Plant–frugivore interactions revealed by arboreal camera trapping

Camera trapping technology – which allows images of organisms to be obtained remotely from the field – has advanced rapidly in recent decades, and its infrared capability has become a standard tool in wildlife monitoring, especially for detecting ground-dwelling endothermic animals (O'Connell *et al*. 2011). However, the activities of animals in arboreal habitats (including the forest canopy) are still poorly known (Gregory *et al*. 2014; Moore *et al*. 2020), and to date, no studies have used arboreal camera trapping to monitor plant–frugivore networks over an extensive area.

Communities of arboreal animals provide essential ecosystem services, such as pollination and seed dispersal, that maintain forest regeneration (Howe and Smallwood 1982). Although arboreal habitats are prominent hotspots of biodiversity (Nakamura *et al*. 2017), knowledge of canopy ecology and other vertical stratifications in forests is limited due to logistical challenges. Arboreal camera trapping therefore has the potential to greatly enhance understanding of the behaviors and life histories of cryptic animals and their roles in ecosystems (Gregory *et al*. 2014; Rivas and Soto-Shoender 2015). While camera trapping in arboreal habitats has been conducted previously (eg Whitworth *et al*. 2016; Laughlin *et al*. 2017), it has rarely been used to monitor plant–animal interactions at large spatial scales, especially in highly fragmented landscapes.

In a recent field study, we positioned infrared digital cameras in tree canopies along line transects on 22 subtropical land-bridge islands in the fragmented landscape of Thousand Island Lake (Qiandao Lake), in eastern China (Figure 1; WebTable 1; WebFigure 1). At 318 sites, cameras were aimed toward target branches with high fruit densities (WebFigure 2) because fleshy fruits attract frugivores steadily during the fruiting period (Jayasekara *et al*. 2007; Olson *et al*. 2012). Eighteen target plant species were monitored during the entirety of their respective fruiting periods (WebTable 2). From more than 2 million images captured between June and December 2019, we identified 49 potential frugivorous bird species (WebTable 3), including, unexpectedly, silver pheasant (*Lophura nycthemera*). Small mammals like rodents (Muridae and Sciuridae) were also frequent visitors to the fruiting trees (Figure 1).

Image analysis revealed species of Muridae – essential seed dispersers on the ground – to be the primary consumers of *Symplocos stellaris* fruits (these rodents were observed at night, running along branches with fruits in their mouths). Compared with their diurnal counterparts, nocturnal mammals, like the species of Muridae observed in this study, have received less research attention as potential seed dispersal agents, but evidence suggests that they may play a larger role than previously known in transporting seeds from trees to the forest floor (Amico and Aizen 2000). Additional studies are needed to more explicitly evaluate the functional role of seed dispersal by members of the Muridae in island ecosystems (Zeng *et al*. 2018).

Silver pheasants were primarily captured on camera while foraging in groups (WebFigure 3). Our images represent – to the best of our knowledge – the first documented record of these birds feeding in trees during the day, and suggest that the species has a more complex relationship with arboreal resources beyond roosting in trees at night. Silver pheasants may disperse seeds, given that they have been observed consuming fruits on the ground in Thailand (Sankamethawee *et al*. 2011).

Plant–frugivore interactions differ among various forest strata and habitats (Schleuning *et al*. 2011; Li *et al*. 2020). Overlooking arboreal species at specific vertical stratifications or during certain temporal periods would result in incomplete species inventories and biased sampling of species interactions. However, arboreal camera trapping can operate remotely 24 hours a day. Continuous and automatic monitoring through the use of cameras facilitates surveys of numerous fruiting trees at multiple sites simultaneously, even in remote or difficult-to-access areas. Our study demonstrates that arboreal camera trapping can not only reliably record the locations and times of day at which frugivorous animals consume fruit, but also provide additional insights. For example, although silver pheasant was suspected of being a seed disperser, all previous records consisted of direct observations of pheasants feeding on fruit on the ground (Corlett 2017). Based on the images from our study, information about the foraging behavior of silver pheasant should be updated to reflect that, at least on these islands, this species feeds on fruits in trees as well. This behavior may possibly be due to reduced availability of food resources on islands, and may have simply never been documented until now.

Although arboreal animal communities contribute greatly to local biodiversity (Kays and Allison 2001), arboreal ecosystems typically receive far less research attention than their ground-based counterparts. Arboreal camera trapping provides an ideal means of inventorying cryptic and nocturnal species, and for observing animal behaviors (Jayasekara *et al*. 2007; Whitworth *et al*. 2016). Part of the appeal of arboreal ecosystems to scientists and the general public is the fact that so little is known about them; as a noninvasive and cost-effective technology, camera trapping may be useful for monitoring and surveying forest canopies, as well as other difficult-to-access habitats. As such, we strongly recommend that camera trapping can be adopted to study the planet's relatively unexplored arboreal ecosystems.

