A2). Results concluded 54% of species richness accounted to Aves, while 46% represented Mammalia. No individuals of other taxonomic classes were found.

b) Sampling effort

With two cameras per trail and 112 days of data collection, this study was initially structured to incorporate a sampling effort of 224. Though cameras were deployed continuously for two-week periods, SD card malfunctions and poor framing were culprits of several 14-day inconsistencies. Arboreal cameras are highly susceptible to interference by wind or vegetation, blocking their fields of view or heat sensors, therefore requiring increased levels of maintenance (Gregory et al., 2014). However, due to their limited access, arboreal cameras require a substantial amount of time, effort and gear to check on a regular basis (Moore et al., 2021). Without regular checking, SD card malfunctions and frame loss to vegetation can only be realized once the collection period has ended. Given these limitations, the intended sampling effort decreased by 18.75% to a realized sampling effort of 182. While capture frequency and sample effort are independent, probability of capture increases as sample effort increases. Applying this concept, sites that were inactive for half of their planned research periods experienced a 50% reduction in potential sample size. Reduced sample sizes contribute to normal distributions deviating further from that of the original population (Libretexts, 2019). As a result, data collected over a 14-day period was more heavily skewed than data collected over a 28-day period at the same site, therefore requiring further evaluation. For example, situated in the same zone of growth and on the same trail, 1GY with a collection period of four weeks documented 18 capture events; three times the event frequency of 2GY with a collection period of two weeks (see Appendix A, table A1).

c) Methodology Comparison

T-test results comparing terrestrial and arboreal methods depict that terrestrial cameras were significantly more likely to be successful in documenting a capture event on an average sampling day (Table 1). This result was unsurprising as it directly corelated with camera placement knowledge, and the lack of thereof within arboreal environments. While arboreal highways are generally hard to find, access and document, ground placements are less complicated with increased visibility, especially on highly trafficked pathways (Moore et al., 2021). Within the nature reserve, game trails that are widely used by ground-dwelling specimen have been camera monitored for several years. As a result, the terrestrial camera placements in the comparative study were strategically planned based on insight provided by prior research, thereby introducing bias that favoured higher event capture probability. This simply encourages further pursuit of arboreal studies to maximize recognition methods of canopy pathways. Footage from this study can be deduced to analyze branch preferences and means of arboreal mobility on some of these pathways.

Additionally, many ground-dwelling specimen that were seen using terrestrial methods were social and routine-based mammals, such as the collared peccary (*Peccari tajacu)* and the white-nosed coati (*Nasua narica)*. *P. tajacu* are highly social mammals that inhabit a small territory, often traveling in mixed herds of five to 25 (Keuroghlian et al., 2004; Bissonette, 1976) while maintaining short inter-individual distances (Byers & Bekoff, 1981). By accounting for 70% of events in the terrestrial investigation, it was highly possible that the same herd, or herds, routinely passed the Jilguero and Gavilan sites, initiating their frequent triggers. As the capture dominance of *P. tajacu* was not matched by any species in the arboreal study and heavily skewed terrestrial distribution, an additional methodology comparison was conducted, this time with omission of *P. tajacu* from the species pool (Table 2). Results that concluded higher capture probabilities following terrestrial methods remained significant. Nonetheless, a high volume of camera events does not equate to being a measure of complete success. In the case of the arboreal methodology, significance was found in the qualitative results. The arboreal camera-trap footage documented the interactive behaviour of vertebrates within an entirely different microhabitat, offering a glimpse into the adapted behaviors and lifestyle preferences of semi-arboreal specimens.

For example, *N. narica*, often captured by terrestrial cameras, exclusively construct arboreal nests which are used for reproduction, resting and parental care (de Lima et al., 2015). Other behaviours such as foraging and locomotion are observable on the ground but exhibit distinct variations when compared to their uses in arboreal environments (McClearn, 1992). In this study, *N. narica* was arboreally captured ascending and descending a fallen tree, using it as a highway to and from the upper canopy. With limited digit movements and large body composition, *N. narica*'s morphology is disadvantageous for climbing (McClearn, 1992). Even their tail, which is semi-prehensile, is partly inefficient for tree climbing, as it can only be used for balancing, and not gripping (Ingles, 1957). The captured footage was exemplary of *N. narica*'s motor adaptation to arboreal living, one McClearn describes as "using adjacent trees to ascend the canopy horizontally" (McClearn, 1992).

As these visits were brief - all ascents followed by a descent some minutes later - and documented multiple times within the following days, it is possible that the same individual was demonstrating foraging behaviour by revisiting a successful site. The behavioural duality of semi-arboreal specimen therefore cannot be solely assessed using terrestrial cameras, proving the unmatched potential in arboreal methodologies.

