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Movement behavior of the Monito del monte (*Dromiciops gliroides*): new insights into the ecology of a unique marsupial

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Abstract

Background: Behavior and activity patterns largely determine animal's fitness and their ecological roles. Those patterns depend on many factors, being body mass, sex and age the most relevant in mammals. Particularly, those factors altogether with environmental conditions could influence movement behavior of mammals that hibernate, such as the Monito del monte (*Dromiciops gliroides*).

Methods: To evaluate its movement behavior and activity we radio-tracked *D. gliroides* 12 individuals (8 females and 4 males, corresponding to 5 adults and 7 sub-adults) during the austral summer. With the estimated locations we estimated home ranges, core areas and their relationship with body mass. We also assessed movement speed during early (19:00 to 01:00 h), peak (01:00 to 03:00 h) and late (03:00 to 07:00 h) activity periods. This study was conducted at the San Martín experimental forest (Valdivia, southern Chile).

Results: Estimated home range areas were 1.04 ± 0.20 ha, and core areas were 0.27 ± 0.06 ha; we found no significant differences between males and females, nor between adults and sub-adults. Home range and core areas were independent of body mass in females but showed positive relationships in males. Core area overlap was larger between sub-adult and adult individuals (35%) than between adult males and females (13%). Average movement *D. gliroides* speed was 1.45 m/min, reaching its lowest value during the peak activity period (01:00 to 03:00 h), but being faster during early and late activity periods. Those speed differences may be related to travelling and foraging activities.

Conclusion: Home range and core areas estimated here showed a large variability, which can be related to environmental factors. Home range size was positively correlated with body mass on males but not on females. Also, lower movement speeds at the peak activity period suggest that *D. gliroides* concentrates feeding activities at this time. As *D. gliroides* disperses the seeds of at least 16 native plant species, its movement behavior also has important consequences at the community level.

Keywords: Body mass, Core area, *Dromiciops gliroides*, Home range, Monito del monte, Movement speed, Southern Chile

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Background

Animal behavior is the result of evolutionary processes that determine how individuals of a given species use the environment and interact with their conspecifics and other species [1]. Therefore, behavioral patterns are a phenotypic expression of the genome, involving heritable but also highly plastic traits [2, 3]. Consequently, this behavioral expression largely determines animal fitness as well as its ecological roles in the ecosystem, considering that the environment is highly dynamic in terms of and resource availability [4, 5]. Spatial behavior, therefore, may be strongly correlated to morphological (body mass), physiological (metabolic rate), ecological (intra- and inter-specific interactions, diet and foraging strategies), social, and environmental factors [6, 7]. Information on spatial behavior in wild animals is difficult to obtain (and particularly for cryptic species), but is important for understanding their home range, social interactions, mating systems and foraging strategies [8]. Such behavior depends on energy requirements, locomotion, habitat productivity, body mass and sex ratio [9]. Small mammals that hibernate usually have discrete activity periods in which they face energy constraints, in response to seasonal and daily changes in environmental factors such as temperature, rainfall, photoperiods, and food availability [10]. These adverse conditions could be compensated through decreased activity and increased daily torpor under colder conditions [11, 12].

Among small mammals that hibernate there is the Monito del monte, *Dromiciops gliroides* (Thomas 1894), a nocturnal arboreal marsupial, considered a living fossil as it is the only living representative of the ancient Order Microbiotheria, and the only species of the Australidelphia Superorder present in South America [13]. This marsupial is endemic to southern Chile and adjacent areas in Argentina, inhabiting in the South American temperate rainforests of northern Patagonia. Recent studies showed that space use (i.e., home range areas and habitat selection patterns) by *D. gliroides* is highly consistent regardless of the forest condition and location [14, 15], even in exotic tree plantations [16]. However, many aspects of *D. gliroides* behavioral ecology remain unexplored. Given that home range size is mainly explained by body mass across mammal species [7] and environmental features [17], we tested whether *D. gliroides* body mass, sex [females are larger and heavier than males; 14], and age explains the variation in home range and core area sizes. We used a sequential hypothesis framework. Firstly, we predict that larger individuals (i.e., females and adults) will use larger areas. Secondly, we tested whether the overlap between adult males and females differs from that between adults and sub-adults. Here we predict that core area overlap will be larger between adults and sub-adults than between males and

females because of the presence of family groups [18]. Thirdly, because camera-trapping efforts [19] obtained the greatest number of observations between 01:00 and 03:00 h, we predict that *D. gliroides* individuals would move faster during this peak activity period.