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Figure 1. (a) The fragmented island landscape of Thousand Island Lake (Qiandao Lake), eastern China. On land-bridge islands in the lake, important seed dispersers may include the following frugivores, whose images were captured by arboreal camera traps: (b) red-billed leiothrix (*Leiothrix lutea*), (c) silver pheasant (*Lophura nycthemera*), and (d) a member of the Muridae feeding on the fruits of a *Symplocos stellaris* tree.

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Amico G and Aizen M. 2000. Mistletoe seed dispersal by a marsupial. *Nature* **408**: 929–30.

Corlett RT. 2017. Frugivory and seed dispersal by vertebrates in tropical and subtropical Asia: an update. *Global Ecol Conserv* **11**: 1–22.

Gregory T, Carrasco Rueda F, Deichmann J, *et al*. 2014. Arboreal camera trapping: taking a proven method to new heights. *Methods Ecol Evol* **5**: 443–51.

Howe HF and Smallwood J. 1982. Ecology of seed dispersal. *Annu Rev Ecol Syst* **13**: 201–28.

Jayasekara P, Weerasinghe U, Wijesundara D, *et al*. 2007. Identifying diurnal and nocturnal frugivores in the terrestrial and arboreal layers of a tropical rain forest in Sri Lanka. *Ecotropica* **13**: 7–15.

Kays R and Allison A. 2001. Arboreal tropical forest vertebrates: current knowledge and research trends. *Plant Ecol* **153**: 109–20.

Laughlin MM, Olson ER, and Martin JG. 2017. Arboreal camera trapping expands *Hyla versicolor* complex (Hylidae) canopy use to new heights. *Ecology* **98**: 2221–23.

Li H, Tang L, Jia C, *et al*. 2020. The functional roles of species in metacommunities, as revealed by metanetwork analyses of bird–plant frugivory networks. *Ecol Lett* **23**: 1252–62.

Moore J, Pine W, Mulindahabi F, *et al*. 2020. Comparison of species richness and detection between line transects, ground camera traps, and arboreal camera traps. *Anim Conserv* **23**: 561–72.

Nakamura A, Kitching RL, Cao M, *et al*. 2017. Forests and their canopies: achievements and horizons in canopy science. *Trends Ecol Evol* **32**: 438–51.

O'Connell A, Nichols JD, and Karanth KU. 2011. Camera traps in animal ecology: methods and analyses. New York, NY: Springer-Verlag.

Olson E, Marsh R, Bovard B, *et al*. 2012. Arboreal camera trapping for the critically endangered greater bamboo lemur *Prolemur simus*. *Oryx* **46**: 593–97.

Rivas J and Soto-Shoender J. 2015. Filling in the gaps: evaluating the use of camera traps in the canopy to examine frugivore visits to *Oreopanax echinops* in the highlands of Guatemala. *Southwest Nat* **60**: 366–70.

Sankamethawee W, Pierce A, Gale G, *et al.* 2011. Plant–frugivore interactions in an intact tropical forest in north-east Thailand. *Integr Zool* **6**: 195–212.

Schleuning M, Blüthgen N, Flörchinger M, *et al.* 2011. Specialization and interaction strength in a tropical plant–frugivore network differ among forest strata. *Ecology* **92**: 26–36.

Whitworth A, Braunholtz LD, Huarcaya RP, *et al.* 2016. Out on a limb: arboreal camera traps as an emerging methodology for inventorying elusive rainforest mammals. *Trop Conserv Sci* **9**: 675–98.

Zeng D, Swihart R, Zhao Y, *et al.* 2018. Cascading effects of forested area and isolation on seed dispersal effectiveness of rodents on subtropical islands. *J Ecol* **107**: 1506–17.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2321/suppinfo

FrontiersEcoPics

Longevity record verified in an Egyptian vulture

Long-term monitoring is fundamental to understand the ecology and conservation of long-lived endangered species. These photos document a record of longevity for a male Egyptian vulture (*Neophron percnopterus*), the only long-distance migratory vulture species in Europe. When captured and tagged in July 1993 (left panel) in Bardenas Reales (northern Spain), it was probably two years old, as indicated by its plumage patterns. In June 2020, the same individual was recaptured as a territorial adult in the Catalan Pyrenees, 200 kilometers away (right panel). To the best of our knowledge, the age of this bird, 29 years, sets the known record for a vulture in the wild. Males are suspected to live longer than females. In the population of vultures to which this individual belongs, annual survival rates for adults are sex-biased (0.91 males; 0.82 females); indeed, of nine birds in this population that are known to exceed two decades of age, six were males, with two 28-year-old males still alive in 2020.

Seabirds of various taxa can apparently live for many years, with records of albatrosses that reach more than six decades of age while still actively breeding. In large avian scavengers, such information is spotty because there have been very few long-term studies and, above all, because most of the populations are subject to strong non-natural mortality like poisoning and collision with wind turbines. For example, in the case of Egyptian vultures, generation times are just over a decade. Having accurate information about the potential longevity of individuals in the wild is essential to refine estimates of population viability in species such as vultures, which are imperiled globally.

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