Furthermore, arboreal cameras documented capture of two species that remained beyond the scope of terrestrial surveillance: the panamanian white-faced capuchin (*Cebus imitator*) and the kinkajou (*Potos flavus).* While both specimens are exclusively canopy-dwelling and thus somewhat elusive, *C. imitator* were sometimes spotted around the reserve, as they are loud, diurnal and travel in troops, while *P. flavus* are notably cryptic due to their nocturnal and asocial lifestyle (Mcclearn, 1992). The documentation of these predominantly arboreal species directly illustrate the success of the methodology by providing results that are terrestrially unlikely. The purpose of this study was not to undermine the importance of terrestrial camera trapping methods, but rather to use them as a template in the overall assessment of arboreal methodologies. Both methods pave their own success within their respective microhabitats of focus and are equally vital in the learning of ecological systems. The future implications of combining arboreal and terrestrial camera trapping techniques are significant, as integrating both methods would widen coverage and enable more complete analyses to be conducted within forest zones.

d) Forest growth influence

Finally, a Mann-Whittney U test indicated that arboreal vertebrate communities in young growth forests were significantly more diverse than in old growth forests (Table 3). As forests inch closer to being climax communities, they exhibit predilections towards stability rather than diversity (Whittaker, 1957). The decline of biodiversity in older forests can be attributed to their roles within ecological succession.

Limited light levels in older, tropical forests promote competition below the canopy level, decreasing growth in smaller or later sprouting trees (Rozendaal et al., 2020). Old forests also face age-related decline, which reduces photosynthesis levels and dry matter production (Kutsch et al., 2009;

Ryan et al., 1997). These factors can contribute to a reduction in nutrient availability and habitat suitability for the forests inhabiting organisms. On the other hand, young growth forests hold a greater array of trees, creating higher niche differentiation both vertically and horizontally, resulting in higher species diversity across all taxa (Bazzaz, 1975).

While diversity levels were confirmed to be higher in young growth forests, the arboreal survey revealed no signs of a dominant species in either environment. This suggests that, as a group, arboreal specimens exhibit considerable diversity. However, the accuracy of these results and interpretation may be skewed due to the physical height limitations of the study. As seen in Appendix B, true canopy heights in secondary forests can range anywhere between five and 15 meters while canopies in mature old forest typically begin within this range, and in turn, average much higher (Kappelle, 2004). With cameras placed at heights of eight to 12 meters in both environments, the true canopy of the old growth forest was inadvertently neglected. Reaching the true canopy of the old growth forest required more equipment, time and personnel to efficiently set up, resources that fell beyond this study’s budget and time constraint. This could have therefore influenced the sightings of arboreal specimen found exclusively in young growth like the black guan (*Chamaepetes unicolor*) and *C. imitator.*

The assumption from these findings might be indicative that, within neotropical montane cloud forest habitats, these specimens primarily inhabit the true canopy. However, this seems improbable for *C. imitator*, as it contradicts recent Costa Rican primate research, which supports the generalist distribution of capuchins, with a bias towards younger forests due to food availability (Johnson et al., 2023).

e) Recommendations for future research

Despite the camera errors and placement limitations that arose within setup, the findings of this study underscore the potential success of the approach. With arboreal camera trapping being a relatively new and understudied method of data collection, errors were anticipated, but served to be a critical aspect in the learning curve. We hope that the flaws conceived within this study yield to be valuable insight for future investigations. For optimal sampling effort, we suggest frequent monitoring of camera placements, as vegetation and wildlife can displace cameras or block framing (Gregory et al., 2014), as well as regular checking of SD card integrity as some may corrupt whilst in the field. Though not necessary, the utilization of an SD card reading device would be helpful to check framing during the setup phase of sites, as it is more effective than the alternative: aligning the camera of a mobile device on the camera-trap lens and taking a picture. For any arboreal studies that involve the monitoring of canopy pathways, it is helpful to observe common, diurnal vertebrates, such as members of *Sciuridae*, and learn how they navigate through the environment prior to site planning (Schipper, 2007). Finally, the challenge of height and wide niche plasticity makes arboreal environments especially hard to monitor with limited equipment. Observed species may drastically vary dependant on the camera's placement, as differing heights and sides of the tree can yield different groups of animals (Bowler et al., 2017; Laughlin et al., 2020; Whitworth et al., 2019). Arboreal pathways do not adhere to a standard form and can vastly differ based on the interacting organisms. As well, two adjacent and intraspecific trees of similar height can still drastically vary in vertebrate composition (Moore et al., 2021). We therefore recommended the installation of multiple cameras on each tree, or, if not feasible, to narrow the study focus by limiting site variability. Implementing these measures will prioritize optimum efficiency, compensating for any potential data gaps.

VI. Conclusion

Amidst an everchanging world, biological research plays a vital role in the conservation of fragile ecosystems. As means of protection are established through the analysis of surveyed data collection, these collection methodologies must therefore be widely available and, more importantly, accurate. In this study, we overviewed arboreal camera trapping, a novel method in investigating canopy ecosystems, relative to terrestrial camera trapping methods. We found that while terrestrial camera traps demonstrated superior efficiency and ease of setup, arboreal camera traps, though technically challenging, offered insight into arboreal interactions that were irreplicable by other methods. Data accumulated from this study was further analyzed to determine the effect of forest age on arboreal vertebrate composition, though results were limited by height access, leading to missed data. While arboreal techniques have the potential to match the success rates of terrestrial traps, we concluded that the method holds a steep learning curve, and in the absence of a standardized approach, is very challenging to execute without limitations. As the future of canopy ecology remains unclear, we encourage the continuity of arboreal investigations and hope that our insight provides helpful recommendations for comparative studies to come.