Methods

Study area

We performed this study at the San Martín Experimental Forest (39°41'S, 73°18'W), an 80-ha land owned by Universidad Austral de Chile, located 80 km north of Valdivia (southern Chile). Ambient temperatures range from 18 ± 1 °C in the austral summer (February) and 7 ± 1 °C in the winter (July). Mean annual precipitation is 2205 mm (ranging between 1500 and 3000 mm), concentrated in the austral fall (April–June) and winter (June–September) [20]. San Martín is a relict fragment of the Valdivian temperate rainforest [21], an ecosystem considered to be biologically unique and critically endangered [22, 23]. This experimental forest is a secondary-growth stand dominated by the evergreen trees *Gevuina avellana*, *Drimys winteri*, *Laurelia sempervirens*, *Embothrium coccineum*, *Luma apiculata*, *Amomyrtus meli*, altogether with sparse old *Nothofagus* spp. trees and the native bamboo *Chusquea valdiviensis* [24].

Data collection

We captured *D. gliroides* individuals at the study site using custom-made, single-door, Tomahawk-like wire-mesh live traps (26 × 13 × 13 cm). Traps were placed 1–2 m above ground level and baited with fresh banana slices [see 25, 26]. We set 144 traps in a web-style trapping grid, consisting in 12 radiating lines of 12 traps at 10 m intervals [27]. Trapping grids were monthly operated over ten consecutive days each month from December 2008 to April 2009 (total trapping effort = 3600 trapnights), avoiding full moon nights. Traps were checked daily at dawn and animals were released at the capture site after processing. We recorded body mass (using a Pesola® spring scale), standard morphometric measurements (total length, tail length, and nose tip to tail base length), sex (based on a visual inspection of the reproductive organs), and age (adult or sub-adult) for each captured individual. To differentiate adults from sub-adults we used the criteria of Salazar and Fontúrbel [16], being adults those individuals with body mass > 24 g and nose tip-to-tail length larger than tail length, and sub-adults those individuals with body mass ≤ 24 g and nose tip-to-tail length shorter than tail length. Capturing and handling procedures followed the guidelines of the American Society of Mammalogists [Sikes et al. 28], and were authorized by the Chilean Agriculture and Livestock Bureau (SAG; permits 161–2006 and 146–2008 granted to LMF).

During the austral summer (January to March) of 2009, 18 *D. gliroides* individuals were captured. Twelve of those individuals (three adult and one sub-adult males, and two adults and six sub-adults females) were fitted with telemetry transmitters (Biotrack® United Kingdom, cable-tie collars of 0.9 g, representing $\leq 5\%$ of the body mass) and intensively tracked from dusk to dawn on a daily basis between 23-Jan and 12-Apr (we have not tracked individuals during rainy nights). Two teams (communicated with handy radios) simultaneously located each individual and registered the geographic coordinates (i.e., GPS position), bearing, time and signal strength to minimize data collection error. Noise and lights were kept to minimum to avoid disturbing the tracked animals. Before taking animal locations we conducted a field test, in which one person placed transmitters with known locations and then were tracked by other people (unaware of the real location) to assess estimation error, which was below 5 m.

Data analysis

We estimated actual locations of the tracked individuals by grouping bearings taken in the field in groups of three or four bearings taken within a 10-min interval, and separated at least by 20° [although we privileged groups with separations between 45° and 135° to reduce triangulation error; 29, 30]. We estimated locations using the software LOAS 4.0 (Ecological Software Solutions, Switzerland), considering a minimum of 30 min between relocations of the same individual to ensure data independence. Error ellipses average values ranged from 0.01 to 0.06 ha. Using the estimated locations, we calculated core areas and home range areas of the tracked *D. gliroides* individuals using the 50 and 90% kernel density estimators (KDE hereafter), respectively [15]. Core and home range areas were obtained with the `adehabitatHR` package [31] in R 3.5.0 [32], using a least square cross validation (LSCV) method for defining kernel bandwidth. In order to assess the robustness of the home range and core areas estimated in function of the number of telemetry locations used, we took the individual with the largest number of locations (individual M01 with 119 locations), and we made 45 location files with random subsets of 5 to 50 locations. Then we estimated home range and core areas for each location subset and compared them with the real values.

