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Confirmation of arboreal habits in *Dromiciops gliroides*: a key role in Chilean Temperate Rainforests

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Citation: Godoy-Güinao, J., I. A. Díaz, and J. L. Celis-Diez. 2018. Confirmation of arboreal habits in *Dromiciops gliroides*: a key role in Chilean Temperate Rainforests. Ecosphere 9(10):e02424. 10.1002/ecs2.2424

Abstract. *Dromiciops gliroides* is a small marsupial endemic to the South American temperate rainforest; it is considered a living fossil because it is the only living species of the order Microbiotheria, more related to Australian marsupials than those found in South America. *Dromiciops gliroides* has been considered a scansorial marsupial most frequently found in the understory. Nonetheless, several authors have hypothesized that this species could be arboreal because of its ability to climb through the vegetation. However, all previous studies on *D. gliroides* have been conducted from the ground, with no documentation of this species' ability to climb trees, or how high they may reach. Here, we present the first evidence of arboreal habits in *D. gliroides*, and we analyze its functional importance for the biodiversity of forest canopies. In the Bosque Pehuén Park (39°25′ S, 71°45′ W), in six emergent *Nothofagus dombeyi* (Nothofagaceae) trees, we installed camera traps, one per tree, between 12 and 21 m aboveground, in the trees' crowns. Camera traps were active from January to April of 2017, during the Southern Hemisphere's summer and fall. We recorded a total of 2319 photographs, including small mammals, birds, and lizards, in addition to several unidentified species. A total of 230 photographs of *D. gliroides* were recorded, across all six of the surveyed trees. In a more recent survey (February 2018), we found this species at 26 m, 2 m from the tree's highest point. *Dromiciops gliroides* is thus a frequent canopy user and could influence canopy biota and ecological processes. *Dromiciops gliroides* is considered a seed disperser of most vascular epiphytes and vines, and may therefore strongly influence epiphytic dynamics. It is also an active invertebrate predator and as such could significantly decrease tree herbivory. The roles that *D. gliroides* plays in this ecosystem need more clarification; this living fossil may be more important for this forest ecosystem than previously believed, modulating biodiversity and functions in unexpected, yet relevant ways.

Key words: Arboreal habits; Camera traps; *Dromiciops gliroides;* Forest canopies; Living fossil; Marsupials; Microbiotheria; South American temperate rainforest; Wildlife–habitat relationships.

Received 24 July 2018; accepted 30 July 2018. Corresponding Editor: Debra P. C. Peters.

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Introduction

To define an animal as arboreal requires not only that the animals have the ability to climb through the vegetation. Several species with climbing abilities do not even use the tree trunk and crown as habitat, such as some understory birds (Willson et al. 2014), while other animals

that have shown no apparent adaptations for climbing live in the tree crowns, such as some amphibians (Kays and Allison 2001, Díaz et al. 2010*a*). For arboreal animals, trees are relevant and frequently used as habitat, although these animals may also be found in the understory or on the forest floor. So, what is an arboreal species? Moffett (2000) defines an arboreal species as an "organism living in trees at least half of the time during at least one stage of its life cycle." Arboreal species can play important functional roles if they affect processes such as seed dispersion or predation (Vieira and Izar 1999); however, the arboreal fauna inhabiting many forests around the world is still not well known. Forest canopies, the forest strata between the understory and the upper parts of the tallest tree, remain a frontier for ecology, even though they host most terrestrial biodiversity (Nakamura et al. 2017).

South American Temperate Rainforests (SATRs) are considered a hot spot for biodiversity conservation (Mittermeier et al. 2004) and are characterized by multilayered canopies dominated by broad-leaved angiosperms, with a high proportion of endemic species, and a disproportionately high number of mutualistic plant–animal interactions in comparison with their Northern Hemisphere counterparts (Willson 1991). The canopies of SATRs have received minimal investigation until recently, showing a high abundance of epiphytic plants, invertebrates, and a high biomass of detritus that forms a dense layer of arboreal soil (Díaz et al. 2010*b*, 2012, Ortega-Solís et al. 2017). However, no studies have yet focused on documenting the arboreal habits of any mammal in SATRs, and all previous studies and observations have been conducted from a ground-based perspective.

Dromiciops gliroides is a small marsupial (24 g) endemic to SATRs; it is considered a living fossil because it is the only living species of the order Microbiotheria, which represents an early branch of marsupials' phylogenetic tree, forming a single clade within the Australian taxa as opposed to other South American taxa (Nilsson et al. 2004, 2010, Beck 2012). This mammal inhabits forests between 36° and 43° S (Gardner 2005, Martin 2010, Celis-Diez et al. 2012) and consumes invertebrates, fleshy fruits, and even vertebrates, such as young birds and bird eggs (Pearson 1983, Meserve et al. 1988, Amico et al. 2009, Celis-Diez et al. 2012, Fontúrbel et al. 2012). For most of the 20th century, the biology of this species has been virtually unknown, but over the last decade, its ecology has been the target of comprehensive field research (Fontúrbel et al. 2010, 2012, Martin 2010, Celis-Diez et al. 2012).