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VII. References

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VII. Appendix

Appendix A

Table A1 Individual arboreal camera placement site ID's, data collection period, functional success, relative sampling effort by number of days and cameras, event frequency and growth category

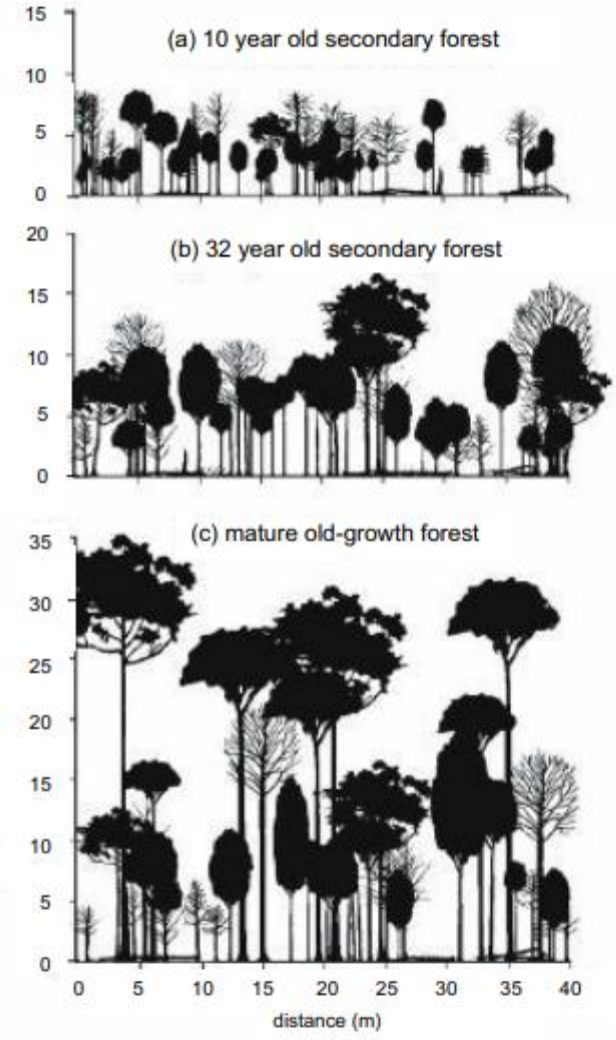
Tree Site ID	Survey period (number of days)	Functional (y/n)	Sampling effort	Event frequency	Forest growth structure
El Jilguero:					
1JY	14 September – 28 September (14) 12 October – 26 October (14)	Y N	14 0	0	Young
2JY	28 September – 12 October (14) 26 October – 9 November (14)	Y Y	14 14	15	Young
1JO	14 September – 28 September (14) 12 October – 26 October (14)	Y Y	14 14	3	Old
2JO	28 September – 12 October (14) 26 October – 9 November (14)	N Y	0 14	1	Old
Gavilan:					
1GY	15 September – 29 September (14) 13 October – 27 October (14)	Y Y	14 14	18	Young
2GY	29 September – 13 October (14) 27 October – 10 November (14)	N Y	0 14	6	Young
1GO	15 September – 29 September (14) 13 October – 27 October (14)	Y Y	14 14	1	Old
2GO	29 September – 13 October (14) 27 October – 10 November (14)	Y Y	14 14	3	Old

Table A2 Clade, scientific and common name of species and their capture frequency. Data accumulated across all arboreal camera-trap sites on both El Jilguero and Gavilan trails

Clade	Species	Common Name	Capture Events
Aves			
	Aulacorhynchus prasinus	Northern emerald toucanet	8
	Lepidocolaptes affinis	Spot-crowned woodcreeper	2
	Chamaepetes unicolor	Black guan	2
	Empidonax atriceps	Black-capped flycatcher	1
	Eupherusa eximia	Stripe-tailed hummingbird	1
	Turdus grayi	Clay-colored thrush	1
	Mniotilta varia	Black-and-white warbler	1
	------------------	Unknown (bird)	1
Mammalia			
	Nasua narica	White-nosed coati	10
	Sciurus granatensis	Red-tailed squirrel	4
	Sciurus variegatoides	Variegated squirrel	3
	Nyctomys sumichrasti	Sumichrast's vesper rat	3
	Cebus imitator	Panamanian white-faced capuchin	3
	Potos Flavus	Kinkajou	3
	------------------	Unknown (bat)	1

Appendix B

Figure B1 Canopy heights at various stages of forest growth



“Schematic lateral profile of three successional stages of tropical montane oak forest at around 2,800 m elevation in the Cordillera de Talamanca. (a) 10-year-old, early successional forest; (b) 32-year-old successional forest; and (c) old-growth oak forest over 250 years of age.” Reproduced from Kappelle 2004, with kind permission from Elsevier.