We compared body mass between males and females and between adults and sub-adults using generalized linear models (GLM) with a Gaussian error distribution. Likewise, we compared KDE home range and core area sizes between males and females, as well as between adults and sub-adults using GLMs. Then, we fitted additional GLM models to assess the relationship between home range and core area sizes with body mass and the

number of locations; we assessed all individuals together first, and then we assessed males and females, and adults and sub-adults separately. Normality and variance structure were checked for each model fitted [33]. We also assessed the extent of overlap in core areas (i.e., KDE 50%) between adult males and females, and between adult and sub-adult individuals, using `Cartographica` 1.4.9 (ClueTrust, Reston VA) GIS software. For this purpose, we merged individual core areas for each group (i.e., males vs. females, adults vs. sub-adults) before conducting the overlap analysis to focus the comparison on the groups and not on the individuals.

Using estimated locations, we then calculated the distance between successive points within a 120-min period as a proxy of movement behavior. We considered three different activity time periods [following 19; based on camera-trap records]: (a) early activity from 19:00 to 01:00 h, (b) activity peak from 01:01 to 03:00 h, and (c) late activity from 03:01 to 07:00 h. Then, we estimated individual movement speed as the ratio between distance and time differences between consecutive locations (expressed in meters moved per minute). In order to determine if movement behavior changes in function of the activity period (early, peak and late) we performed a mixed-effects generalized linear model (GLMM) with a Gaussian error distribution, using movement speed as a response variable, the activity period as a fixed factor, and the tracked individual id as a random factor to account for inter-individual variability [34]. GLMM parameters and their significance were estimated using restricted maximum likelihood (REML) t -tests, with a Kenward-Roger approximation to degrees of freedom [35]. Values are presented as mean ± 1 SE unless otherwise indicated. GLM and GLMM results in the main text are presented using t - and P -values obtained, while estimates for each variable and their standard error are presented in the Supporting Information available online. GLMs and GLMMs were implemented in R 3.5.0 [32] using the packages `lme4` [36], `lmerTest` [37], and `pbrktest` [35], illustrations were developed using `ggplot2` [38].

Results

Tracked individuals differed in body mass, with females (26.2 ± 3.1 g) heavier than males (24.6 ± 2.4 g) (GLM comparison, $t = -3.55$, $P < 0.01$), and adults (32.4 ± 2.5 g) heavier than sub-adults (20.0 ± 0.5 g) ($t = -9.42$, $P < 0.01$; detailed GLM results are available in Additional file 1: Table S1). We obtained a total of 652 locations (54 ± 12 locations per individual) for the tracked *D. gliroides* individuals. Core areas (KDE at 50%) ranged from 0.05 to 0.64 ha (0.27 ± 0.06 ha) whereas home ranges (KDE at 90%) ranged from 0.16 to 2.20 ha (1.04 ± 0.20 ha; Table 1). Our results show that home range estimations

Table 1 Descriptive information of the tracked *Dromiciops gliroides* individuals (gender, age and body mass). The number of telemetry locations estimated for each individual is showed together with core areas (KDE 50%, in ha) and home ranges (KDE 90%, in ha)

ID	Gender	Age	Mass (g)	Locations	CA (ha)	HR (ha)
F03	Female	Adult	39.0	27	0.38	1.59
F07	Female	Adult	36.0	103	0.14	0.65
F02	Female	Sub-adult	21.0	27	0.06	0.23
F04	Female	Sub-adult	18.5	27	0.61	2.20
F05	Female	Sub-adult	19.5	27	0.10	0.40
F06	Female	Sub-adult	20.8	21	0.14	0.46
F08	Female	Sub-adult	21.0	20	0.64	1.89
F01	Female	Sub-adult	21.0	88	0.30	1.06
M01	Male	Adult	32.8	119	0.29	1.46
M02	Male	Adult	27.0	124	0.30	1.52
M03	Male	Adult	27.0	42	0.21	0.82
M04	Male	Sub-adult	18.0	27	0.05	0.16
		Mean	25.1	54.3	0.27	1.04
		SE	2.1	11.9	0.06	0.20

became stable at ~30 locations, after this value adding more locations have a negligible effect on the home range and core area values obtained (Additional file 1: Figure S1).