Dromiciops gliroides has been considered a scansorial marsupial (Pearson 1983), although several authors have hypothesized that *D. gliroides* could be an arboreal species because of its ability to climb through the vegetation (Osgood 1943, Mann 1978, Fontúrbel et al. 2010, 2012, Celis-Diez et al. 2012). At the same time, several studies have indicated that the understory is their main or even exclusive habitat (Pearson 1983, Kelt and Martínez 1989, Uribe et al. 2017), where they build nests in bamboo thickets or tree cavities and live in groups of up to five individuals (Kelt and Martínez 1989, Celis-Diez et al. 2012). Nonetheless, all previous studies of this species have been conducted <3 m from the ground, where *Dromiciops* have been trapped. Until recently, no studies have truly documented their arboreal habits. Here, we present the results of the first survey of mammals living in the canopy of a SATR.

We conducted our surveys in Bosque Pehuén Park (39°25′ S, 71°45′ W), a privately protected area dedicated to biodiversity conservation. We used single- and double-rope techniques to access the canopies of six large emergent *Nothofagus dombeyi* (Nothofagaceae) trees between 80 and 200 cm in diameter at breast height, between 26 and 28 m tall, and more than 200 yr old. *Nothofagus dombeyi* is the dominant tree species in the landscape, presenting the largest individuals within the forest. Since the home range of *D. gliroides* is around 1.6 ha (Fontúrbel et al. 2010), the sampled trees were separated between 250 and 1000 m of each other to insure independence among them. Two of them were located in areas dominated by second-growth forest, and four were located in areas dominated by old-growth forest. We installed one camera trap per tree (Bushnell Trophy Cam, Bushnell Corporation, Overland Park, Kansas, USA) between 12 and 21.45 m aboveground. In each tree, we installed a small, ~20 × 15 cm, wooden platform. We then set up camera traps firmly attached to bamboo

sticks nailed to the surveyed trees; these were aimed at the platforms, but located 1.5 m away (Fig. 1). We configured the camera to take a set of three photographs per each activation of the movement sensor followed by a 20-s lag before taking a new set of photographs. Hence, we considered as a single photograph the results obtained from each set of three photographs. We did not correct the results for any other criteria since we were not quantifying abundance; we were interested in knowing how frequently *D. gliroides* use the forest canopy. We baited each platform with oatmeal and fresh bananas to attract small mammals, but the bait was added only once, when camera traps were first mounted. We installed the camera traps in January 2017, and we collected the information in April 2017. The camera traps therefore captured 12 weeks of canopy surveys during the Southern Hemisphere's summer and fall.

We recorded a total of 2319 photographs, including small mammals, birds, and lizards. Small mammals were recorded in 361 photographs, all of which were taken at night. A total of 230 photographs (63%) were of *D. gliroides*, distributed in the following way: The four trees surrounded by old-growth forest showed between 14% and 37% of the photographs, while the two trees located in secondary forest showed between 0.9% and 3.5% of the photographs. Despite the lower records in secondary forest, these results showed that *D. gliroides* was present across all six of the surveyed trees. The only other mammal clearly recorded was a single photograph of a rodent, probably *Irenomys tarsalis* (Cricetidae). The remaining 109 photographs, also small mammals, could not be identified, as they were heavily overexposed.

These are the first records to show truly arboreal habits in any SATR mammal. The results

Fig. 1. (A) Authors ascending to one of the *Nothofagus dombeyi* trees in this study; (B) group of *Dromiciops gliroides* nesting together inside a nest box at 2 m aboveground; (C) single *D. gliroides* on a small branch at 2.5 m aboveground; and (D) image of *D. gliroides* captured at 14.4 m aboveground, in the canopy of this SATR, using a camera trap. Photograph in (A) is courtesy of Felipe González, and photographs in (B) and (C) are courtesy of Andrés Charrier.

strongly suggest that the most frequent and perhaps the only arboreal mammal that lives in SATR canopies is *D. gliroides*. We also found two nests of *D. gliroides*, 6 and 10 m aboveground (J. Godoy-Güinao et al. *unpublished manuscript*), and we recently (February 2018) recorded this marsupial at a height of 26.5 m, two meters from the tree's topmost branches, showing that this species uses the full vertical profile of the forest. These findings confirm that an important part of *D. gliroides'* lifecycle occurs in the canopy, thereby fulfilling Moffett's (2000) criteria to be considered as a truly arboreal species. The other species recorded the rodent *I. tarsalis* may be an occasional canopy user since it was only recorded in a single photograph vs. the 230 photographs recording *D. gliroides*. This rodent is mostly granivorous (Meserve et al. 1988) and may also be an important arboreal species, most likely a seed predator (Amico et al. 2009) that is scarce in our study site. Further studies may confirm or discard the arboreal habits of *I. tarsalis* and its possible ecological roles in the canopy.