Neither home range nor core areas differed between males and females (0.99 ± 0.32 versus 1.06 ± 0.26 ha, $t = -0.55$, $P = 0.59$ for home range; 0.21 ± 0.06 versus 0.30 ± 0.08 ha, $t = -0.72$, $P = 0.49$ for core area), or between adults and sub-adults (1.21 ± 0.19 versus 0.91 ± 0.31 ha, $t = -0.87$, $P = 0.41$ for home range; 0.26 ± 0.04 versus 0.27 ± 0.10 ha, $t = -0.30$, $P = 0.77$ for core area; detailed GLM results are available in Additional file 1: Table S2; individual home range and core areas are presented in Additional file 1: Figures S2 and S3, respectively). Home range and core area size did not vary according to body mass in any case ($t = 0.68$, $P = 0.51$ for home range; $t = 0.07$, $P = 0.95$ for core area; detailed GLM results are available in Additional file 1: Table S3). Further, neither home range ($t = 0.53$, $P = 0.61$) nor core area ($t = -0.18$, $P = 0.86$) sizes varied in function to the number of telemetry locations (detailed GLM results are available in Additional file 1: Table S4), except for home range area in males, which showed a marginally significant ($P = 0.049$) relationship. Core area overlap between adult males and females was 12.7% (Additional file 1: Figure S4), whereas the overlap between adult and sub-adult individuals was 35.5% (Additional file 1: Figure S5).

Movement speed (m per minute) significantly varied among activity periods ($t = 9.14$, $P < 0.001$; detailed GLMM results are available in Additional file 1: Table S5), reaching its highest value at the early period, its

lowest value at the peak period, and an intermediate value at the late period. Movement speed at the late period was statistically different from the early period but not from the peak period (Fig. 1).

Discussion

Our tracked *D. gliroides* individuals showed a large variability in spatial behavior. We found no significant differences between home ranges or core areas of males and females, nor between adults and sub-adults. This was despite *Dromiciops gliroides* female individuals being larger and heavier than males, and adults were larger and heavier than sub-adults. This result suggests that other variables (e.g., food availability, environmental conditions, predation risk) may be more important than body mass for defining home range size in this species. Particularly, females might be establishing home range sizes independently of their body mass. In this case it might be determined by food gathering and their higher protein requirement for reproduction, related to post-reproductive period, parental care and the need to ensure that juveniles grow rapidly to gain sufficient weight and survive their first winter during the hibernation period [18].

Likewise, we found no differences between adult and sub-adult individuals despite being a large body mass difference. In other marsupial species, sub-adults showed large home ranges than adults. In those cases, males and juveniles of some mammal species exhibit greater movement related to foraging and mating behavior [39]. Home range and core areas estimated for *D. gliroides* in this study were similar to those reported by previous studies on this species in different localities of Argentina and Chile [14–16]. This similarity across a large spatial extent suggests that spatial movement is a highly repeatable behavioral trait in this species, irrespective to its location or particular habitat conditions.

Fontúrbel et al. [19] showed that activity in *D. gliroides* starts at 19:00 h and lasts until 07:00 h during the austral summer, with an activity peak between 01:00 to 03:00 h (i.e., the time period concentrating most of the photographic records). Based on those observations by Fontúrbel et al. [19] we predicted that *D. gliroides* would move faster during the presumed peak in activity from 01:00 to 03:00 h. In contrast, however, tracked individuals moved faster at the beginning of its activity period, showing the lowest movement speed at the peak activity period. We believe that this reflects greater foraging activity during the peak activity period [40]. We expected *D. gliroides* to move more during this period as it concentrates most of camera-trap observation [19], but finding the opposite suggests that such time frame is devoted to feeding activities. Further, moving longer distances during the early activity period (when there is more light at dusk, and hence more exposure to predators)

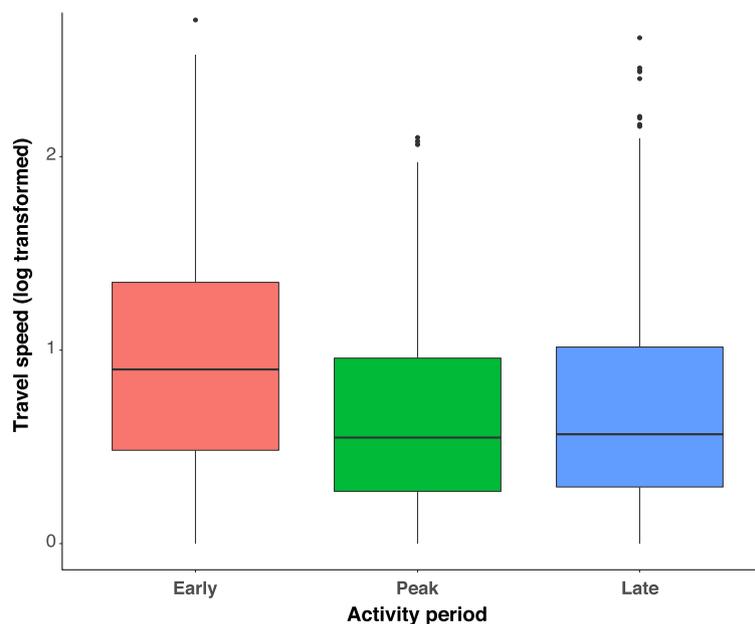


Fig. 1 Travel speed (m / min) during the early (19:00 to 01:00 h), peak (01:00 to 03:00 h), and late (03:00 to 07:00 h) activity periods

could be related to round trips from nesting to feeding sites. In addition, hibernating small mammals like *D. gliroides* are expected to be more active when environmental conditions are favorable [i.e., austral summer; 11]. These findings are consistent with the movement velocity estimations by di Virgilio et al. [41], who found that *D. gliroides* move faster after sunset and before sunrise, based on videos obtained using camera-traps, supporting our inference of rapid movement during travel to foraging sites.

Studying movement behavior is also important to understand other ecological processes such as feeding behavior. *Dromiciops gliroides* is a generalist frugivore with a key ecosystem role as the primary seed disperser of at least 16 native plant species [42, 43]. Thus, its spatial behavior also should have community-level consequences as both home range and movement speed largely determines seed deposition patterns [44, 45]. Taking the mistletoe *Tristerix corymbosus* as the most significant example, as it is only dispersed by *D. gliroides* below 37°S [46], and using the time budget and feeding behavior estimations by di Virgilio et al. [41], we may expect that each of our tracked individuals to disperse up to 405 seeds per night (under ideal conditions). Considering an average gut passage time of 30 min [42 and personal observations], feeding periods of 15 min neighboring mistletoes [40] and an average movement speed of 1.45 m/min (this study), we estimated an average seed dispersal distance of 43.68 m.

Conclusions

In summary, *D. gliroides* home range and core areas at our study site showed large variability, but this is

consistent with previous research on this marsupial. We found no significant differences in the movement behavior between males and females [being consistent with 15], nor between sub-adults and adults, despite significant variation in body mass, suggesting that home range differences might be more attributable to extrinsic factors. Also, tracked *D. gliroides* individuals moved faster at the beginning of their activity period, but reached its lowest speed during its peak activity period, contrary to our expectations. However, such movement pattern is consistent with a recent study of *D. gliroides* feeding behavior [41], suggesting that they concentrate fruit manipulation and consumption between 01:00 and 03:00 h, moving shorter distances among fleshy-fruited plants [41]. Despite its key ecologic role as primary seed disperser in South American temperate rainforests, the behavior of *D. gliroides* remains poorly known. We encourage future studies on this subject, as behavioral information is necessary to define appropriate conservation and management actions, aiming to protect this relict species thriving into a vanishing habitat.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s40693-019-0088-y>.

Additional file 1: Supporting Information associated to this article contains: Accumulation curves showing the effect on increasing number of locations on home range and core area estimations (Figure S1.), home range (Figure S2.) and core areas (Figure S3.) of tracked *Dromiciops gliroides* individuals; core area overlap between adult males and females (Figure S4.) and between adults and sub-adults (Figure

S5.); detailed GLM results of: body mass comparison between males and females, and between adults and sub-adults (**Table S1.**), home range and core area comparisons between males and females, and between adults and sub-adults (**Table S2.**), home range and core area vs. body mass relationships (**Table S4.**), home range and core area vs. number of locations relationships (**Table S5.**), and movement speed among activity periods (**Table S5.**).

Abbreviations

GLM: Generalized linear model; GLMM: Generalized mixed-effects linear model; KDE: Kernel density estimator

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Conflict of interest

The authors declare that they have no competing interests.

Author's contributions

LMF designed the study and conducted the research. LMF and MSG conceived the idea. LMF and GG collected field data. FEF analyzed the data and led manuscript writing with contributions of LMF, GG and MSG. LMF and MSG provided considerable resources for the research. All authors read and approved the final manuscript.

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Availability of data and materials

Original data associated with this manuscript can be accessed from the figshare digital repository: <https://doi.org/10.6084/m9.figshare.6807470>

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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