The high number of *D. gliroides* records was unexpected. The bait did not attract *D. gliroides* for long because birds, such as the Chimango Caracara (*Phalcoboenus chimango*, Falconidae), consumed all of it within two or three weeks of installation. Additionally, camera traps can only record animal presence in a small area of a single branch, thus surveying a considerably small extent of the crown. In spite of this, *D. gliroides* was frequently recorded. Fontúrbel et al. (2010) also documented a high abundance (up to 20 individuals/ha), as well as highly overlapping home ranges (up to 80%). This high abundance may even be underestimated because it was determined from the ground perspective, while the high overlap in home ranges occurs in a two-dimensional representation of the forest. Based on our results, we hypothesize that the home ranges of *D. gliroides* may be vertically segregated since the forest is a three-dimensional habitat.

Dromiciops gliroides is most likely the only mammalian seed disperser in the canopy of SATRs and could play a significant role in the dispersal of most canopy plants, which in turn affects the structure of epiphytic communities (Amico et al. 2009, Celis-Diez et al. 2012, Fontúrbel et al. 2012). South American temperate rainforests are characterized by a high abundance of plants with fleshy fruits that are dispersed by animals (Armesto and Rozzi 1989, Willson 1991). *Dromiciops gliroides* has been described as the disperser of most (at least 22) angiosperm vines and epiphytes found in SATRs (Amico et al. 2009, Celis-Diez et al. 2012), including at least two holoepiphytes, which grow in the canopy and never root in the ground, *Sarmienta repens* (Gesneriaceae) and the bromeliad *Fascicularia bicolor* (Salinas and Armesto 2012, Ortega-Solís et al. 2017). The latter was described as an ecosystem engineer that is very important to canopy biodiversity (Ortega-Solís et al. 2017). In SATRs, epiphytes support an abundant and diverse invertebrate community (Díaz et al. 2012, Ortega-Solís et al. 2017) and may play important functional roles, even as fundamental as primary productivity (the green tissues of epiphytes can represent a greater biomass than those of the host tree; Díaz et al. 2010*b*). Through its role in dispersing seeds of these epiphytes, *D. gliroides* may have tremendous functional importance for those species and ecological processes supported by epiphytes.

Our results also suggest that *D. gliroides* could be an abundant invertebrate predator in the canopy of SATRs. The most abundant insectivorous vertebrates that have been documented are two bird species, *Aphrastura spinicauda* (Furnariidae) and *Elaenia albiceps* (Tyrannidae), which together account for ~50% of bird communities in SATRs (Díaz et al. 2005). In our study site, these two bird species were recorded in 181 photographs, an equivalent of 78% of the *D. gliroides* photographs. Insectivorous vertebrates, such as birds, play an important role in reducing foliar herbivory by consuming herbivorous insects (Mazía et al. 2009, Mäntylä et al. 2011). The high frequency of *D. gliroides* suggests that it may be as or more plentiful as the two most abundant bird species together. The study of Fontúrbel et al. (2010) documents abundances of *D. gliroides* up to 20 individuals/ha, clearly in agreement with our results and larger than the abundance of any of the most abundant insectivorous birds. *D. gliroides* could also therefore have an important, but yet unknown, effect in reducing foliar herbivory. The confirmation or rejection of these ideas could provide important insights for biodiversity conservation in managed forests.

The presence and frequency of *D. gliroides* in the canopy suggest a new perspective on SATR ecosystems. This species could influence epiphyte dynamics, provide dispersal to ecosystem engineers, prey on canopy invertebrates, and even on other vertebrates know to have functional consequences on the ecosystem as a whole. Further studies should focus on this species' abundance, their use of the whole vertical profile, their association with tree cavities, and their ecological functions. According to UICN, the conservation status of *D. gliroides* is near threatened (Martin et al. 2015) because it is strongly susceptible to forest loss and fragmentation, since it is unable to disperse across open fields (Fontúrbel et al. 2010). Heilmayr et al. (2016) showed that the Chilean forest biodiversity hot spot, which is the habitat of *D. gliroides*, has been continuously retreating for the last 30 yr, mostly replaced by exotic tree plantations, agricultural fields, and shrublands. In fragmented forests, *D. gliroides'* abundance may decrease (Rodríguez-Cabal et al. 2007) and its functional influence may also decrease with negative consequences for the associated species.

Our observations suggest that a reduction in *D. gliroides'* population could affect a significant proportion of associated species in the SATR biodiversity hot spot. Interactions in SATRs are not balanced; there are few insectivore vertebrates, few seed dispersers for numerous plant species (Willson 1991), and some canopy plants have particularly strong effects on the whole community (Ortega-Solís et al. 2017). The role of *Dromiciops* in this system needs more clarification; this living fossil may be more important for this forest ecosystem than previously believed, modulating biodiversity and functions in unexpected, yet relevant ways.

Acknowledgments

We express our gratitude to Guillermo Mendez (alias Don Segundo) and his family, to Daniela Mellado, Gabriel Ortega-Solís, and Felipe González for their field assistance and company. We are grateful to the comments, advice, and suggestion of D. Kelt to the manuscript. We also are grateful to the comments of E. Silva-Rodríguez and H. Samaniego to the manuscript. This study was funded by a collaboration agreement between Fundación Mar Adentro and Universidad Austral de Chile.

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